

**A New Systemic Model for the Implementation
of Sustainable Space Science and Technology
Investment for Sub Saharan African Economies:
An Implementation Process Derived from a
Case Study of MeerKAT and the Square
Kilometre Array Projects**



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Abstract

This research develops a sustainable implementation model for African developing nations undertaking space science and technology (SST) programmes, using the MeerKAT project and the forthcoming Square Kilometre Array (SKA) as central case studies. Econometric analysis of Sub-Saharan African (SSA) economies reveals that standard economic inputs namely labour, capital, and technology, are insufficient to plan for or predict growth in this context. Instead, a broader set of socio-economic variables, often overlooked in conventional models, must be considered. Panel data from 48 SSA countries informed the construction of four composite variables—access to finance, employment, education, and technology efficiency—which more accurately reflect the region's structural and cultural conditions.

Findings indicate that SST investments have an inconsistent impact on labour productivity, largely due to inefficiencies in technology absorption and local capacity utilisation. In response, this research proposes a three-phase Space Science and Technology Framework (SSTIF) made up of the Impact Causality Cycle (ICC) which establishes causal links between SST investments and socio-economic outcomes, emphasising effective technology deployment. The Political Decision Matrix (PDM) which guides sustainability-oriented investment planning by evaluating socio-economic benefits, as demonstrated through the MeerKAT project. A result of the PDM case study is that socio economic investment reduces project risk and improves sustainability. The Science-Driven Economic Benefit (SDEB) which model translates these insights into a practical implementation cycle, tested through a detailed application to the MeerKAT case.

Together, these phases form an integrated pathway from theory to decision-making to implementation. The SKA project, as an expansion of MeerKAT, validates the framework's scalability and relevance, reinforcing the case for strategic SST investment in SSA. Ultimately, this thesis contributes a practical roadmap for policymakers—linking science infrastructure to inclusive economic development and long-term investment sustainability.

Acknowledgements

‘One of the central tenets of Christian economics is the principle of stewardship. The Bible teaches that everything we possess—our time, talents, and treasures—is a gift from God. As such, Christians have a God-given responsibility to manage these resources wisely and effectively.’ (Derick Dickens, 2023).

I thank God for carrying me through this process of over a decade to complete this work. Compassion cannot be excluded from economics in my opinion and in my experience collaboration is Africa’s road to successfully contributing to space science and technology, and being a part of the global future.

It is the compassion of others, my son, my family, my friends and my mentors, and certainly their patience, that has made every step possible.

“Jesus says: do not store up treasures for yourself on Earth, where moth and rust destroy, and where thieves break in and steal, store your treasures in Heaven, where moths and rust cannot destroy and thieves cannot break in and steal, wherever your treasure is, there the desires of your heart will also be.” NLT Matthew 6:19-21

Table of Contents

Declaration	2
Abstract.....	3
Acknowledgements.....	4
LIST OF GRAPHS.....	8
LIST OF EQUATIONS.....	9
LIST OF IMAGES.....	9
LIST OF FIGURES.....	9
LIST OF TABLES.....	9
LIST OF ABBREVIATIONS.....	1
TERMINOLOGY	1
Part 1 Introduction	7
1. Introduction.....	8
2. Introduction To The SKA	14
2.1. The Bid To Host The SKA And The South African Economy.....	14
2.2. The Square Kilometre Array (SKA)	18
2.3. SKA Activities In South Africa	19
2.4. Human Capital Development (Skills Development)	22
2.4.1 Human Capital Development Strategy.....	22
2.5. Commercialisation And Technology Development	25
2.6. SKA In South Africa: Economic Breakdown	26
2.7. Socio Economic Impact.....	26
2.8. The SKA Phase 1 Business Case.....	30
2.8.1. SKA Project Revenue Model To South Africa.....	30
2.9. SKA: Status.....	31
2.10. SKA Africa: The African Vlbi Network (Avn).....	32
2.10.1. The Colocation Programme	33
Part 2 Literature Review.....	37
3. Literature Review	38
3.1. Introduction.....	38
3.2. Sub-Saharan Africa – An Economic Overview.....	39
3.3. Current Economic Theories	41
4. Pillars Of Success For Economic Growth From Sst In Developing Nations	47
4.1. Introduction.....	47
4.2. Institutions And Policy.....	47
4.3. Education.....	50
4.4. Technology And Innovation	52
4.5. Equality	56
4.6. Trade And African Value Chains.....	57
5. Unique Economic Considerations	62
5.1. Economics Of Culture	62
5.2. Economics Of Regime And Regime Change	67

6.	Time Valuation Of Money.....	71
6.1.	Propensity To Value Time In Terms Of Money.....	74
6.1.1.	Interest Rates	74
Part 3 Data Analysis.....		79
7.	Data Analysis	80
7.1.	Introduction.....	80
7.2.	Methodology.....	82
8.	Exploring Labour Productivity In The African Context.....	85
8.1.	Labour Productivity As A Contributor To Economic Growth	85
8.2.	Labour Productivity And Business Competitiveness.....	91
8.3.	Labour Productivity And Fdi	99
8.4.	Labour Productivity And Education	102
8.5.	Labour Productivity And Technology.....	108
8.6.	Labour Productivity And Employment.....	112
9.	The Labour Productivity Gap.....	118
9.1.	The Effects Of The Informal Sector.....	120
9.2.	Technology And The Informal Economy	128
9.3.	Foreign Direct Investment, Labour Productivity And The Informal Sector.....	133
9.4.	Informal Sector Labour Productivity	136
9.5.	Leveraging Sst For Socio-Economic Development In Sub-Saharan Africa	138
Part 4 Model Development		139
10.	Model Development - Quantitative Analysis.....	140
10.1.	Labour Productivity As A Proxy For Socio-Economic Impact	140
10.2.	SST Impact-Causality Cycle.....	146
10.3.	Development Of The Labour Productivity Sst Equation.....	149
10.3.1.	Methodology	149
10.3.2.	Education Ratio	150
10.3.3.	Employment Ratio	154
10.3.4.	Access To Finance Ratio	156
10.3.5.	Technology Efficiency Ratio	158
10.3.6.	Data Set.....	159
10.3.7.	Hypothesis Testing.....	161
10.3.8.	Propensity To Value Time In Terms Of Money (Pvtm)	167
11.	Econometric Analysis	173
11.1.	Introduction.....	173
11.2.	Econometric Analysis Of The Model: World Data	175
11.3.	Econometric Analysis Of The Model: Ssa Data	178
11.4.	Adjusted Model.....	183
11.5.	The Uncertainty Associated With Using Labour Productivity As A Proxy	186
11.5.1.	Quantifying Statistical Uncertainty (Model Fit & Error Terms)	186
11.5.2.	Model-Specific Error Decomposition (Sfa Results)	186
11.5.3.	Proxy Validation Through Iv Regression (Instrument Strength)	186

11.5.4.	Alternative Scenarios & Model Comparison (Ssa Vs. Global)	186
11.5.5.	Inclusion Of Weighted Labour Productivity & Informal Sector Output.....	187
Part 5	Case Study	188
12.	Case Study.....	189
12.1.	Decision-Making Matrix.....	189
12.1.1.	Introduction	189
12.1.2.	Development Of The Decision-Making Matrix	190
12.1.3.	Application Of The Sst Decision-Making Matrix: Meerkat Case Study (Ref Year 2008)	193
12.1.4.	Comparative Results.....	199
12.1.5.	Application Of The Sst Decision-Making Matrix: Meerkat Extension Case Study (2019)	202
12.2.	The Sdeb Implementation Framework	204
12.2.1.	Meerkat Case Study Of The Science-Driven Economic Benefit Cycle.....	206
12.2.2.	Intervention Phase.....	208
12.2.3.	Development Phase.....	217
12.2.4.	Growth Phase.....	225
12.2.5.	The Ska Project And The Sdeb Model.....	226
13.	Conclusion	227
13.1.	Future Work	233
	References.....	235
	Appendices	253
	Appendix A: Sst Contribution To Addressing The Challenges Outlined By The Sdgs	253
	Appendix B: Project Failure Review.....	256
	Appendix C: Statistical Outputs.....	260

List of Graphs

Graph 4.3.1 Africa SKA Partner Countries: Standardised GDP per Capita and Govt Expenditure on Education and R&D, 1990 to 2022 (Data Source: World Bank Data).....	51
Graph 6.1.1 SSA Countries: Clustered Data by GDP per capita and Interest Lending Rate.....	75
Graph 6.1.2 3D scatter plot of clusters.....	77
Graph 9.1.1 Residual plot versus fitted values/ Graph 9.1.2 Scatter plot of actual versus predicted values.....	86
Graph 9.1.3 Africa SKA Partner Countries: Standardised Economic Growth Factors with GDP, 1990 to 2022.....	87
Graph 9.1.4 Scatter plot of actual versus predicted values.....	89
Graph 9.1.5 SKA Africa Partner Countries: Labour Productivity, years 1990 to 2022 (Data Source: World Bank Data).....	90
Graph 9.2.2 Unique SSA Cases: Standardised Business Competitiveness Indicators,.....	96
Graph 9.4.2 Residual Plot versus Fitted Values for Regression Table 9.4.1.....	104
Graph 9.4.1 Scatter plot of actual versus predicted values of Labour Productivity.....	104
Graph 9.4.3 World Data: Scatter plot of actual versus predicted values of Labour Productivity Regression.....	105
Graph 9.4.4 Africa SKA Partner Countries: Standardised Educational Enrolment.....	106
Graph 9.5.1 Scatter plot of actual versus predicted values Labour Productivity (Regression Table 9.5.2).....	110
Graph 9.5.2 Scatter Plot of actual versus predicted values Labour Productivity (Regression Table 9.5.3).....	111
Graph 9.6.1 Scatter plot of actual versus predicted values Labour Productivity (Regression Table 9.6.2).....	114
Graph 9.6.2 Residual Plot Labour Productivity (Regression Table 9.6.2).....	115
Graph 9.6.3 Africa SKA Partner Countries: Employment levels by sector, 1990 to 2022.....	42
Graph 10.1 Africa SKA Partner Countries: Formal and Informal Labour Productivity.....	120
Graph 10.1.1 SSA Countries: Residual Plot Informal Output versus GDP per Capita.....	121
Graph 10.1.2 SSA Countries: Regression Informal LP and GDP per Capita, actual versus predicted values.....	122
Graph 10.1.3 World Data: Scatterplot of GDP per capita and the size of the informal employment workforce.....	123
Graph 10.1.4 Actual versus Predicted Plot of Labour Productivity with the.....	126
Graph 10.1.5 Residual Plot of GDP per Capita, Labour Productivity, Informal Labour.....	128
Graph 10.2.1 Residual Plot Table 3.17 Regression, Informal LP and TAI.....	130
Graph 10.2.2 Residual Plot of Informal Labour Productivity and Mobile Subscriptions.....	131
Graph 11.1.1 Kernel Density Estimate (KDE): normality plot.....	142
Graph 11.1.2 SEM Results: Actual versus Predicted values of ln GDP per Capita.....	143
Graph 11.3.4.1 SSA Countries: Actual versus Predicted values for Labour Productivity.....	157
Graph 11.3.7.1 Residuals versus Actual Values: RND Expenditure as a percentage of GDP.....	164
Graph 11.3.7.2 Regression Residual plot: Formal Labour Productivity.....	165
Graph 11.3.7.3 GDP per Capita and the Labour Productivity Difference.....	167
Graph 12.1.1 World Data: IV GMM Regression Residuals Versus Prediction.....	176
Graph 12.1.2 World Data: IV GMM Regression Residuals Versus Actuals Plot.....	177
Graph 12.2.1 SSA Data: Residual Plot Informal Labour Productivity.....	179
Graph 12.2.2 SSA Data: Predicted Values versus Actual Values Plot.....	180
Graph 12.2.4 Labour Productivity And Technical Efficiency.....	182
Graph 12.3.1 The kernel density plot.....	185
Graph 13.2.1 Number of Grants Awarded by Year (Data Source: SARAO).....	221

Graph 13.2.2 Number of Grants Awarded by Study Level (Data Source: SARAO)	222
Graph 13.2.3 Distribution of Grants by Broad Category of Nationalities (Data Source: SARAO)	222
Graph 13.2.4 Graduation Rates by Academic Level (Data Source: SARAO)	223

List of Equations

Equation 4.2.1	48
Equation 7.1.1	80
Equation 8.1.1	85
Equation 8.1.2	85
Equation 8.6.1	113
Equation 10.3.1.1	149
Equation 10.3.1.2	150
Equation 10.3.1.3	150
Equation 10.3.1.4	150
Equation 10.3.7.1	162
Equation 11.4.1	183

List of Images

Image 2.3.1 KAT7 Antennas (Credit: SARAO)	21
Image 2.3.2 MeerKAT core (Credit: SARAO)	21
Image 2.10.1.1 The Colocation Model (Credit: Dewald Lloyd)	35

List of Figures

Figure 11.2.1 The SST Impact-Causality Cycle	147
Figure 13.2.1 The SDEB Cycle	205
Figure 13.2.2 FAP Programmes 2022	219

List of Tables

Table 2.7.1 National socio-economic impacts	29
Table 2.7.2 Karoo socio-economic impacts	29

Table 6.1.1 Clusters for 2010	75
Table 6.1.2 Clusters for 2020	76
Table 9.1.1 Fixed Effects Regression on SSA Panel Data: Economic growth model	86
Table 9.1.2 Fixed Effects Regression on SSA Panel Data: GDP per Capita and	88
Table 9.2.1 Regression of Standardised Elements of Business Competitiveness	93
Table 9.2.2 GMM Labour Productivity and Business Competitiveness	94
Table 9.2.3 Correlation table of Labour Productivity and the selected	95
Table 9.4.1 SSA Panel Data: OLS Regression Educational enrolment is a determinant of Labour Productivity	103
Table 9.4.2 World Panel Data: Educational enrolment is a determinant	105
Table 9.4.3 Correlation of Educational Enrolment at different levels and Labour Productivity	107
Table 9.5.1 World Data: OLS Regression SST Investments and Labour Productivity (Standardised)	109
Table 9.5.2 SSA Countries: OLS SST investment and Labour Productivity	110
Table 9.5.3 SSA Countries: IV Regression GMM SST investment and Labour Productivity	110
Table 9.6.1 World Labour Productivity, employment in services, industry and employment in agriculture	113
Table 9.6.2 Fixed Effects Regression SSA Labour Productivity and Employment Sectors	114
Table 10.1.1 SSA Countries: Fixed Effects Regression Labour Productivity and the Informal Sector	125
Table 10.1.2 SSA Countries: Fixed Effects Regression GDP per Capita, LP and the Informal Sector	126
Table 10.2.1 SSA Countries: Fixed Effects Regression Informal LP and TAI	130
Table 10.2.2 SSA Fixed Effects Regression Informal Labour Productivity and Mobile Subscriptions	131
Table 11.1.1 Structural Equation Model: GDP per Capita, Informal Output and Labour Productivity	141
Table 11.2.1 The SST Impact-Causality Cycle Elements	148
Table 11.3.2.1 Comparison of Education data for South Africa, years 2010 - 2019	151
Table 11.3.2.2 Labour Productivity Regression with Education Ratio and Unemployment	152
Table 11.3.3.1 Comparison of Employment data for South Africa, years 2010 - 2019	155
Table 11.3.3.2 Labour Productivity Regression with Employment Ratio	155
Table 11.3.4.1 Comparison of Financial data for South Africa, years 2010 – 2019	156
Table 11.3.4.2 Labour Productivity Regression with Access to Finance Ratio	156
Table 11.3.5.1 SSA Data: Regression Labour Productivity and Technology Efficiency Ratio	159
Table 11.3.6.1 Summary country list from SSA, comprised of the SKA Africa countries, 2018	160
Table 11.3.7.1 IV Regression Labour Productivity Regression with Instruments: RND Expenditure and Patent receipts	163
Table 11.3.7.2 SSA Data Labour Productivity Regression with Informal Output and Informal Workforce	165
Table 11.3.7.3 SSA Regression of GDP per Capita and the Labour Productivity Difference	166
Table 11.3.8.1 Factor Analysis	170
Table 11.3.8.2 Factor Loadings	170
Table 11.3.8.3 Regression Factor and Tourism	172
Table 11.3.8.4 Regression Factor and Informal Output	172
Table 12.1.1 World Data: Fixed effects regression results	175
Table 12.2.1 Regression of Labour productivity and the predictive ratios	178
Table 12.3.1 One-Step GMM For Labour Productivity Per Hour With The Weighted Labour Productivity	184
Table 13.1.2.1 Development steps of the Decision-Making Matrix	190
Table 13.1.2.2 Elements of the Risk Scoring Table	191
Table 13.1.2.3 Risk Scoring Table	191

Table 13.1.2.4 Notes to Complete the Risk Scoring Matrix	.....192
Table 13.1.2.5 Indicator Dimensions	.....193
Table 13.1.2.6 Matrix Outputs	.....193
Table 13.1.3.1 The Risk Scoring Table – MeerKAT Case Study 2008	.....194
Table 13.1.3.2 Notes to The Risk Scoring Table – MeerKAT Case Study 2008	.....195
Table 13.1.3.3 SEB in terms of Labour Productivity	.....198
Table 13.1.4.1 Labour Productivity Change Calculation	.....200
Table 13.1.4.2 Calculation of Annual LP Change due to the MeerKAT Project.....	201
Table 13.1.5.1 The Political Decision Matrix – Comparative table MeerKAT 2019	.....202
Table 13.2.1 Phases and Steps of the SDEB Framework	.....207
Table 13.2.2 Technologies under commercialisation development	.....220

List of Abbreviations

Abbreviations	Denotation
AfCFTA	African Continental Free Trade Area
AGA	Astronomy Geographic Advantage
APC	Africa Partner Country
ARF	African Renaissance Fund
ASKAP	Australian Square Kilometre Array Pathfinder
AU	African Union
AVN	African VLBI Network
BBEEE	Broad-Based Black Economic Empowerment
BEE	Black Economic Empowerment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CHPC	Centre for High Performance Computing
CPI	Corruption Perceptions Index
CPIA	Country Policy and Institutional Assessment
DIRCO	Department of International Relations and Cooperation
DST	Department of Science and Technology
DTI	Department of Trade and Industry
ESA	European Space Agency
ESF	Economic Status Factor
EVN	European VLBI Network
FBE	Free Basic Electricity
FDI	Foreign Direct Investment
FET	Further Educational Training
GAEC	Ghana Atomic Energy Commission
GDP	Gross Domestic Product
GNI	Gross National Income
GSD	Ground Sample Distance
GSSTI	Ghana Space Science and Technology Institute
HCD	Human Capital Development

HDI	Human Development Index
HSRC	Human Sciences Research Council
ICC	Impact Causality Cycle
IDIA	Inter-University Centre for Data Intensive Astrophysics
IEA	International Energy Agency
IHDI	Inequality Adjusted Human Development Index
IMF	International Monetary Fund
IPR	Intellectual Property Rights
ILO	International Labour Organisation
ISO	International Standards Organisation
IV	Instrumental Variables
KAT	Karoo Array Telescope
LDC	Lesser Developed Country
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
NASA	National Aeronautics and Space Administration (USA)
NASRDA	National Space Research and Development Agency (Nigeria)
NEPAD	New Partnership for Africa's Development
NDP	National Development Plan
NIP	National Industrial Participation
NIPMO	National Intellectual Property Management Office
NLT	New Living Translation
NPV	National Ventilator Project
NRF	National Research Foundation
OECD	Organisation for Economic Cooperation and Development
OPPG	Operationalizing Pro-Poor Growth
OTT	Office of Technology Transfer
PAU	Pan African University
PDM	Political Decision Matrix
PFMA	Public Finance Management Act
PSF	Political Suitability Factor
PVTM	Propensity to Value Time in terms of Money
R&D	Research and Development
RFI	Radio Frequency Interference

SAASTA	South African Agency for Science and Technology Advancement
SADC	Southern African Development Community
SACSA	South African Council for Space Affairs
SA DOE	South African Department of Energy
SANRAL	South African National Roads Agency Limited
SANSA	South African National Space Agency
SARAO	South African Radio Astronomy Observatory
SDEB	Science Driven Economic Benefit
SEM	Structural Equation Modelling
SFA	Stochastic Frontier Analysis
SKA	Square Kilometre Array
SKAO	Square Kilometre Array Observatory
SKA SA	Square Kilometre Array South Africa
SEB	Socio-Economic Benefit
SMME	Small, Medium and Micro sized Enterprise
SSA	Sub-Saharan Africa
SST	Space Science and Technology
SSTIF	Space Science and Technology Framework
STEM	Science, Technology, Engineering and Maths
TFP	Total Factor Productivity
TLF	Technology Level Factor
UCT	University of Cape Town
UN	United Nations
UWC	University of the Western Cape
VLBI	Very Long Baseline Interferometry
WHO	World Health Organisation
YP	Young Professional
YPD	Young Professionals Development Programme

Terminology

Analytics: Analytics refers to the systematic analysis of data using statistical, mathematical, or computational techniques to uncover patterns, relationships, or insights. In this thesis, analytics is used to process and interpret data from the MeerKAT project—particularly to assess labour productivity and estimate socio-economic impacts. Analytics provides the empirical evidence upon which models are calibrated and validated, supporting the credibility of the proposed framework.

Appropriate technology: This is a school of thought encompassing technological choice and application that is small scale, decentralised, labour intensive, energy efficient, environmentally sound, and locally autonomous. The emphasis is also on the fact that the technology is people centred.

Developing Nation: Also called a less developed country or an underdeveloped country, a developing nation is a nation or sovereign state with a less developed industrial base and a low Human Development Index (HDI) relative to other countries. The World Bank's classification of countries, of which there are four groupings: low income, lower middle income, upper middle income and high income. The classification is defined, once again, by GNI per capita. Revisions to the classification are annual, on 1 July. All countries below the high-income level are, by convention, considered "developing."

Digitalisation: Is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business. In the context of this research it also encompasses developing nation public administrations that are changing to digital, leveraging disruptive technologies for better service delivery and improved efficiency.

Economy: An economy is the large set of interrelated production and consumption activities that aid in determining how scarce resources are allocated. The economy applies to everyone, from individuals to entities such as corporations and governments. The economy of a particular region or country is governed by the culture, laws, history, and geography, among other factors, and it evolves out of necessity.

Economic Development: This is the process by which a nation improves the economic, political, and social well-being of its people.

Economic Growth: Economic growth is an increase in the capacity of an economy to produce goods and services, when comparing one period of time to another. It can be measured in nominal or real terms, the latter of which is adjusted for inflation.

Emerging Market: An emerging market economy refers to a type of economy that is progressing toward becoming more advanced, usually by means of rapid growth and industrialisation. Such countries experience an expanding role both in the world economy and on the political frontier.

Foreign Direct Investment (FDI): This is an investment made by a company or an individual in one country in business interests in another country, in the form of either establishing business operations or acquiring business assets in the other country, such as ownership or controlling interest in a foreign company.

Framework: A framework is a structured conceptual approach that organises key concepts, components, or steps necessary to understand and address a particular problem. Frameworks are broader than models and may incorporate one or more models within them. In this thesis, the Space Science and Technology Investment Framework (SSTIF) serves as the overarching structure guiding the sustainable implementation of SST projects in Sub-Saharan Africa. It provides a phased approach, from identifying impact linkages (ICC), to decision-making (PDM), to project implementation and outcome evaluation (SDEB), that is adaptable to different national contexts.

Frontier Market: A frontier market is an economic term for the type of developing country that is more developed than the least developing countries, but too small to be generally considered an emerging market.

Gross Fixed Capital Formation: This includes a country's spending on land improvements, plants, machinery and equipment purchases; the construction of roads, railways, private residential dwellings, and commercial and industrial buildings. Disposal of fixed assets is excluded from the total.

Information Economics: This theory studies how information and information systems affect an economy and economic decisions.

Innovation: The process of translating an idea or invention into a good or service that creates value or for which customers will pay. To be called an innovation, an idea must be replicable at an economical cost and must satisfy a specific need. Innovation involves the deliberate application of information, imagination and initiative in deriving greater or different values from resources, and includes all processes by which new ideas are generated and converted into useful products. In business, innovation often results when the organisation applies such ideas in order to satisfy the needs and expectations of the customers.

Innovation Economics: This economic doctrine reformulates the traditional model of economic growth so that knowledge, technology, entrepreneurship, and innovation are positioned at the centre of the model.

Investment Climate: This refers to the general atmosphere in a country, as influenced by economic, legal, political and social factors that could influence the performance of an investment both directly and indirectly. The investment climate is affected by many factors, including poverty, crime, infrastructure, workforce, national security, political instability, regime uncertainty, taxes, rule of law, property rights, government regulations, government transparency and government accountability.

Isoquant: An isoquant is a curve that shows all the combinations of inputs that yield the same level of output.

Knowledge Economy: The knowledge economy is a system of consumption and production that is based on intellectual capital. The knowledge economy summarises the level of education, skills development and intellectual property in the economy.

Labour productivity: Labour productivity refers to the amount of output (goods and services) produced per unit of labour input, typically measured as output per hour worked or output per worker. It reflects the efficiency with which labour is used in the production process and is a key indicator of economic performance, competitiveness, and standard of living. In macroeconomic analysis, higher labour productivity generally signals improvements in technology, skills, and capital intensity.

Lesser Developed Country (LDC): A lesser developed country is a country that is considered lacking in terms of its economy, infrastructure and industrial base. The population of a lesser developed country often has a relatively low standard of living, due to low incomes and abundant poverty.

Model: A model is a simplified representation of reality that illustrates the relationships between different variables in order to understand, predict, or explain a phenomenon. In this thesis, the proposed models—such as the Political Decision Matrix (PDM) and the Science Driven Economic Benefit (SDEB) model—are conceptual and quantitative tools designed to demonstrate how SST investments influence socio-economic outcomes, particularly labour productivity and long-term sustainability. Models in this context aim to support policy decisions by clarifying causal pathways and estimating potential impacts

Political Suitability: The suitability of the political climate, financial and governance systems to exploit the socioeconomic benefits from science and technology investment.

Production Function: In economics, a production function relates physical output of a production process to physical inputs or factors of production.

Productivity: Productivity is an economic measure of output per unit of input. Inputs include labour and capital, while output is typically measured in revenues and other gross domestic product (GDP) components such as business inventories.

Quality Education: Quality education is a dynamic concept. It evolves with time and is subject to social, economic and environmental conditions. It includes the aims of education that impact on the content of education, teaching and learning processes and materials, the learning environment and learning outcomes.

Simulation: A simulation is the imitation of a real-world process or system over time, often using a model, to study its behaviour under various scenarios. Simulations allow for the testing of different assumptions, policy choices, or investment strategies without actual implementation. In this thesis, simulation is implied in the conceptual testing of the models—for example, by applying hypothetical SST investment inputs into the PDM to project their likely socio-economic outcomes. Although detailed computational simulations are not the focus, the models are structured to support simulation-based decision-making in future applications.

Socioeconomic Impact: This refers to how economic activity affects and is shaped by social processes. In general, it analyses how societies progress, stagnate, or regress because of their local or regional economy, or the global economy.

Space Science: This encompasses all of the scientific disciplines involved in space exploration and studying phenomena occurring in outer space.

Space Technology: Space technology is technology developed by space science or the aerospace industry for use in spaceflight, satellites, or space exploration. Space technology includes spacecraft, satellites, space stations, and support infrastructure, equipment, and procedures.

Square Kilometre Array (SKA): The SKA is an international project with the purpose of designing and constructing the world's largest radio telescope of its kind. The SKA Observatory (SKAO), based in the UK, is responsible for coordinating the global activities of the SKA project. This includes engineering, science, site evaluation, operations and public outreach.

South African Radio Astronomy Observatory (SARAO): SARAO (formerly known as SKA SA) is a national facility of the National Research Foundation (NRF), a statutory entity established in terms of the National Research Foundation Act, 1998. SARAO is responsible for implementing South Africa's commitments to the SKA, including but not limited to, the design and construction of the 64-dish array in the Karoo, known as MeerKAT. The South African MeerKAT radio telescope is a precursor to the Square Kilometre Array (SKA) telescope and will be integrated into the SKA telescope.

Sustainability: Sustainability refers to the ability to foster long-term economic progress without excessive external support or financial instability, while also ensuring that growth does not lead to environmental degradation or social inequality. In the context of science, technology, and innovation investments, sustainability implies that economic benefits derived from these investments can be maintained over time through resilient institutions, adaptive policies, and inclusive development strategies.

Technology Adoption: The technology adoption lifecycle is a sociological model that describes the adoption or acceptance of a new product or innovation, according to the demographic, infrastructural, economic and psychological characteristics of defined adopter groups.

Technology Development: This refers to the application of science, especially to industrial or commercial objectives. Technological innovation is a subset of innovation that draws heavily on the scientific and engineering knowledge pool to create value for society through translational research.

Translational Innovation: This refers to an innovation cycle that requires the integration of multiple disciplines and that is developed in collaboration with industry or other practitioners.

Technology Transformative efficiency: The ability of an economy to drive innovation, to adapt and adopt technologies, and then to reap the benefits from them.

Part 1

Introduction

1. Introduction

Space science and technology (SST) infrastructure has emerged as a critical lever for national development, especially in regions seeking to leapfrog industrial development stages through technology-driven growth. Ground-based mega-science projects like the MeerKAT and SKA have illustrated that investments in SST can catalyse long-term benefits across multiple sectors; education, industry, innovation, and governance. However, there remains a lack of coherent frameworks for how these benefits can be harnessed sustainably in developing countries, particularly across Sub-Saharan Africa.

This research draws on endogenous growth theory, which posits that investments in human capital, innovation, and knowledge contribute directly to economic growth. It also engages with development economics, focusing on how structural characteristics unique to African economies affect the translation of high-tech investments into inclusive growth. By integrating economic modelling with science and technology policy studies, this thesis builds a tailored theoretical framework to evaluate SST investment sustainability.

Although there is increasing interest in space science and its potential to address developmental challenges, African governments face acute opportunity costs. Investments in SST must compete with more immediate socio-economic priorities. Compounding this challenge is the fact that traditional economic models and planning tools often fail to capture the indirect and long-term benefits of such investments. As a result, there is a gap in understanding how to plan, measure, and justify SST infrastructure investments in a manner that supports sustained socio-economic development in African contexts.

The case study for this research is situated in South Africa, focusing on the MeerKAT radio telescope and its integration into the Square Kilometre Array (SKA). The SKA project, as an expansion of MeerKAT, validates the framework's scalability and relevance, reinforcing the case for strategic SST investment in SSA. These projects are not only space science endeavours but also socio-technical initiatives supported by government policy, international collaboration, and investment into human capital development. As one of the few African nations to successfully implement a large-scale SST programme, South Africa provides a rich context to evaluate the socio-economic implications and sustainability potential of such initiatives.

The MeerKAT telescope is the first mega science research infrastructure in Africa and has been accompanied by an ostensibly significant socio-economic development programme, and rests upon a foundation driven by sustainability. Sustainability refers to the ability to foster long-term economic progress without excessive external support or financial instability, while also ensuring

that growth does not lead to environmental degradation or social inequality. In the context of science, technology, and innovation investments, sustainability implies that economic benefits derived from these investments can be maintained over time through resilient institutions, adaptive policies, and inclusive development strategies.

The purpose of this research is to derive a sustainable implementation model that may be utilised by African developing nations embarking on space science and technology (SST) programmes, and this is achieved by data analysis and examination of the case study of the MeerKAT project and the future Square Kilometre Array (SKA) in South Africa.

This literature review explores economic theory, the African SST landscape, as well as economic inhibitors and enhancers of the long-term sustainability and socio-economic growth that impact African developing nations' investment in SST programmes.

Space sciences generally involve the use of infrastructure on the ground in order to view space from below, with the primary goal of research, to answer our burning and existential questions about the universe. Some infrastructure is, of course, based in space – an example is the James Webb telescope, launched on the 25th of December 2021¹. In contrast, the space industry has its largest expenditures on space-based infrastructure – that is, in space looking back at Earth. The global space economy was valued at approximately USD 630 billion in 2023, encompassing satellites, launch systems, and related services . In contrast, while comprehensive valuations for ground-based space infrastructure are less frequently aggregated, significant investments have been made into major facilities. For instance, the European Southern Observatory's Extremely Large Telescope (ELT) in Chile has an estimated construction cost of €1.45 billion . Similarly, the Square Kilometre Array (SKA), an international radio telescope project in Australia and South Africa, has an initial construction cost projected at €1.3 billion . These examples illustrate that individual ground-based projects can command investments exceeding a billion dollars, highlighting their substantial scale and financial commitment. The distinction is important to this research as the ground-based infrastructure for space science is both broadly impacting and large in scale, as with the MeerKAT telescope, affording opportunities for inclusive, positive externalities to industry, academia and employment, from low to high skill levels, over long operational time frames. Ground-based space infrastructure often fosters extensive societal engagement and long-term employment due to its physical accessibility and integration with local communities. For example, the European Southern Observatory (ESO) employs approximately 700 staff members across various roles, including scientists, engineers, and administrative personnel . These facilities also attract numerous visiting researchers and students, contributing to education and public outreach.

¹ The James Webb Space Telescope is a space-based telescope designed primarily to conduct infrared astronomy. It is the largest optical telescope in space, its infrared resolution and sensitivity allow it to view very distant, or faint objects (NASA, 2021).

In contrast, space-based infrastructure, while representing a larger economic sector, tends to be more capital-intensive with fewer direct employment opportunities during operations. Nonetheless, it stimulates high-tech industrial development and generates significant downstream economic activities in telecommunications, Earth observation, and related services. Therefore, while both types of infrastructure offer substantial benefits, ground-based facilities typically provide more direct local employment and community engagement, whereas space-based systems drive broader economic impacts through technological advancements and global services.

The SKA will be a profound engineering and technological feat, the most sensitive telescope of its kind, and in fact the largest SST project in Africa, after MeerKAT and the driver behind the MeerKAT telescope. It is an international project, with the low-frequency array of the SKA to be built in Australia and the mid-frequency array to be built in South Africa. The time frame for construction of the first phase (SKA Phase 1) of this telescope is approximately 7 years, with an operational lifetime of 50 years. As a precursor contribution to the project, South Africa built the MeerKAT telescope, which will be integrated into the SKA upon completion of the SKA Phase 1 construction. “SKA is referred to as a textbook example of diplomacy for science whereby governments are cooperating to create major scientific infrastructures that would be too complex and expensive for one single country to build and maintain on its own” (Rüland, 2022, Pozza 2015).

In African nations, as in most developing nations, governments are often confronted with the need to justify investment into SST in the face of many other challenges, or rather the opportunity cost of SST investment. However, SST contributes to the solutions of all 17 of the Sustainable Development Goals (SDGs), as laid out by the United Nations². This is explained in more detail in Appendix A. In their paper, Baumgart et al. (2021) show that space-related projects, the SDGs and the associated SDG Targets to achieve these goals, are highly interconnected. The 506 space-based projects that were examined, have a total of 1542 connections with different SDGs and SDG Targets. Each space-based project contributes, on average, to more than three SDGs or their associated Targets. Baumgart et al. (2021) also state that “the space contributions to the SDGs are constantly increasing with the invention of new applications, the adoption of new tools, and the deployment of new projects.”

From the examination of the successes and failures of mega projects, it is clear that preparation is the key to success (Garemo, et al., 2015), as explained in Appendix B. This may seem logical, but in developing nations, project success does not just entail the planning of sound infrastructure and construction alone, but rather relies on holistic planning over a number of socio-economic areas

² In September 2015, the United Nations General Assembly adopted a set of global objectives, the Sustainable Development Goals (SDGs), as part of the 2030 Agenda for Sustainable Development (UN, 2015).

over an extended period of time. Holistic preparation incorporates the fostering of fertile environments for the growth of the intended benefits, to derive positive externalities extending beyond the scope of the project. The socio-economic benefits derived from large-scale science and technology projects generate economic sustainability and are often inter-generational in nature. Although there are both short- and long-term impacts, the time frame for value capture often does not occur immediately. Measurable and demonstrable value might not appear for several years, or even decades (Nalewaik and Williams, 2020).

In addition, an examination of Sub-Saharan African (SSA) economies shows that it is not sufficient to consider standard indicators for economic inputs such as labour, capital and technology for the planning and prediction of growth. Rather it is the environment in which the labour base is living, the suitability of the environment for capital growth and the ability of the economy to develop and absorb technology that are critical areas to measure and address in developing economies. Without the appropriate environment, economic growth factors will not bear fruit. A significant challenge with classic indicator measurement, in African developing countries, is that the indicators are not necessarily built on the structural and cultural features of the specific country. This research assumes that social and economic benefits are the primary reasons that governments would invest in SST projects, and it can be shown from the case study that successful project implementations can in fact produce national benefits, experienced as Foreign Direct Investment (FDI), public goods, education, training, industry growth, innovation and of course science products. In addition to these, the skills developed in such programmes are transferable between sectors. The Chief Scientist of SARAo encapsulated it when he said that “the best telescopes expand our horizons in unexpected ways” (Camilo, 2022).

In the literature review, both neoclassical and growth models are examined, as well as the common economic metrics used to model and simulate adjustments in economies. The unique characteristics of SSA economies are investigated, as it is these characteristics that make common models and metrics less efficient tools to analyse the impacts and potential benefits of science and technology-based programmes. Examination of the case study, as well as the unique challenges faced by the continent, reveal gaps and the requirement to consider economic metrics in a more appropriate light concerning labour, capital and technology growth environments, which can make modelling for SST programmes in these nations, both more accurate and revealing. It is widely asserted that technology development is a driver of economic growth, yet without a minimum level of socio-economic development, technology investment cannot drive growth and this relationship cannot be assumed. It is proposed that African governments should analyse the environments fostering economic inputs more holistically, rather than the inputs themselves, in

order to identify the critical areas within their economies to address, so as to maximise socio-economic benefit from SST investments.

This research proposes the Space Science and Technology Investment Framework (SSTIF) made up of three phases. The first phase proposes a comprehensive interconnected cycle, the Impact Causality Cycle (ICC), that attempts to establish a chain of relationships linking SST investment to various socio-economic indicators, emphasising the need for more than access to basic technology but also its effective utilisation to spur innovation and economic development. The second phase is the Political Decision Matrix (PDM) with the objective of sustainability-based effective decision-making. In utilising the composite variables developed for this matrix, derived from phase one, based on the MeerKAT case study, it was possible to estimate the contribution of the large-scale investment into SST through the MeerKAT Programme, to the labour productivity of the country. A unique outcome of the PDM case study is that it illustrates that investment into socio-economic development affiliated with the SST project reduced risk and improved project sustainability. Thus it is posited that long-term project sustainability is closely related to the socio-economic impact of SST projects, in the SSA context. The Science Driven Economic Benefit (SDEB) model is the third phase and is essentially an implementation model developed from the MeerKAT case study. The three phases provide a basis for decision-making, investment and implementation that propose to aid in planning and maximising socio-economic benefit and growth from investment into SST programmes. As a result, the essence of this thesis is to contribute to the development roadmap for SST implementations in SSA countries, whereby these governments can invest in sustainable programmes to enhance their technology development, sustainability and economic growth.

This thesis is structured into five parts. Part 1 is the overall Introduction and an Introduction to SKA which establishes the context, rationale, and scope of the study. It introduces the MeerKAT and SKA projects. Part 2 contains the extensive literature review and examines relevant economic theories, development literature, and the current discourse on science and technology investments in African economies. It critiques standard modelling approaches and highlights the need for more contextually grounded frameworks. Part 3 contains the Labour Productivity Analysis which uses empirical data to assess the impact of economic indicators on labour productivity and the interrelationships, highlighting measurable socio-economic outcomes from SST investment. Part 4 is the section containing Model Development. This section develops the Space Science and Technology Investment Framework (SSTIF), consisting of three interlinked components: the Impact Causality Cycle (ICC), the Political Decision Matrix (PDM), and the Science Driven Economic Benefit (SDEB) model.

Part 5 contains the Case Study: The final part applies the developed framework to the SKA and MeerKAT case studies, illustrating how the model can be used to guide sustainable SST investment and implementation in the SSA context.

Together, these parts contribute a comprehensive model and set of recommendations for African policymakers, aiming to support strategic, inclusive, and long-term investment in space science and technology.

2. Introduction to the SKA

2.1. The Bid to host the SKA and the South African economy

At the time of bidding to host the SKA in 2010, South Africa was ranked 47th out of 139 countries (World Economic Forum, 2011) in its capacity for innovation, 29th for the quality of scientific research institutions and 24th for university industry collaboration and research and development by the Global Innovation Index³, thus providing an attractive option for hosting the SKA.

In December 2010, South Africa was invited to join the BRICS group of countries affirming its strategic role in Africa. South Africa's membership of BRICS and its relations with other countries in the region, affording South Africa the opportunity to be a meaningful partner in Africa's development. South Africa's physical infrastructure is the most developed in Sub-Saharan Africa, and the country hosts the continent's largest rail network. The country has seven commercial ports that serve as hubs for shipping traffic between Europe, Africa, Asia and the Americas. Most imports to the SADC region are transported via South Africa.

South Africa has developed a number of regulatory strategies and policies relevant to the SKA. For example, the Astronomy Geographic Advantage (AGA) Act (2007) was promulgated in order to advance astronomy and related endeavours through skills development and protection of geographical areas. This is of particular importance with regards to the reduction of light pollution for optical observatories and the elimination of radio frequency interference (RFI), which is essential for radio telescopes, such as the SKA.

The Department of Science and Technology (DST) issued the National Research and Development Strategy (2002) which was implemented to create an enabling environment for scientific and technological innovation through human capital development and effective governance. The Advanced Manufacturing Technology Strategy (2005) was implemented by the DST to identify and develop industries and their associated technologies, which will positively affect manufacturing, innovation and technological infrastructure. The South African Earth Observation Strategy (2007) was developed by the DST to improve capabilities in the processing, dissemination, sharing, standards, linkages and archives of earth observation data. The South

³ WIPO – World Intellectual Property Organisation.

African National Space Agency Act of 2008 was brought into force to support industrial development, research, skills and international cooperation in space and scientific technologies. The act mandated the formation of the South African National Space Agency (SANSA), and the agency was officially launched in 2010.

The New Growth Path (2010) presented by the South African Minister of Economic Development, identified and proposed the implementation of employment drivers. Relevant areas include regional trade integration, targets of additional engineers and technicians as well as increased research and development in technology and innovation. Property rights and intellectual property are also strongly protected in South Africa and the regulatory environment is similar to those of developed countries with various regulatory bodies that govern how business is conducted in different industries.

In 2010, the SKA South Africa (SKA SA) project was a business unit of the National Research Foundation (NRF), a statutory entity established in terms of the National Research Foundation Act, 1998. As a public entity the NRF is subject to the Public Finance Management Act (PFMA). The PFMA 1999 (Act No. 1 of 1999) (as amended by Act No. 29 of 1999) was one of the most important pieces of legislation passed by the first democratic government in South Africa. The Act promotes the objective of good financial management in order to maximise service delivery through the effective and efficient use of limited resources. The key objectives of the Act were to modernise the system of financial management in the public sector, to enable public sector managers to manage and equally to be held accountable, to ensure the timely provision of quality information and to eliminate waste and corruption in the use of public assets.

In South Africa, the national elections in 2014 were declared free and fair by domestic and international observers. In terms of political pluralism and participation, the ruling party is part of a tripartite governing alliance, which has won every election since 1994. However, opposition parties are able to compete in elections, and there are frequent upsets on the level of local government. Nonetheless, corruption hampers the functioning of government, despite comprehensive anti-corruption laws and the existence of several agencies tasked with combating corruption. Enforcement remains inadequate and public servants regularly fail to declare their business interests, as required by law. In December 2015, the President unexpectedly fired the finance minister and replaced him with a low-profile legislator. After a national uproar, the currency plummeted to a record low, pressure mounted and the President replaced the new appointee with Pravin Gordhan, who had previously held the position from 2009 to 2014.

South Africa narrowly missed two ratings downgrades in 2016. Amongst a number of concerns outlined by the international ratings agencies were: political instability, state corruption and policy

uncertainty. However S&P Global Ratings downgraded South Africa's credit rating to junk in November 2017, citing sluggish GDP growth, rising fiscal deficits and an increasing burden of debt. Investment thus became problematic and civil liberties and political freedoms came under threat by a government that began to marginalise the rule of law and the constitution from its decision-making processes. The risk associated with crime was moderate, due to the reasons given above, as well as due to the high rates of industrial crime, high unemployment and a weak police force that requires supplementation by private security elements. The SKA core site in the Karoo was assessed as a low threat, however, due to the remote nature of the sites and their limited attractiveness as a target (Kroll, 2011).

Freedoms of expression and the press are protected in the Constitution and generally respected in practice. Moreover, the Constitution guarantees freedoms of association and peaceful assembly. Freedom of assembly is generally respected, and South Africa has a vibrant protest culture. Although demonstrators must notify police ahead of time, they are rarely prohibited from gathering. The Constitution also guarantees judicial independence, and courts operate with substantial autonomy. In terms of Personal Autonomy and Individual Rights, there are no official restrictions on housing, employment, or freedom of movement for most South Africans, but travel and some other personal freedoms are inhibited by the country's high crime rate (Freedom House, 2016). Several apartheid-era laws and a 2004 Law on Antiterrorism have been used by authorities to restrict reporting on the security forces, prisons, and any sites or institutions deemed by authorities to be important to the national interest. South Africa, during the post bidding period, scored 36 out of 100 on the Press Freedom Index, where 0 is worst and 100 is best (Freedom House, 2014).

Although South Africa is not directly adjacent to a conflict situation in another country, as a country it has itself experienced internal instability as well as the spillover effects from socioeconomic difficulties in neighbouring countries. In the process to award the hosting of the SKA project to one of the international bidders, South Africa was assessed by external consultants in terms of the security threat the country might face and the political stability as a host country of the SKA. One major challenge to South Africa attracting investment and large science, technology and infrastructure projects is clearly shown in the results of the assessment.

South Africa was given a low to moderate overall threat profile in the security threat report. The summarised threat profile determined that, despite government's efforts, South Africa still struggles with critically high crime rates, an HIV/AIDS epidemic, significant class disparity, energy shortages and political instability. Many crimes in South Africa are characterised by a high rate of violence, and the country has some of the highest rates in the world for murder, rape and car theft. Major cities are considered the country's crime capitals with underdeveloped townships on the

outskirts being hotspots of theft, assault and murder. Additionally, corruption in South Africa has infiltrated many vital economic and political sectors, while perpetuating crime, civil unrest and infrastructural deficiencies.

The risk associated with political instability was low to moderate, due to incidents of unrest and violence associated with elections as well as incidents of public utilities and transportation being shut down because of civil unrest. The risk associated with terrorism was low.

In 1996, South Africa had implemented the National Industrial Participation (NIP) programme, which seeks to leverage economic benefits and support the development of South African industry by effectively utilising the instrument of government procurement. The NIP programme is mandatory for all government and parastatal purchases or lease contracts for goods and services with an imported content equal to or exceeding USD 10 million. This of course had an impact on the Meerkat procurement plan. The first customers of NIP are the South African industry that benefits through the NIP business plans, which, when implemented, generate new or additional business activities through one or more of the following; investment, export opportunities, job creation, increased local sales, promotion of small, micro, and medium enterprises (SMMEs) and black economic empowerment (BEE), research and development and technology transfer. The second customers of NIP are the foreign suppliers who benefit from the programme through increased participation in the South African economy. In the case of foreign customers, the imported content of the purchase or lease contract for goods and services must be equal to or exceed USD 10 million to qualify for participation. In the case of South African industries, participation is dependent on enterprise capability to satisfy the requirements of both the NIP programme and the foreign supplier.

As part of the Schauenburg International Group, Stratosat Datacom won the tender issued by SKA SA in 2012 to design, build and install the 64 antennas for the MeerKAT project. Stratosat Datacom provides satellite hardware and solutions on the African continent, through their registered subsidiary companies in South Africa, Nigeria and Kenya. Stratosat partnered with South African company, General Dynamics SATCOM Technologies, a global leader in the design and building of advanced radio telescope antennas.

The MeerKAT project, which formed part of the greater SKA project, required that at least 75 percent of the components be manufactured locally and, as a result, the Panel Manufacturing Facility of Stratosat Datacom was established in Kempton Park, South Africa in 2014. In addition, Stratosat Datacom inaugurated its Sub-reflector Manufacturing Facility in Elandsfontein, South Africa, in 2015. As per the NIP programme, Stratosat Datacom is required to invest in the South African economy to the value of a percentage of the imported content.

The reflector panels for the first two MeerKAT dishes were manufactured at a facility belonging to General Dynamics in Estonia, after which the fabrication was moved to South Africa, with the appropriate training and knowledge transfer. A key objective for Stratosat Datacom was to support the development of local fabricators into high quality suppliers.

Stratosat Datacom's vision was that the facility would serve as a technology hub for the telecommunications industry to promote the continuing development of radio astronomy research by bringing new technology and skills into the country. At that time, the long-term intention was to manufacture panels for commercial antennas locally and to export them into other regions of Africa.

The National Key Points Act 1980 (Act No. 102 of 1980) is an act of the Parliament of South Africa that provides for the declaration and protection of sites of national strategic importance. Essentially, National Key Points are strategic installations, such as military bases or factories, which require special security. The SKA site in the Karoo has been made a National Key Point and the required security measures are being implemented.

2.2. The Square Kilometre Array (SKA)

The SKA Observatory (SKAO) is an inter-governmental organisation, mandated to construct and operate the SKA telescope with its head office located at Jodrell Bank Observatory in Cheshire, United Kingdom. On 12 March 2019, the South African Minister for Science and Technology signed the Convention to establish the international SKA Observatory, an inter-governmental organisation. The SKA Observatory came into force in 2020, following the ratification of the Convention by the three host countries namely Australia, South Africa and the United Kingdom, as well as by China, Italy, The Netherlands, and Portugal. The SKA Observatory consists of fourteen participating nations in total, these are Australia, Canada, China, France, Germany, India, Italy, Japan, the Netherlands, South Africa, Spain, Sweden, Switzerland, and the United Kingdom. The SKA represents an unrivalled opportunity for the development of high-level skills and expertise in Africa and will allow the continent to become a significant contributor to the global knowledge economy.

The international bidding process took place in order to determine the best site to host the telescope, ending in 2011. The site decision was contingent on several factors, such as the availability of a radio quiet area with power supply, and the host nation's relevant economic indicators and science capacity as discussed. The two shortlisted bidders were South Africa and Australia. As part of the bid process, both countries undertook to build and contribute precursor

telescopes. South Africa committed to construct the MeerKAT telescope and Australia committed to construct the ASKAP telescope.

On 25 May 2012, the Board of Directors of the SKA project announced that the SKA telescope would not be hosted in only one country, but rather that it would be split over the proposed South African and Australian sites. The portions of the telescope hosted in South Africa and at other African sites are the mid frequency arrays (SKA MID), whereas Australia will host the low frequency array (SKA LOW). The SKA telescope will be constructed in several phases to manage risk and to allow for technological advancement over the lengthy construction and commissioning periods. SKA MID Phase 1 originally included the construction of 133 antennas, due for completion in 2028, though the eventual number of dishes remains variable. Thereafter, SKA Phase 2 construction will commence, contingent on meeting the funding availability, with expected completion after 2030. It was envisaged that the full SKA telescope will consist of approximately 2000 antennas. The word ‘antennas’ here refers to what are more commonly termed ‘dishes’ or ‘radio astronomy dishes’. Each antenna will have a diameter of 15.5 metres and the array’s longest baseline will span a length of 120 kilometres. The SKA Project Phase 1 has a cost cap of approximately EURO ⁴1 billion and Phase 2 is anticipated to cost upwards of EURO 2 billion. The project will be acquired and operated through the SKA Observatory, funded by the member countries either by cash or in-kind contributions, with a system of fair returns in terms of procurement contracts to the members based on their levels of contribution. The core site in South Africa is located in the Karoo area of the Northern Cape Province, about 80 kilometres northwest of the town of Carnarvon.

SKA Phase 2 was intended to include remote arrays in African Partner Countries (APCs), namely, Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia and Zambia. A vital part of the effort towards building the SKA on the African continent is the African Very Long Baseline Interferometry Network (AVN) which is intended to build the required capacity and capabilities to host the SKA.

2.3. SKA activities in South Africa

The established project office for the SKA in South Africa (SKA SA) was merged with the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in 2017, to form the South African

⁴ This research utilises USD for quantitative analysis, note that in places it does report the South African expenditures in ZAR, the local project currency and SKA expenditures are quotes in EURO, the chosen project currency.

Radio Astronomy Observatory (SARAO). South Africa's commitments to the SKA Observatory are implemented through SARAO, under the mandate of the Department of Science and Innovation (DSI)⁵.

As of the completion of MeerKAT in 2018, SARAO employed approximately 400 people at multiple sites in Cape Town, Carnarvon and Gauteng. SARAO's mandate includes the design, construction and operation of radio astronomy research infrastructure platforms in the country, comprised of the Hartebeesthoek Radio Astronomy Observatory (HartRAO), Karoo Array Telescope (KAT-7), the MeerKAT (inaugurated in 2018) and various African Very Long Baseline Interferometry (AVN) nodes, and eventually the transitioning of MeerKAT into SKA phase 1. Efficiency gains were made by merging these programmes into one new national facility from both the funding, operational and human resource perspectives. In addition, DSI Minister Pandor, in her budget vote of 16 May 2017, directed the Department to explore the possibility of creating a South African Astronomy Institute as a consolidated single national multi wavelength astronomy institute and to hopefully conclude this prior to the completion of SKA phase 1.

In 2010, South Africa completed the construction of the KAT-7 radio telescope as an engineering test bed and prototype for the MeerKAT telescope. KAT-7 was constructed in order to learn the intricacies of building a radio telescope. KAT-7 was a success, allowing for it to be used to perform scientific observations that were published in scientific journals.

In July 2016, the MeerKAT Array Release One (AR1) was announced. This consisted of 16 MeerKAT antennas. Although the telescope was only partially completed, this array was dubbed the best radio telescope of its kind in the southern hemisphere (NRF, 2016). At this time the KAT-7 telescope was made redundant due to the superior capabilities of the MeerKAT AR1.

The MeerKAT telescope was completed on time, to budget, and many factors have contributed to it becoming more powerful and sensitive than what had previously been promised. The telescope was officially launched by the Deputy President, Mr David Mabuza, on 13 July 2018, and has already made globally significant scientific discoveries, based on preliminary and early commissioning radio astronomy observations, published in the world's leading scientific journals. The first light image was released in 2018, the clearest image of the centre of the Milky Way galaxy to date. Seven refereed papers on that image and 128 refereed papers from MeerKAT data since have been published.

This project has attracted the best scientific talent from around the world. SARAO has pioneered advances in high performance and big data computing, providing a platform to create skills, and

⁵ Previously known as the Department of Science and Technology.

stimulate interest in mathematics related careers. In addition, the new infrastructure development created opportunities for innovation, which have yielded commercial spinoffs – and will no doubt yield further spinoffs. The various impacts from project inception to date allow for both regional and national impact assessments.



Image 2.3.1 KAT7 Antennas (Credit: SRAO)



Image 2.3.2 MeerKAT core (Credit: SRAO)

2.4. Human Capital Development (Skills Development)

Establishment of the SRAO Human Capital Development (HCD) Programme followed an instruction from the then Minister of Science and Technology (now the Minister of Higher Education, Science and Innovation) to develop a community of scientists, engineers, technicians and artisans to ensure that SRAO fulfilled its mandate to design build, operate and exploit the MeerKAT and the SKA radio telescopes, and to secure South Africa's return on its strategic investments in radio astronomy. The programme was devised in a structured and proactive way to be fit-for-purpose for enabling SRAO to deliver on this mandate.

When South Africa submitted its expression of interest to host the SKA in 2003, there were less than five radio astronomers in South Africa. Since then, over 1500 grants have been awarded to postdoctoral fellows, postgraduate and undergraduate students at universities, as well as to students training at a technical and artisan level.

In the South African President's 2019 State of the Nation Address, he stated that the MeerKAT and SKA projects have, and will continue, to contribute in a major way to building up the expertise and skills that South Africa urgently requires to be a successful player in the Fourth Industrial Revolution (4IR). The current SRAO HCD programme was designed from the outset to use the MeerKAT and SKA projects to build the expertise and skills to which the President referred, through mission driven innovation. The intention is that SRAO's HCD programme continues into the era of the SKA because the construction and operation of the SKA, as well as the significant science opportunities the telescope will provide, necessitates that relevant capacity development continue, at least at the current annual rate.

2.4.1 Human Capital Development Strategy

SRAO's capacity development strategy is premised on creating a critical mass of diverse, world leading research groups in South African universities, and to a lesser extent in universities in the SKA APCs, through supporting science and engineering undergraduate and postgraduate students, postdoctoral fellows and academics, and collaborations with leading international universities. In parallel, the strategy addresses capacity requirements for the maintenance and operation of the telescopes by supporting the attainment of the relevant technician and artisan qualifications and experience. This strategic focus realises additional benefits through the upskilling of local Karoo communities, and thereby increasing their participation in, and benefit from, the government's investment into radio astronomy.

Within the research capacity development and the site capacity development programmes of SRAO HCD, targeted initiatives focused on areas specific to MeerKAT and the SKA, namely mathematics, science, astronomy, physics, and engineering. These are supported at all academic levels, and have been implemented to ensure a continuous throughput of young people moving into relevant studies and research.

At each academic level, students are selected and equipped with the appropriate financial support, information and skills to proceed to the next level of education. This leads to the establishment of a large number of representative postgraduates, and postdoctoral fellows, in radio astronomy and the related engineering disciplines, as well as the required artisanal and technical on-site capacity. Simultaneous support for the development of relevant teaching and supervisory capacity at South African universities is also addressed.

The research focus at the postgraduate and postdoctoral levels is determined by SRAO, based on its priorities, gaps in skills and expertise, and the requirements of the SKA and MeerKAT. The research focus is decided by SRAO's Chief Scientist and Chief Technologist, in consultation with SRAO scientists and engineers.

In order to attract the best and brightest young people, and to drive transformation, SRAO's scholarships are always positioned to be competitive with industry offerings, and to cover all costs associated with studies (inclusive of tuition fees, accommodation costs, meals, sundries and stationery). SRAO's postdoctoral fellowships are sufficiently competitive with local industry salaries and are sufficiently attractive compared to international research opportunities in order to retain doctoral graduates in research in South Africa, and to attract excellent international postdoctoral fellows.

In the allocation of scholarships to undergraduate and postgraduate students, SRAO strictly applies demographic targets that align with Ministerial instructions on transformation targets, and actively prioritises support to black African, Indian, and Coloured⁶ background (ACI) and female South Africans. The undergraduate programme was started with the primary aim of identifying and supporting ACI candidates and female South Africans who have the potential to pursue postgraduate research. Financial support is a critical enabler of transformation and so, as mentioned above, the level of scholarships and postdoctoral fellowships offered by SRAO ensure that students can focus on their studies without needing supplementary sources of funding, such as part-time work, and without imposing additional financial burdens on their families.

⁶ The term Coloured is used in South Africa in a non-discriminatory way.

The creation of an interactive, collaborating and informed community of students, local and international researchers, and the SRAO team in South Africa, around the SKA and MeerKAT, has been crucial to the sustainable development of capacity in radio astronomy in Africa. SRAO HCD has created such a community by organising and supporting student-focused conferences, skills development workshops, research groups, international and local travel grants, co-supervision, and a free flow of information across the community.

In addition to offering scholarships, SRAO has initiated programmes – some in partnership with other institutions – that train students in the skills necessary to participate in radio astronomy research and innovation efforts. The UK-SA Newton Fund’s Development in Africa with Radio Astronomy (DARA) project was established in 2015, and provided radio astronomy training to students from the eight SKA partner countries in Africa. The programme was led by Leeds University in the United Kingdom, in partnership with SRAO as the main delivery partner for South Africa. The DARA programme consisted of two components, the first being the Basic Training Programme, an introduction to radio astronomy for graduates. Approximately 40 trainees per year were trained through this programme. The technical and observational training was carried out at HartRAO in South Africa and at Kuntunse in Ghana. In addition to this, computer training in Linux and Python was provided by the South African Centre for High Performance Computing (CHPC). The second offering was the Advanced Training Programme that offered Master’s and Doctoral scholarships to individuals who had undertaken the basic training programme, to study at a UK or African university. The DARA training programme concluded in 2022.

The UK-SA Newton Fund’s Development in Africa with Radio Astronomy (DARA) Big Data programme, was an intervention to increase Africa’s research and skills base in data-driven science and associated technologies needed for dealing with extremely large data sets – it is seen as a scientific driver for research relevant to the 4IR⁷. DARA Big Data has provided further training and development opportunities in data science to science and engineering students from the SKA Africa partner countries since 2017.

The Radio Astronomy Advancement Programme (RAAP) was established in 2019, and funds interventions, mostly workshops, that contribute to the development of critical skills in radio astronomy-relevant science and engineering, within SRAO, the general radio astronomy community in South Africa, and in the SKA African Partner Countries. Training workshops are

⁷ The Fourth Industrial Revolution (4IR), also known as Industry 4.0, refers to the age of digitalization, from the digitally connected products and services we consume, to advancements in smart cities and factories and the increasingly common automation of tasks and services in our homes and at work.

aligned with SARA0's requirements and skills shortage, which may vary from year-to-year, depending on the needs of the organisation.

An e-learning platform⁸ offering online teaching and training resources in radio astronomy was launched in August 2020. The aim of the e-learning platform is to support the growing community of students and young researchers undertaking research in astronomy at universities in South Africa and the eight SKA Africa partner countries. The platform allows young researchers to develop their skills in radio astronomy, enabling them to participate in research with the MeerKAT telescope, and other international radio astronomy facilities. The platform also hosts online workshops and schools that introduce radio astronomy concepts to young researchers, with hands-on practical sessions using MeerKAT data. An e-seminar series of public talks focuses on developments increasing the radio astronomy footprint on the African continent through scientific, technical and human capital advancements.

2.5. Commercialisation and Technology Development

The design process for the SKA Phase 1 was initiated in 2013, through the SKA International Project Office (Precursor organisation to the SKA Observatory) and the design consortia were established. SARA0, together with a number of South African companies and institutions, participated in several of the design consortia and provided direct support to the SKA Project Office. Local industry and institutions are assisted financially through the Financial Assistance Programme (FAP) to enable their participation in the SKA design phase.

This programme enhanced South African industry competitiveness internationally, and built experience within the SKA project, and South African industry is now able to contribute critical skills to SKA efforts in technology and engineering areas. Six FAP programmes were completed in total, concluding in 2021.

The SARA0 Commercialisation team works with the Science Data Processing team, Electronics team and the RFI team towards the development of technologies and the identification of opportunities to provide assistance in project development, sourcing partners and funding. As of 2020, eight technologies are in various stages of development and commercialisation.

⁸ <https://www.sarao.ac.za/e-learning-portal/>

2.6. SKA in South Africa: Economic breakdown

The MeerKAT and other strategic initiatives were completed at a cost of R3,28 billion. The total cost of the SKA project to South Africa excluding the MeerKAT, KAT-7, SKA lobbying activities, totalled approximately ZAR 5,85 billion as at the end of the 2022 financial year.

As discussed, the move by South Africa to join the SKA was informed by the strategy to grow the knowledge-based economy and to build on the niche strength of our natural geographic advantage of clear Southern skies, little light pollution and radio-quiet zones presented by the Karoo desert in the Northern Cape province. Astronomy is becoming an increasingly important discipline across Africa, with South Africa taking a lead on investing in astronomy as a priority science mission through flagship projects including the MeerKAT telescope in Carnarvon, the Southern African Large Telescope (SALT)⁹ in Sutherland and the African Very Long Baseline Interferometry Network (AVN)¹⁰. South Africa has invested considerably into the telescope projects which have achieved not only the successful implementation of the requisite infrastructure, but also contributed to human capital development in radio astronomy and socio-economic development, creating jobs and business opportunities in the Northern Cape province at the national level. In addition to South African telescopes there are also those in Africa outside of South Africa such as the High Energy Stereoscopic System (HESS)¹¹ gamma-ray telescope in Namibia, and several other exciting astronomy initiatives such as the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX)¹² developing on the continent.

2.7. Socio Economic Impact

MeerKAT, the precursor telescope to the SKA telescope, is a premier facility delivered by SARAO on time, on budget and with four times the anticipated performance. The participation in this project has led to the development of home-grown, cutting-edge technologies and commercialisation programmes. In the field of 'Big Data' SARAO has provided commercialisable

⁹ The single largest optical telescope in the Southern Hemisphere.

¹⁰ The project to build an African array of telescopes in the SKA African partner countries to prepare their readiness to host the outer stations of SKA Phase 2, and to fill the scientific gap in the Southern Hemisphere for long baseline observations.

¹¹ Cosmic magnetic fields are extremely effective in shaping the universe but are difficult to track and measure. Manuel Meyer has completed a Marie Curie-Project to study cosmic magnetic fields using gamma-rays observed with the H.E.S.S. array and the Fermi-LAT satellite.

¹² The Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX) is a radio telescope array that will map nearly all of the southern sky in radio continuum and neutral hydrogen line emission over a frequency range of 400 to 800 MHz. The primary goal of HIRAX is to use 21-cm intensity mapping to measure baryon acoustic oscillations (BAOs): these are remnant ripples in the distribution of galaxies that are imprinted by primordial sound waves that existed in the early universe.

technology solutions. Growth in scientific output has increased immensely with research publications having increased from below the global average to twice the global average. In the development and construction of the MeerKAT telescope, 80% of the supply was local content and a significant focus was placed on Karoo supplier development. Local community development has included the implementation of a Knowledge Centre and an Artisan Training Centre in the Karoo. Karoo Economic Investment includes developing SMMEs through key training interventions, supplier development programs and partnerships. SARAo has developed a critical mass of transversal skills for high-tech project delivery, and transformation and job creation in the STEM sector has been successful.

This project has enhanced South Africa's global reputation for science and technology cooperation and investment. South Africa is recognised as an influential partner in radio astronomy and is leading African cooperation on radio astronomy and human capital development.

An independent socio-economic study has been undertaken to consider the impact of radio astronomy investments in MeerKAT and the SKA project over the period 2011 to 2022. This period covers MeerKAT construction and five years of scientific operations. Results of the economic modelling indicate the follow impacts:

Overall, approximately 6,233 FTE jobs have been created throughout the country due to capital expenditure over the period. As the production impact filters through the economy, 3,765 FTE jobs have been created indirectly, and 1 490 FTE jobs have been induced. Overall, operational expenditure has generated 13,989 new FTE jobs, equating to 1,166 new FTE jobs per annum for the period 2011 to 2022.

Total household income has increased by R929.9 million throughout the country. Production-induced impacts have generated an increase in household income to the value of R207.9 million over the period. The majority of it was earned by households involved in construction (34.2%), manufacturing (23.2%) and wholesale and trade (11.3%). Economic production is an activity implemented under the control and responsibility of an institutional unit that utilises inputs of labour, capital, and goods and services to produce outputs of goods and services. Approximately R4.95 billion of new business sales has been generated, equating to R413 million annually. Due to the multiplier effect which has resulted in a total indirect impact of R3.6 billion, equating to approximately R295.6 million annually. Around 37.9% of this will be accrued in research. The remaining 62.1% has been distributed across other sectors, with manufacturing and other community activities benefiting the most. The total impact on GDP induced by SARAo's operational expenditure has directly created R2.89 billion in GDP, equating to approximately R241.4 million per annum. An additional 3.7 billion of GDP has been generated through the

indirect and induced impact of SARAo's operations. Overall, operations have grown the national economy's GDP by approximately R6.7 billion, equating to R555 million per annum.

The contribution made as a result of operational expenditure to date is estimated at a total of approximately R13,1 billion on production and R6,7 billion on GDP. The project has therefore had a significant impact on the growth of the South African economy.

In the Northern Cape, approximately R366 million was spent during construction including spending on building materials, general labour, transportation, and accommodation. The capital expenditure has an estimated impact of increased production in the provincial economy, of approximately R741 million. The succeeding effect on employment creation due to the direct and indirect impacts is the consumption-induced effect of R306 million on the province. Expenditure on establishing the SKA is likely to have increased the Northern Cape's GDP by approximately R250 million. R245 million in wages and salaries has been paid to local workers throughout the economy over the construction period of the project. The labour costs directly associated with the project are estimated to be around R174.87 million to date .

SARAo focuses on Human Capital Development from community upliftment and education initiatives to the 100 grants awarded annually, covering national diplomas through to PhD. To date over 1,600 grants and bursaries have been awarded over the last 16 years. Socioeconomic benefits from SKA also include Foreign Direct Investment (FDI), knowledge transfer through education and training, industry spill-overs, ICT and data spill-overs, cultural benefits, and public good benefits. In addition, the Women in Science report highlights human capacity development to increase Africa's female research and skills base in data-driven science and associated technologies needed for dealing with extremely large data sets associated with SKA.

Declaration of the Meerkat National Park facilitates the establishment of multi-disciplinary research platforms. Several research activities have already taken place, including PhD research into Human-Wildlife Conflict, Biocontrol of Prysopsis Trees, global climate change monitoring, and archaeological and paleontological conservation. The Integrated Environmental Management Plan (IEMP) for the SKA Phase 1 mid-frequency array (SKA1_MID) in South Africa is exhaustive and regularly updated. SARAo has a history of maintaining regulatory requirements .

The Innovation and commercialisation activities at SARAo familiarise staff with the management of Intellectual Property (IP) considering the institutional policies and compliance with the IPR Act. SARAo supports staff in identifying projects that have commercial and impact potential, the protection of IP that is generated by the organisation, and programs that promote a culture of innovation, supports staff to source resources, including funding, to support project development to commercial success, manage the commercialisation agreements, licensing and spin-outs with third parties and industry and partner development with other similar structures to strengthen the

technology innovation system. The overall socio economic impacts of the Meerkat and SKA investment are summarised in Tables 2.7.1 and 2.7.2 below. The three impacts identified as having low or very low, negative impacts are mitigated as follows: Crime: This is not based on an increase in crime statistics, but rather an expected outcome due to increase household income in the area. Given the nature of the SKA project, a strong relationship exist with the security cluster in the region, with active a positive crime prevention programs in place; Agricultural production: Reduction in potential agricultural production, due to the acquisition of farms in the area, has been mitigated through the establishment of a feeding lot to support local and emerging farmers; Historic value: Mitigated through the implementation of key actions and interventions as set out in the SKA Integrated Environmental Management Plan.

Impact	Nature	Significance
<i>National economic growth and development</i>	Positive	Very high
<i>Household income</i>	Positive	Moderate
<i>Employment - construction</i>	Positive	Moderate
<i>Employment - operation</i>	Positive	Moderate
<i>Human resource capacity</i>	Positive	Very high
<i>Innovation</i>	Positive	Very high
<i>Scientific activity</i>	Positive	Very high
<i>Society</i>	Positive	Moderate

Table 2.7.1 National socio-economic impacts

Impact	Nature	Significance
<i>Local infrastructure</i>	Positive	High
<i>SMME development</i>	Positive	Moderate
<i>Youth education</i>	Positive	High
<i>Interest in STEM</i>	Positive	Low
<i>Educational infrastructure and resources</i>	Positive	High
<i>Average income levels</i>	Positive	Moderate
<i>Skills development</i>	Positive	Moderate
<i>Crime</i>	Negative	Very Low/No
<i>Internet connectivity</i>	Positive	Moderate
<i>Temporary local employment</i>	Positive	High
<i>Permanent local employment</i>	Positive	Low
<i>Agricultural productivity</i>	Negative	Low
<i>Historical value, culture, and sense of place</i>	Negative	Low
<i>Migration</i>	Positive	Low
<i>Property prices</i>	Positive	Moderate
<i>Economic growth</i>	Positive	Moderate
<i>Economic production</i>	Positive	Moderate

Table 2.7.2 Karoo socio-economic impacts

2.8. The SKA Phase 1 Business Case

2.8.1. SKA Project Revenue Model to South Africa

South Africa as a member state of the SKA IGO, contributes to the SKAO by both cash and in-kind contributions. For the purposes of this research we will only consider cash payments. The cash payments are made towards the capital costs of the SKA 1-Mid telescope construction and towards the operational costs of the SKAO over the operational lifetime of 50 years. South Africa has committed to contribute 14 percent of the SKAO costs.

Based on this 14 percent contribution, South Africa will receive the proportional value of construction contracts that will be awarded to SARAO and South African industry. South Africa will also receive the proportional value of operational contracts, and rental revenues for certain infrastructure provided. This rental revenue will provide the basis for the funding model of the infrastructure (buildings) that South Africa is required as per South Africa's host obligations.

The capital cost for the SKA 1-Mid in South Africa and the SKA 1-Low in Australia, as committed to by the SKAO is currently ¹³estimated at EURO 1.132 billion Euros, including contingency, to be spent over a 7 year construction period. The construction cost funding due by South Africa, based on South Africa's agreed 14% financial contribution is approximately ZAR 3.4 billion.

Operating expenses for the SKA 1-Mid project will be incurred annually, starting in the first year of construction. Operations will, however, slowly ramp up during the seven year construction period, and stable operations will be reached from year eight. The operational expense funding due by South Africa, based on South Africa's agreed 14 percent financial contribution is approximately ZAR 180 million per year, for the first ten year period.

The construction revenues which will feed back into South Africa through the construction contracts awarded to South Africa within the first ten years of the project. The estimated split in the awarded contract revenues will be 35 percent of the contracts awarded to SARAO and 65 percent of contracts awarded to South African industry. South African capital expenditure on the SKA project will be returned in construction contracts on an approximate 1:1 ratio.

Operational costs of the SKA project due to be paid by the SKAO to South Africa, based on South Africa's 14 percent financial contribution, will amount to approximately ZAR 4,6 billion in contracts to be placed in the first ten years.

¹³ As at December 2022.

According to current estimates, approximately 33 percent of the total operating budget for the SKA project is expected to flow into South Africa, resulting in a net return of 19 percent in foreign investment.

SKA1 construction contracts will see the awarding of construction contracts to South Africa, informed by the expected and negotiated principle of *juste retour*¹⁴ resulting in direct contracts being placed on South African industry, and SARAQ, to deliver work packages. Payment for these contracts shall either be via cash transactions by the SKA Observatory, or in lieu of payments by South Africa to the SKA Observatory for SKA1 construction, referred to as in-kind contributions. Current estimates indicate that ZAR 1,2 billion worth of construction contracts will be placed with SARAQ directly, and a further ZAR 2,2 billion worth of construction contracts being allocated to South African industry.

South Africa's Net Present Value for investing in the full 50 year programme is approximately ZAR 3,06 billion with an internal rate of return (IRR)¹⁵ of 5,16 percent. This was calculated using a compounded growth rate of 12 percent over ten year intervals with a discount rate of 3,5 percent. The discounted net cash inflow to South Africa is approximately ZAR 15,9 billion over the 50 year period¹⁶.

2.9. SKA: Status

South Africa's successes with respect to radio astronomy and the associated benefits are largely attributable to the teams and dedication of the stakeholders of the project itself, however it must not be ignored that the MeerKAT and associated programmes were driven ultimately for the purposes of the SKA to be hosted in South Africa, based on the returns expected to be generated from the SKA for the economy. It will be an interesting study to revisit this research upon full completion by 2029.

The SKA project has suffered many schedule challenges from its inception, as megaprojects of this nature do. The design phase was a difficult phase in terms of the number of contributing countries and organisations, over several design consortia, developing in some cases, new technologies and solutions. The integration of this work over many time zones, languages and cultures and geography should be a study on its own. The governance and structural portion of the project still suffers some delays in 2022 due to the establishment of the inter-governmental

¹⁴ The *juste retour* principle means that national contributions are distributed only to selected research teams from that particular country.

¹⁵ The IRR is the annual income from an investment expressed as a proportion of the original investment.

¹⁶ As at December 2022.

organisation and the associated council, committees, and policies which took an extended process. This in particular affects the ability, prior to establishment of the structures, of the SKA to enter financial and legal commitments. In addition to these challenges, the COVID pandemic caused significant challenges, similar to those experienced around the world for the years of 2020 and 2021. The project expects for construction to physically begin in early 2023, with the award of the initial infrastructure contracts having been awarded in 2022. Construction completion for SKA Phase 1 is expected in 2028¹⁷. A short analysis on project status is further expanded on following the chapter case study of the MeerKAT SDEB model in Chapter 9.

2.10. SKA Africa: The African VLBI Network (AVN)

The AVN project is a partnership between the National Research Foundation (NRF) through the office of the SKA in South Africa and new institutions that are being established in the SKA Africa partner countries. Initial South African funding for the AVN, in the order of approximately ZAR 140 million, was provided for by the African Renaissance Fund (ARF) within the Department of International Relations and Cooperation (DIRCO) and the then Department of Science and Technology (DST).

This programme was initiated to develop the skills and infrastructure required for the larger SKA project which in later phases, plans to implement remote arrays across the APCs.

Activities are ongoing in the APCs to establish radio astronomy research communities and to develop the skills to mine data in order to conduct publishable science. In addition, the activities include the development of core teams with the appropriate skills to engage in the engineering, technology development and operations related to radio astronomy instrumentation.

In Ghana, the Ghana Space Science and Technology Institute (GSSTI) is the custodian of the AVN radio observatory. The GSSTI was established in 2012 as an institute within the Ghana Atomic Energy Commission (GAEC). SARA0 activities in Ghana converted the redundant 32-metre telecommunications antenna at Kutunse, north of Accra, into a VLBI¹⁸ capable radio telescope. In addition to the 26-metre HartRAO VLBI capable telescope that already exists in South Africa, Ghana was the first country of the APCs to establish a VLBI capable telescope for the AVN project. This telescope is well placed to fill the gap between Europe and Africa for VLBI

¹⁷ SKA Observatory SKA Phase 1, Construction Proposal, 2020.

¹⁸ Very-long-baseline interferometry (VLBI) is a type of astronomical interferometry used in radio astronomy. In VLBI a signal from an astronomical radio source, such as a quasar, is collected at multiple radio telescopes on Earth or in space. The distance between the radio telescopes is then calculated using the time difference between the arrivals of the radio signal at different telescopes. This allows observations of an object that are made simultaneously by many radio telescopes to be combined, emulating a telescope with a size equal to the maximum separation between the telescopes.

with the European VLBI Network (EVN). The EVN was formed in 1980 by five of the major radio astronomy institutes in Europe and now consists of 14 partner institutes.

The telescope in Ghana was inaugurated by the President of Ghana at Kuntunse, Accra on 24 August 2017. During the launch proceedings, the Ministers and Deputy Ministers representing the nine APCs concluded their Fourth Ministerial Meeting with the signing of a Memorandum of Understanding to collaborate in radio astronomy. Programmes to establish astronomy related research infrastructure in other partner countries are being developed through the SARA Africa Program Strategy, which includes partners such as the South African Centre for High Performance Computing (CHPC) as well as partners in the United Kingdom through the Newton Fund¹⁹.

A number of challenges, in particular to resourcing have influenced the AVN programme and as such the new Africa Radio Astronomy Programme (ARAP), broader than the original African VLBI Network (AVN) and, although it still incorporates VLBI activities, it also aims to capitalise on the achievements to date while reflecting on the challenges encountered in order to design a coherent programme that will accelerate the SKA Africa partnership objectives.

The original Africa VLBI Network (AVN) as supported by the African Renaissance Fund (ARF) in 2012 had to evolve over time due to resourcing and other constraints. The South African SKA Steering Committee (SASSC) requested an appropriate update of the Africa Strategy and the Budget. These were proposed to, and supported by, the SASSC in February 2022 and accepted by the SKA Africa Partner Countries (APC's) Meeting in June 2023. The new strategy enables the Africa Radio Astronomy Programme (ARAP) which incorporates a wider range of interventions and significant partnerships and collaborations. The ARAP Vision is the sustainable establishment of African science and technology networks, as well as the growth of skills and science and technology capacity in the SKA Africa Partner Countries. New and creative programmes have been developed under the ARAP umbrella to enhance capacity and development and to provide project longevity; one such programme is the colocation programme.

2.10.1. The Colocation Programme

The African Colocation Programme is an evolving programme designed to colocate space science and technology infrastructure on the AVN sites within the APCs. The programme is designed to grow expertise, industry, innovation and academia in the partner countries, in turn creating larger African networks for data, fibre, satellite ground stations and science instrumentation. In other

¹⁹ The UK-South Africa Newton Fund is a partnership administered by South Africa's Department for Science and Technology and the UK's Department of Business, Innovation and Skills. Based on a matched funding model.

words, the AVN colocation is a proposed central and southern African network of space-based industry and science infrastructure. The network will provide augmented solutions to users through collocated sites designed to promote sustainability, industry development, training, and scientific research collaboration.

In order to identify and manage expectations, it was essential to develop a proposal for buy-in by both local and African partner stakeholders, with a roadmap that realises quick wins as well as long-term solutions and importantly, sustainable income-generation capabilities. The roadmap addresses the basic requirements for technology advancement in a phased approach, and this will be achieved through the implementation of the colocation of science instruments, satellite data receiving ground stations, passive tracking radar for southern and central African aircraft security and data processing infrastructure. The colocation of all these services and infrastructure on one site allows for site operations and infrastructure to be shared. In addition, some of these implementations will be based on low cost, robust computing solutions developed for the MeerKAT telescope, as well other locally-developed technologies.

Each APC Site would be able to address Human Capital Development (HCD), African technology infrastructure and science goals, as well as industry development and revenue streams.

This programme has been designed in order to provide sustainable revenue for programmes and ongoing operations and maintenance of colocation sites, and employment, education and training opportunities in areas such as radio astronomy, related technology development, data administration and management skills. In addition to offering value added data solutions from data applications of earth observation data including but not limited to agricultural and environmental monitoring, illegal fishing monitoring, poaching mitigation, fire tracking, disaster management, resource management and more. The provision of new innovations such as the passive radar solutions that not only contribute to conventional aircraft tracking but also aid in security concerns such as addressing illegal trafficking activities.

In essence, the colocation of science, technology and industry solutions on one site allows for cost and resource sharing for ongoing operations and maintenance of the sites. Through academia, government and industry activities sharing not only a geographic site, but skills, knowledge and innovation opportunities, fostering the creation of a fertile environment for growth and development.

No one partner owns the programme, and each collaboration within the programme, and specific to each site, will develop their own partnership and sharing agreements. Each colocation site will be provided with a basic implementation to build on over time, this implementation will include a

physical satellite receiving dish²⁰ the relevant hardware and software required, basic satellite data contracts relevant to the country's initial needs, value add services to address the information requirements as well as a distribution solution. The full implementation would also be supported through a thorough training solution. It is thus a dynamic programme that allows for unique solutions to partnership and development and an overview of the programme is expressed below in Image 2.10.1. The immediate implementation requires that the partner country establishes the lead agency mandated to govern space related activities. This phase should lead to data and information solutions that would be provided to countries through centralised government procurement and distribution. In addition, this phase should see the parallel implementation of skills development. Once these activities have been successfully implemented, the satellite receiving station can be implemented and this will greatly reduce the cost of, and access time to data.

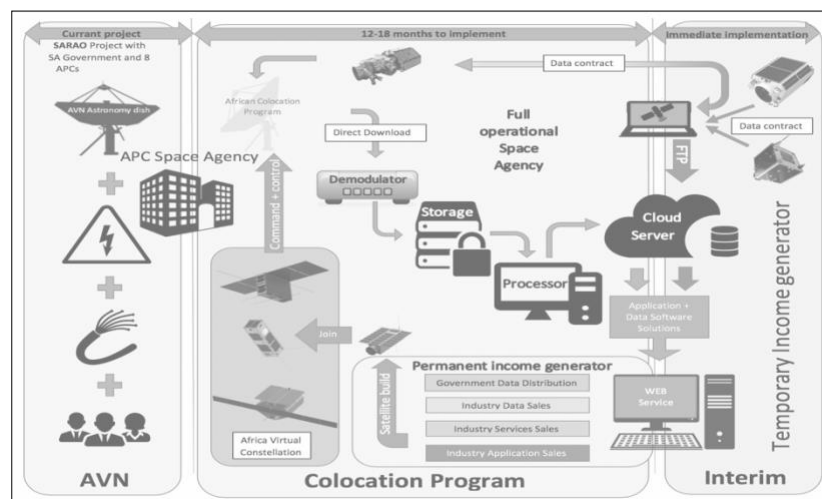


Image 2.10.1.1 The Colocation Model (Credit: Dewald Lloyd)

The colocation pilot programme was implemented at the Ghana Space Science and Technology Institute (GSSTI), a statutory organisation under the Ghana Atomic Energy Commission (GAEC) of the Ministry of Environment, Science, Technology and Innovation (MESTI). The programme was implemented as a collaboration between industry, the Ghanaian government and academia. A satellite ground station was constructed at the Ghana Radio Astronomy Observatory (GRAO) at Kuntunse, in Ghana. The satellite ground station was successfully installed, tested and commissioned and began formal operations by the 1st October 2021. The partnership has generated hosting fees, training and the contribution of funds towards the operational costs of the

²⁰ The satellite receiving dish is in addition to the radio astronomy dish, the business case is not assuming a dual use dish but rather collocated instruments.

site, such as electricity use. This programme has provided the financial and technical support required to convert an originally science driven site to one that hosts space science, data science and space industry activities in collaboration with one another, on the basis of sharing knowledge and resources for long term sustainability.

The impacts of the programme, as reported by the Deputy Director-general of GAEC in April 2022, are technical training for staff, motivation and retention of employees, support for research and development activities at GSSTI, enhanced policy maker support, enhanced publicity and public image, and of course site sustainability.

In conclusion to Part 1, this introduction sets the stage for the remainder of the thesis, which is organised into four subsequent parts. Part 2 presents a comprehensive literature review, exploring key theoretical frameworks and empirical studies related to economic growth, labour productivity, and space science and technology (SST) investments. Part 3 offers an in-depth analysis of panel data from Sub-Saharan African (SSA) countries, identifying patterns and challenges within the regional socio-economic landscape. Part 4 introduces the development of the proposed analytical framework, derived from the findings of the literature and data analysis. Finally, Part 5 applies this framework to the MeerKAT case study, culminating in the presentation of conclusions, policy implications, and recommendations for future research and implementation strategies.

Part 2

Literature Review

3. Literature Review

3.1. Introduction

An examination of the trajectory of economic development over the course of history shows that growth and change have taken place over several phases, typically beginning in agrarian communities that developed over time through trade and innovation; through industrial revolutions; arriving at contemporary developed economies.

For most African developing nations, however, this has not been a natural process, with many having entered stages of development without completing those preceding it. Moreover, many African nations were subject to newly implemented, externally imposed borders which eroded the societal fabric formed by existing cultures, traditions, and community heritage. These disruptions have required significant adjustment, change management and catch-up on the part of these societies and their economic planning.

In a developmental context, the catch-up effect refers to the notion that all economies will eventually converge in terms of per capita income, due to underdeveloped economies tending to grow more rapidly than wealthier economies and will ultimately ‘catch up’ with their counterparts. To grow in highly competitive international markets from a relatively low developmental baseline, many developing economies have been tasked with leapfrogging over natural development phases – a process which only a few emerging economies have successfully undergone without accruing severe structural imbalances.

A key takeaway from these experiences is that it is not sufficient to simply cut and paste solutions from the developed world and hope for successful economic outcomes when the foundation for these solutions is unstable or not there at all. Approaches to economic development in African countries need to be centred on devising solutions that, at their core, are designed to incorporate the idiosyncratic cultural characteristics of the nations in question, and to develop synergetic foundations necessary to underpin a sustainable and inclusive growth agenda. If economic growth is not rooted in the structures of the society it serves, it cannot possibly succeed in the long run.

3.2. Sub-Saharan Africa – An Economic Overview

Sub-Saharan Africa (SSA) consists of 48 countries with over 3000 tribes and more than 2000 different spoken languages. It is home to more than one billion people, and it is predicted that half of the SSA population will be under the age of 25 years old in 2050 (World Bank, 2022). This demographic trend can offer both opportunities and challenges, with implications for education, healthcare, employment, and economic growth strategies in the region. Africa has the world's largest free trade area²¹ and as such the continent has significant potential if it can harness its resources and people. The region is composed of low, lower-middle, upper-middle, and high-income countries – 22 of which are fragile or conflict-affected²². Africa also has 13 small states, characterised by a small population, limited human capital, and a confined land area. There are significant political, economic, social and cultural differences between and within the countries, and as such Africa cannot be treated as homogeneous nor as separate from the rest of the world (Hillbom & Green, 2019). While the term Sub-Saharan Africa (SSA) is widely used in policy and academic discourse, it includes the majority of African countries, approximately 48 out of 54—and therefore represents a broad and highly diverse region. Although SSA covers roughly 90% of African nations by number, this classification masks the economic, cultural, linguistic, and institutional variation among these countries. Thus, while SSA is a useful geographic and economic shorthand, this research recognises that African countries within this group are not homogenous in terms of their readiness for or response to space science and technology (SST) investments. For this reason, the case study approach—focusing on South Africa—is used to generate insights that may be adaptable, but not universally generalisable, across all SSA nations. In addition, the continent is rich in natural resources, yet growth is still low and inconsistent compared to its potential.

Africa's overall economy began to grow significantly by the early 2000s (IMF, 2021)²³, as political situations improved and national governments began to make improvements concerning corruption, large-scale urbanisation and implementing macroeconomic growth plans aimed at improving living conditions (Toh, 2016). SSA's physical geography is also considered as a contributor to its poor economic performance, since the agricultural conditions or disease environment are determined by a country's geographical location, as well as the country's relative

²¹ The African Continental Free Trade Area (AfCFTA) agreement creates the largest free trade area in the world measured by the number of countries participating (World Bank, 2020).

²² Countries with high levels of institutional and social fragility were identified based on indicators that measure the quality of policy and institutions, and manifestations of fragility. Countries affected by violent conflict, are identified based on a threshold number of conflict-related deaths relative to the population (World Bank Group, 2023).

²³ The International Monetary Fund (IMF) is an international organisation that promotes global economic growth and financial stability, encourages international trade, and reduces poverty (IMF, 2020).

position to other countries, which then affects the ease of access to foreign markets. The importance of market access for manufacturing has been demonstrated in explaining the observed income differences between SSA countries (Bosker & Garretsen, 2012).

Looking at the past, (Jedwab & Storeygard, 2019) found that between 1960 and 2015, there were strong correlations between transportation investments and economic development. Railway projects were important infrastructural facilitators for mining districts from the late 19th century, and these large railway and road projects were characteristic of late 19th century growth. Another part of Africa's economic history was heavily influenced by the decisions of European colonial institutions²⁴. In most cases, these governments had no incentive to create institutions capable of fostering economic development in African colonies, tending to focus on the extraction of available economic resources. In addition, colonialism left different institutional, legal and property rights legacies (Acemoglu, et al., 2001). Today, many African institutions are still impacted by these early decisions. The findings by Sachs and Warner (1997) imply that Africa's colonial legacy, ethnic divisions, or geographical difficulties may help to explain the ineffective economic policies, which in turn are responsible for much of the growth shortfall.

Another important factor in considering SSA economies is the distribution of property rights. These normally emerge from the setup of the society, which is more collective than individual in nature, with tribes or families playing a particularly important role in the structure of African socio-economic relations. Consequently, the distribution of property rights remains an obstacle to classical economic development. In addition, there are the historic impacts of unequal resource endowments between specific regions, as well as a then, scarcity of labour. Baten (2016) noted that these factors, combined with bad institutions from pre-colonial or colonial times, have hindered the extensive implementation and use of technology which has impeded economic development. In terms of technology development, particularly within the arena of SST, for SSA economies to become and remain competitive in the knowledge economy and sustain their growth, they require systems of economic innovation that have the ability to convert research and development (R&D) investments and their educational capacities into industrial and export strengths (Dahlman, 2007). The ability to adapt to technological changes to increase efficiency is particularly important. Unfortunately, SSA lags behind other regions in terms of R&D investments.

SSA countries have employed diverse development strategies to fast-track economic growth and alleviate poverty. Most of the development strategies were designed by external actors and have included initiatives such as the highly contentious Structural Adjustment Programs (SAP) of the

²⁴ Institutions in economics refers to institutions are durable systems (1) of established and embedded social rules and. conventions that structure social interactions, or (2) well-established arrangements and structures that are part of the culture or society (Orji, 2021).

Bretton Woods institution, which often failed to produce the expected results (Gumede, 2018). This was proposed to be an engine of economic growth by the IMF and World Bank, but made several African economies worse off. The implementation of the SAP in the 1980s by SSA governments gave the IMF and the World Bank input into deregulating and privatising state enterprises. Benistakorbah (2018) argues that this also culminated in reduced government spending, led to huge debt, and devaluation of currencies. As documented by Calderón and Poggio (2010), though the policy has had its benefits, the era was one of the most difficult periods economically for African countries.

3.3. Current Economic Theories

Although there are divergences between theory, data and reality in the context of SSA economics, it is essential to start with the generally accepted economic theories and then look to adjustments within the SSA context. The importance of economic growth and development of a nation cannot be overemphasised and is premised on the fact that economic growth is the most important instrument for reducing poverty and improving the quality of life (Benistakorbah, 2018). As observed by Fosu (2003) as well as by (Ramirez, et al., 1997) institutional stability and steady economic growth is required for faster progress, and in the long-run it transforms to human development. Available statistics show that the poor constitute the vast majority of the population of developing countries, which in turn account for 82 percent of the world population – an overwhelming majority of which is in SSA, South Asia and East Asia (Benistakorbah, 2018, Nafziger, 2006).

According to the Harrod-Domar Growth Model, an economy's rate of growth depends on the level of saving and the productivity of investment (Harrod, 1939). This model was initially developed to assist in analysing the business cycle and was later adapted to understand economic growth. The model shows that economic growth depends on the amount of labour and capital available in an economy. Many developing nations have an abundant supply of labour or human capital and natural resources, but it is the lack of physical capital, one of the three primary factors of production, that reduces economic growth and development. Investment is thus required for capital accumulation, which in turn generates higher output and income. Higher income allows for higher levels of saving, and higher saving implies greater access to capital for investment. Of course, this does not account for the role of technological progress in generating growth.

The Solow Growth Model is an extension of the Harrod-Domar Model. It states that there are three factors driving economic growth: technology; capital accumulation; and the labour force (Swan, Solow, 1956). This model shows that an increase in capital accumulation as well as the

labour force will cause the economic growth rate to rise, but only temporarily because of diminishing returns. Eventually, the economy will grow at a steady rate, with GDP growing at the same rate as the increase in labour force and productivity. Once this steady state is reached and the resources in a country are fully utilised, the economic growth rate can only be increased through innovations and subsequent improvements to technology. The Solow model also predicts that the gap between rich and poor countries will ultimately narrow – a concept called catch-up growth. This is because poor countries have less capital to start with, so each additional unit of capital will have a higher return.

The Solow residual is the portion of an economy's growth in its output that cannot be attributed to the factors of production, namely the accumulation of capital and labour. In other words, the Solow residual represents growth in output that happens due to reasons beyond the simple growth of inputs. The Solow residual is thus often described as a measure of productivity growth due to technological innovation and is also referred to as total factor productivity (TFP). According to Solow's Residual, increasing TFP is achieved through innovation, investment into more productive sectors, and economic policies aimed at liberalisation and competition. TFP is a measure of productive efficiency in that it measures how much output can be produced from a certain quantity of inputs, and it accounts for part of the differences in cross-country per-capita income. TFP is calculated by dividing output by the weighted geometric average of labour and capital input, with the standard weighting of 0.7 for labour and 0.3 for capital. (Gordon, 2017).

In the case where two countries have implemented the same technologies, their economic output will differ if one country has institutions that are better suited to support growth (Acemoglu, et al., 2005). TFP may then be considered in part, a reflection of differences in policies and institutions. However, while institutions and rules form the foundation of an economy and shape incentives, much of the variation in TFP reflects differences in the availability and efficient deployment of technology and innovation in business practices (Bloom & Van Reenen, 2010).

By contrast, slowing productivity growth is both a matter of declining technological progress and a lack of skills necessary to adopt existing technologies (Baily & Montalbano, 2016). Ever more investment is required for innovation even as the productivity growth rate falls. This is partially due to a combination of having exhausted the simpler opportunities for technological progress and the inefficiencies in the innovation-generating pipeline (Shambaugh et al., 2017). The exhaustion of simpler opportunities is likely to be an inevitable feature of technological progress, but inefficiencies in the pipeline can be addressed.

The Lewis Structural Change Model addresses dual economies, which applies to many African developing nations (Lewis, 1954). A dual economy refers to the traditional agricultural sector on one hand – assumed to be of a subsistence nature and characterised by low productivity – and an

industrial sector on the other – assumed to be technologically advanced, with high levels of investment in an urban environment. This model suggests that the modern industrial sector would attract workers from rural areas, offering wages that provide for increases in welfare. Since the level of labour productivity in traditional agricultural areas is low, the people leaving the rural areas would have little impact on output in the agricultural areas. The agricultural outputs would have to be shared by fewer people, allowing for a surplus that could be sold to generate income. Higher incomes generate more savings, and increased savings means that more funds are available for investment. This leads to more capital and increased productivity in the industrial sector. Lewis's model was to a certain extent supply-oriented, the model focused primarily on the transfer of labour from the traditional agricultural sector to the modern industrial sector and did not consider the interactions or the trade of capital between these sectors.. It was also criticised for advocating industrialisation and ignoring agriculture.

The Rostow Model of Economic Development postulated that economic growth occurs in five basic stages of varying length that countries pass through, namely: the traditional society; preconditions for take-off; take-off; drive to maturity; and the age of mass consumption (Rostow, 1960). According to Rostow, development requires substantial capital investment. For the economies of developing countries to grow, the right conditions for such investment would have to be created. For example, if FDI occurs at stage three, the economy needs to have reached stage two. If stage two has been reached by the economy, then the injections of investment may lead to rapid growth. The transition from underdevelopment to development would take all five stages. As stated by Ghatak (2003), the Harrod–Domar model highlights the role of investment in the economy as with Rostow's stages of growth model. He suggests that for underdeveloped countries to develop they need reasonable levels of available capital for investment to achieve a targeted growth rate. A major lapse of these models is their oversimplified supposition for the respective resource bundles of all developing countries (Adelman et al., 2006).

The new growth theory promotes the role of government and public policies in complementing investments in human capital formation and the encouragement of foreign private investments in emergent knowledge-intensive industries such as information and communications technology (ICT) (Meier, et al., 2000). New growth theorists are of the opinion that economic growth can be stimulated towards increasing returns through the use of knowledge rather than labour and capital as inputs and investments into knowledge creation are important in fostering sustainable growth (Aghion, & Howitt, 1992). The theory posits that the higher rate of return, as expected in the Solow model, is greatly eroded by lower levels of complementary investments into human capital, infrastructure, or R&D. As a result, investments into knowledge creation are assumed to be a pivotal factor in bringing about sustained growth. Unlike the Solow model which treats

technological change as an exogenous factor, the new growth model notes that technological change has not been equal, nor has it been exogenously transmitted in most developing countries (World Bank, 2000).

The theory of coordination failure became popular in the 1990s and is widely used by development economists in the analysis of a case for industrial policy (Rodrik, 2004). Rodrik argues for a new approach to industrial policy, focusing on strategic collaboration between the private sector and government to remove obstacles to economic restructuring. According to this theory, low development is thought to be the result of coordination failures. Coordination failure is the concept that describes the situation whereby there is a failure in the economy to achieve coordination among complementary activities. Some investment projects are not undertaken because complementary investments do not exist, and these investments do not exist because the former are absent. Coordination failure leads the market to an inferior outcome compared to the potential situation where resources would be correctly allocated and all agents would be better off. Coordination analysis however cannot be used to improve the allocation of resources by comparison with the level that would be reached in a free market (Glavan, 2008).

Coordination failure happens, as suggested by Cooper and Andrew (1991), when firms can achieve the desirable equilibrium in their production process, but fail to do so because they do not sufficiently coordinate their decision-making. According to Dang and Sui Pheng (2015), coordination failure among diverse individuals can cause the economy to have multiple points of equilibria, in which not all are necessarily good or desirable for the economy. To Hoff and Stiglitz (2000), the interaction of these slightly distorted behaviours at the level of the firm may produce large economy-wide distortions.

The necessary role of the government, as highlighted by Hirschman (1957), is in state intervention that can assist in augmenting the economy towards an optimal equilibrium, such as large state-led public investment programmes which can affect complementarities. Hirschman (1957) noted that developing countries also lack sufficient managerial and entrepreneurial abilities. Thus, he argued that the optimal policy should prioritise unbalanced growth, with investments concentrated in major sectors with significant external effects that can facilitate and promote investments in the rest of the economy. Despite disappointments from these push policies in past years, development economists have more recently re-emphasised the relevance of big push policy, lent credence by the adoption of the Millennium Development Goals (MDGs) by the United Nations (U.N., 2005, p. 19).

Hakura et al. (2016) noted that empirical evidence suggests that the presence of high levels of socio-economic inequality, whether income or gender-related, can impede economic growth. Their research found that both income and gender inequalities, including from legal gender-based

restrictions, are jointly negatively associated with per capita GDP growth. In their study of the relationship in countries at different stages of development, they found that this effect was primarily dominant in lower-income countries. High levels of income inequality in SSA appear partly driven by the structural features of the economies. However, their findings show that policies that influence the opportunities of women and low-income households to participate in economic activities are relevant (Hakura et al., 2016). If these interventions are well-designed and appropriately targeted, they play a role in alleviating inequalities.

In the study which covered 97 countries over a significant time series, Sachs and Warner (1995) documented that the economic growth rate of natural resource exports in resource-rich countries tend to be lower in comparison to countries without abundant natural resource endowments. Invariably, the authors identify a relationship between the abundance of natural resources and poor economic growth. “Other writers have equated the resource curse to the task of lottery winners in managing the effect of newfound wealth” (Mbah, Ojo, 2018, P. 26). Nurkse (2009) argued that the successes or failures of a country can be attributed to a variety of factors, and not necessarily whether the country is endowed with natural resources or not. Nurkse emphasised that a lack of capital was a significant barrier to economic development and that overcoming this barrier required a comprehensive approach that went beyond simply exploiting natural resources. He advocated for investment in a wide range of sectors simultaneously to avoid bottlenecks and to stimulate demand for domestic products, that a balanced growth strategy could help overcome the limitations of market size in small economies and lead to sustainable development.

There are many different reasons for poor economic growth and policy choices in Africa, with many instances of poor economic growth directly caused by the policy choices. In the period from 1965 to 1990, the quantitative results suggest that poor policies and institutions explain a large share of the slow growth and that better policies would contribute to stronger economic performance (Sachs & Warner, 1995).

Olawuyi (2017) identified three main areas that constrain Africa's assimilation and development of technologies: cultural and traditional barriers, weak legal protection for imported technologies, and weak investment environments. A key concern facing technology absorption across Africa is local and cultural resistance to transferred technology. Many imported technologies have been rejected by local communities for various reasons, including cultural, religious, or political factors.

Another barrier to the absorption and assimilation of technologies is the weak legal protection for intellectual property rights (IPRs) in many African countries. The absence of robust IPR systems can discourage both domestic innovation and foreign technology transfer, as innovators may migrate to countries with stronger protection mechanisms.

The third major constraint is the weak investment environment, which refers to the lack of financial infrastructure, political stability, and policy incentives needed to attract and retain both domestic and foreign investment in technological innovation. Without supportive institutions, access to financing, and investor confidence, entrepreneurs and technology developers face significant hurdles in scaling up and commercialising innovations. This limits the continent's capacity to build home-grown technological solutions.

As stated by the African Development Bank (2014), “poor technological capability remains one of the major constraints to Africa's efforts to achieve sustainable development.” For Africa to move beyond its dependence on technology transfer, it must create the right economic, social, and environmental conditions for entrepreneurs to develop, deploy, and commercialise technologies (Olawuyi, 2017).

SSA still has much to overcome in the way of the aforementioned challenges, but many more loom in the future, such as the challenge of climate change that comes with the reliance on largely agrarian economies. Approximately 23 percent of SSA's GDP comes from agriculture with 60 percent of the population of SSA made up of smallholder farmers, (Goedde et al., 2019). African agriculture is vulnerable to the impacts of climate change, in particular rainfall patterns that are changing. The variations in large-scale climate phenomena have enormous implications for the amounts and patterns of rainfall in individual African countries. Since agriculture is such a critical factor in Africa's economic sustainability, climate change could destabilise local markets, increase food insecurity, limit economic growth, and increase risk for investment in the agricultural sector (Wouterse, 2023).

What is clear is that policy action is needed to enhance economic diversification, mitigate against economic shocks, unleash the private sector's potential, and address the challenges of the past and present so that SSA is able to meet the challenges of the future.

4. Pillars of Success for economic growth from SST in developing nations

4.1. Introduction

Derived from the literature review, the core of this research holds that institutions and policy, education, technology and innovation, equality and African value chains are the pillars without which economic growth cannot be successfully achieved from SST investments in the developing nations of SSA, a summary of which is provided in this section.

4.2. Institutions and Policy

Robust institutions have a necessary role to enhance consumer confidence and safeguard rights, which in turn drives consumption (North, 1990) and furthermore, the quality of institutions is instrumental in guiding investment decisions (Acemoglu & Robinson, (2012). As noted by Rodrik, et al. (2004), clear property rights, effective legal frameworks, and good governance diminish transaction costs and investment risks, fostering both domestic and international investment inflows essential for GDP growth. Effective and transparent institutions ensure that government spending is allocated efficiently towards public goods and services that support economic growth, such as infrastructure, education, and healthcare. Conversely, weak institutions may lead to misallocation of resources, corruption, and inefficiency, which can reduce economic performance (Tanzi & Davoodi, 1997). Institutions that support open markets and facilitate international trade can lead to an increase in exports. Efficient customs, regulatory quality, and standards help integrate a country into the global economy, enhancing its export potential. Similarly, institutions that promote a competitive domestic market influence the import levels by determining how easily foreign goods can enter the market (Frankel & Romer, 1999).

As discussed, SSA countries have had a complex past when it comes to good governance institutions. Fayissa & Nsiah (2013) showed that good governance or lack thereof, contributes to the differences in the growth of SSA economies. Economists and policy-makers alike, recognise the importance of good governance and institutional strength for economic growth and development. Institutional integrity and policy direction form the foundation of development in any nation, without which investment and collaboration are inevitably hampered. It is thus sound

policies, strategies, legislation and institutional support that enable large-scale programmes to take effect, become sustainable and ultimately produce the potential benefits. The issue of good governance and transparency is more than simply the consideration of wasted resources but it is a focus on the “erosion of the social contract and the corrosion of the government’s ability to grow the economy in a way that benefits all citizens” (Akuamoah-Boateng, 2022, P.1). Poor quality institutions, weak rule of law, absence of accountability, information controls, and high levels of corruption have unfortunately characterised many African economies.

The quality of institutions from an economic perspective plays a significant role in shaping the national accounting equation, which fundamentally represents the balance between a nation's total production (GDP) and the components of its expenditure. In economic theory, the national accounting equation can be simply expressed as

$$\text{GDP}=\text{C}+\text{I}+\text{G}+(\text{X}-\text{M}) \qquad \text{Equation 4.2.1}$$

where C represents consumption, I is investment, G is government spending, X is exports, M is imports. GDP is a reflection of a country's economic health.

This equation is based on the seminal work by Kuznets (1941), and although it is far more complex in reality, the simple equation does provide a means to evaluate impacts and flows. Good governance in Africa, as promoted by the New Partnership for Africa’s Development (NEPAD), can significantly influence the national accounting equation. NEPAD is a socio-economic flagship Programme of the African Union (AU), and it facilitates and coordinates the development of continent-wide programmes and projects in order to mobilise resources and engage the global community with Africa. NEPAD has four main goals: eradicating poverty; promoting growth and development; integrating Africa into the world's economy; and accelerating the empowerment of women. In their study, Fayissa and Nsiah (2013) indicate that the impact of governance on economic growth depends critically on the level of income or GDP per capita. Gani’s (2017) study concluded that political stability and government effectiveness are significantly positively correlated with growth, and the indicators of ‘voice²⁵ and accountability’, and corruption are significantly negatively correlated with growth.

The promotion and implementation of effective governance can lead to more transparent and accountable financial systems, attracting investments and fostering a healthy business environment, and ultimately an increase in a nation's assets. Conversely, governance challenges

²⁵ World Bank's Worldwide Governance Indicators define "Voice and Accountability" as capturing perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.

can hinder NEPAD's objectives, impacting the equitable distribution of resources and potentially leading to a misallocation of assets, thereby affecting overall economic health. Fayissa and Nsiah (2013) confirmed that without the establishment and maintenance of good governance, achieving the goals of NEPAD will be an increasingly difficult task with a diminishing probability of success. Between 1970 and 1998, when aid flows to Africa were at their peak, poverty in Africa rose from 11 percent to 66 percent (Moyo, 2009). She states that the history of aid in Africa has thwarted accountability mechanisms, encouraged rent-seeking behaviour, siphoned away talent, and removed the pressures to reform inefficient policies and institutions. In addition to these, Moyo (2009) notes that aid contributes to the crowding out of domestic exports and raises the stakes for conflict.

The impact of aid can then be considered in terms of governance. Bräutigam (2004) noted that although receipts of development aid have been reduced in many parts of Africa, in countries with poor governance records, aid continues to form a high percentage of government budgets. Aid should release governments from revenue constraints, enabling them to strengthen domestic institutions and increase public sector wages (Bräutigam & Knack, 2004). Although governance reforms do happen, and they can happen in poor countries, however, the foreign aid system although well-intentioned, can also induce challenges to governance in aid-dependent states and high levels of aid can even hamper governance improvements. The delivery mechanism of large amounts of aid can weaken institutions through high transaction costs, the fragmentation that multiple donor projects and agendas promote, problems of obstruction of opportunities to learn, as well as the impact it has on the budget process. Indirectly, high levels of aid can generate negative incentives. Robust institutions and effective policies are fundamental to fostering economic growth in SSA. Quality institutions enhance consumer confidence, safeguard rights, and reduce transaction costs, thereby attracting both domestic and international investments. Good governance ensures the efficient allocation of resources towards public goods, supports open markets, and promotes competitive environments, which are crucial for GDP growth. Conversely, weak institutions and poor governance lead to corruption, resource misallocation, and inefficiency, hampering economic development. The evidence underscores the importance of institutional integrity and sound policy frameworks in driving sustainable growth.

Robust institutions are a critical part of ensuring that SST investments translate into meaningful economic growth in SSA. The integrity and effectiveness of institutions determine the success of these investments by fostering a stable and predictable environment that attracts both domestic and international investors. Strong governance structures ensure that the legal and regulatory frameworks are conducive to innovation, protect intellectual property, and facilitate the commercialisation of space and science technologies. Moreover, institutions that uphold

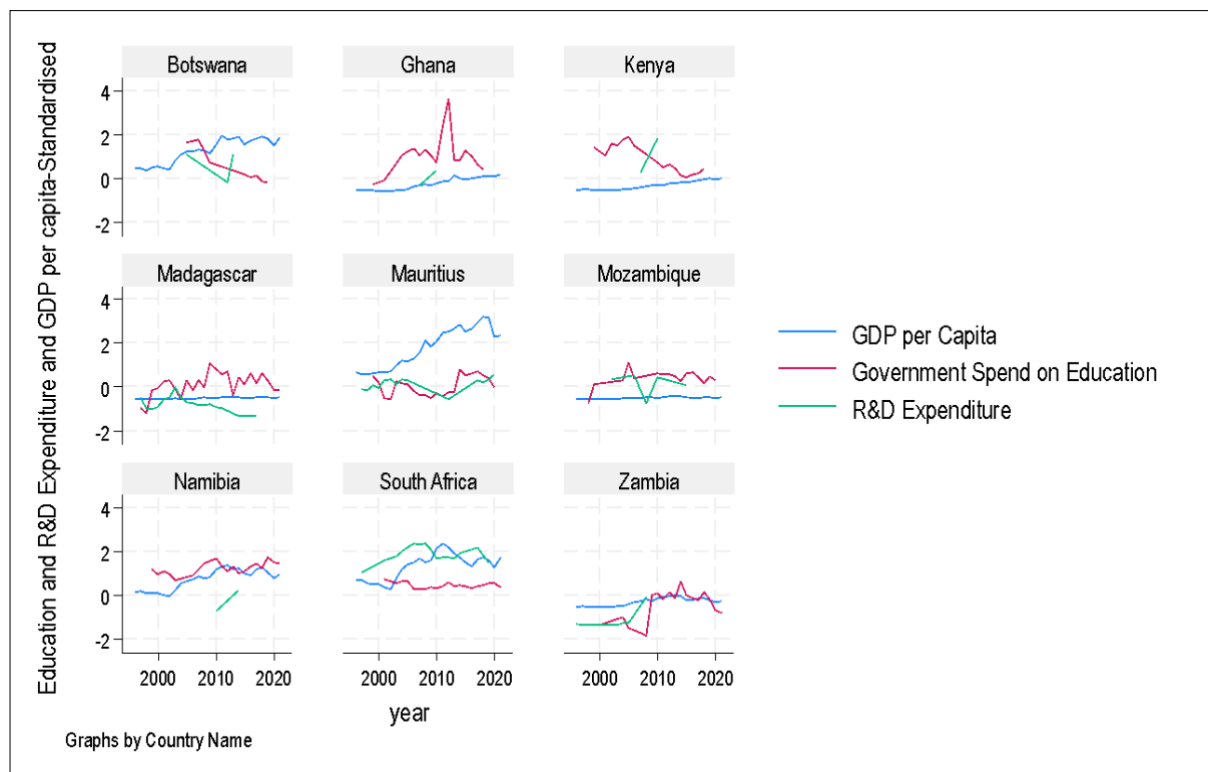
transparency and accountability are crucial in managing the financial resources associated with SST projects, minimising corruption, and ensuring that funds are allocated efficiently toward critical infrastructure, research and development.

4.3. Education

Ozturk (2008) stated that education in every sense is one of the fundamental factors of successful development. No country can attain sustainable economic development without substantial investment in human capital (Malangeni & Phiri, 2017). The literature emphasises at least three mechanisms through which education may affect economic growth. Firstly, education can increase the human capital inherent in the labour force, which in turn increases labour productivity and thus growth towards a higher equilibrium level of output. Secondly, education can increase the innovative capacity of the economy and this process promotes growth, in other words, an economy with a larger total stock of human capital will experience faster growth (Romer, 1990). Thirdly, education can facilitate the transmission of the knowledge needed to understand and process new information, and to successfully implement new technologies, which would then promote economic growth (Malangeni, Phiri, 2017). Benhabib and Spiegel (1994) found that the growth rate of TFP depends on a nation's human capital stock level. The study by Hanushek et al. (2010) found evidence to support the notion that the quality of education – measured on an outcome basis of cognitive skills – has powerful economic effects and reiterates that economic growth is strongly affected by the skills of the workers in that economy. It should be noted that a year of schooling does not produce the same cognitive skills everywhere, families and peers contribute to education, as do health and nutrition which further impact cognitive skills, yet these factors are largely ignored. In developing nations, much of the discussion of development policy tends to oversimplify this message. It recognises that education is important, but focuses on ensuring that everybody is enrolled in school, regardless of the effective learning that happens at school (Hanushek & Woessmann, 2008). The rapid growth of technology also gives rise to a new set of challenges and pressures for educational institutions. Many teachers, schools, educational authorities and research bodies are considering a range of questions about how to use technology within the classroom (Lim et al., 2013). Effective integration of technology into learning systems is more complicated than, for example, providing computers and securing digital connectivity. Technology integration into the school system is essential but it has not yet been resolved as to how to do so at the scale of a national school system. Lim et al. (2013 Pg. 65) conclude that “imposing policy decisions is often less responsive to teacher perspectives and often neglects

workplace constraints. A way forward is stressing the responsibilities of local schools to develop a school-based technology plan.”

The World Bank Independent Evaluation Group (2006) documented that a high priority was afforded to increasing primary school enrolment in developing countries over the past 15 years. Whether or not children were learning, however, was not the focus. International testing indicates that even among those completing lower secondary schooling, literacy rates were low in many developing countries. Many of these countries have less than 10 percent of their youth currently reach minimal literacy and numeracy levels, even when school completion data appears to have significantly improved (Hanushek, Woessmann, 2008). The data from the SSA region is made up of indicators from 48 countries, which is challenging to represent visually. As such for the purposes of visual representation, the nine SKA Africa Partner countries were selected, as laid out in the Introduction to the SKA.



Graph 4.3.1 Africa SKA Partner Countries: Standardised GDP per Capita and Govt Expenditure on Education and R&D, 1990 to 2022 (Data Source: World Bank Data)

In terms of national accounting, education enhances individual earning potential, which, in turn, increases disposable income and consumption. Becker (1964) in the human capital theory, posited that investment in education improves the productivity and skills of the workforce, leading to higher wages and increased consumption levels in the economy. Education contributes to the formation of human capital, a critical component of investment in any economy. Schultz (1961)

argued that human capital is as important as physical capital in economic development, suggesting that investments into education yield returns similar to investments into physical capital. This not only includes direct investments in educational institutions but also investments in technology and research that are made more productive through an educated workforce. Government expenditure on education is a significant part of public investment in human capital. This spending is aimed at improving educational outcomes, which contributes to economic growth by creating a more skilled and efficient labour force. Mankiw, et al. (1992) demonstrated that government spending on education is positively correlated with economic growth, as it enhances the productivity of the workforce and educational spending itself could be considered a factor of production. An educated workforce is pivotal in increasing a country's competitiveness in the global market. Krueger and Lindahl (2001) found that improvements in educational attainment are associated with higher economic growth rates, partly due to the enhanced ability of a country to produce and export high-value goods and services. Education fosters innovation and adaptability, allowing economies to move up the value chain in global trade and improve their trade balances.

Substantial investment into human capital is indispensable for achieving economic progress. Education enhances labour productivity, drives innovation, and facilitates the diffusion of new technologies, all of which are critical for economic growth. However, the effectiveness of education policies depends significantly on the quality of education provided and the integration of technology within educational systems (Lim et al., 2013). While increasing school enrolment is crucial, it is equally important to ensure that students achieve meaningful learning outcomes (World Bank, 2006). The evidence suggests that investments into education, particularly those that improve the quality and relevance of education, are key to boosting economic growth and enhancing a country's competitive edge in the global market (Krueger & Lindahl, 2001). Thus, policymakers must focus not only on access to education but also on the quality and applicability of education to meet the demands of the economy.

4.4. Technology and Innovation

Technological growth is a process whereby innovations lead to new technologies, to new applications, and to adaptations of current technologies. For the purposes of this research, the term technological growth includes innovation, and is not separate from it. Innovations can be used to increase productivity through increased efficiency, creation of new industries, manufacturing, new employment opportunities and advances in infrastructure. Technological advances do not only lead to economic benefit, but also to improved social well-being. Examples

of this can be seen in advances in healthcare, resource management and improved access to information and communications.

Technological progress, as opposed to a sustained level of technology, is essential to driving economic growth, and this progress should be largely driven from within the economy in order to ensure sustainable growth. In certain economies, innovation is largely imported and manufacturing drives growth by means of large investments in capital and education. However, imported technology solutions are not able to drive long-run economic growth on their own – at some point, such economies, for example, Singapore, begin to experience a stagnation in the growth rate.

It has been widely asserted that public sector investments into science and technology promote broader socio-economic development. Many developing nations with emerging national space science programmes cite this as one of the reasons for their pursuit of such programmes. A positive correlation between the impact of technological innovation on economic growth has been established in developed nations, but such a correlation had only been assumed in developing economies. In their research, however, Mohamed, et al. (2022), aimed to measure the impact of technological innovation on economic growth in developing countries. They produced results that showed that an increase in technological innovation indicators, including education, number of patents for residents and non-residents, R&D expenditures, number of researchers in R&D, high-tech exports, and scientific and technical research papers, lead to an increase in economic growth in the short term and over the long-term. It was noted that the long run showed a two-way causal relationship between technological innovation and GDP (Mohamed et al., 2022).

It is assumed in this research that certain basic requirements need to be met within an economy to drive innovation, to adapt and adopt technologies, and then to reap the benefits from them. The skill sets must be available to innovate, and innovators must have access to the capital requirements in terms of infrastructure, manufacturing capability and finance to promote innovation and to translate ideas into tangible and available technologies. In addition, one must consider the requirements in turn for economic growth. As such, a cornerstone of the thesis is the notion that the successful adoption of technology for socio-economic benefit can only create benefits in an economic climate where basic growth potential can be realised.

In this context, some of the factors that can hamper economic growth are the political climate, financial and governance systems, as well as population characteristics, including the levels of education and skills and access to basic resources. In terms of political climate, the level of stability and corruption can hamper or drive growth, affect investment levels and influence the will towards technological development. Technological advancement improves the efficiency of production processes and reduces the costs of goods and services, making them more accessible to a broader segment of the population. This affordability can lead to an increase in consumption. Bresnahan

and Trajtenberg (1995) discuss how major innovations or General Purpose Technologies (GPTs), such as the personal computer, give rise to increasing returns-to-scale and fundamentally change consumer behaviour, leading to new forms of consumption and higher overall consumption levels. However, these impacts are less in a decentralised economy, as is the case within SSA, which would have difficulty in fully exploiting the growth opportunities of GPTs.

The concept of technology efficiency can be understood as the ratio of output such as goods, services, and innovations to the input, being investments into science and technology. Economies that perform well in technology efficiency are those that manage to leverage their investments into significant improvements in productivity, innovation, and ultimately, economic expansion (Hall & Lerner, 2010). The technology efficiency leads to direct productivity gains by enabling more output with less input, thereby enhancing the overall economic performance. Furthermore, economies that efficiently convert science and technology investments into new products and services experience faster growth by creating new markets and expanding existing ones (Kortum & Lerner, 2000). This stimulates economic activity and contributes to a competitive advantage in the global market, where the ability to quickly adapt and innovate is essential (Aghion, et al., 2005).

Absorptive capacity refers to the ability of an economy to adapt, integrate, and utilise new technologies effectively. This capacity is essential for ensuring that investments in science and technology are not just made but are translated into tangible economic benefits (Cohen & Levinthal, 1990). The technology absorption capability is also linked to sustainable economic growth. Economies that can effectively integrate and utilise new technologies are better positioned to adopt sustainable practices. This includes the use of green technologies, efficient resource management, and the reduction of environmental impacts. Such practices not only support long-term economic growth but also ensure that this growth is environmentally sustainable. An economy with a high absorptive capacity enhances productivity gains as new technologies can be more effectively implemented and integrated within existing industries. This capacity is critical for fostering an environment conducive to innovation and it allows for rapid experimentation and adaptation of new ideas, leading to the development of novel products, services, and business models that fuel economic growth (Zahra & George, 2002).

Investments in education and training are foundational for both technology efficiency and absorptive capacity, as they equip individuals with the necessary skills to adapt to and utilise new technologies (Becker, 1964). Policymakers play a crucial role in this regard, by fostering an environment that encourages innovation, supports the education and training of a skilled workforce, and investment in research and development.

Bach et al. (1992) described the many ways in which the European Space Agency (ESA) programme was beneficial to society, this information was obtained through interviews with ESA

contractors. They highlighted mechanisms for positive spillovers including the innovation of new products, technologies, improved product characteristics, new organisational modes, the creation of networks, and the training of scientists, managers and personnel. According to Bach et al. (1992), the case studies illustrated how valuable their approach was, given the long time lag between R&D and the full returns, which makes for challenging empirical analysis. The pitfall, however, of such case studies is that they tend to focus on the ‘winners’, those being the successful innovations. By focusing on the ‘winners’, the cost of the ‘losers’ may be underestimated and the ‘losers’ were necessary before the “winner” innovations took place. It is important to acknowledge that not all research projects will lead to success, and those that do will need to earn a high rate of return to cover the cost of all those that fail (Hall et al., 2010)

In their study, Hall et al. (2010) found that social returns – which are almost always estimated to be substantially greater than private returns – are often asymmetric among trading partners and industries. In addition, most estimates for publicly funded R&D suggest that it is less privately productive than privately funded R&D. This is consistent with expectations, given the fact that publicly funded R&D targets goals that either do not show up in GDP or have substantial positive externalities. Hall et al. (2010) also found that the rates of return to R&D are positive in many countries, and usually higher than those of ordinary capital.

Technology plays a critical role in enhancing the productivity of investments. By adopting new technologies, businesses can achieve higher returns on investment through improved operational efficiencies and the creation of innovative products and services. Romer (1990) posits that technological change is a key driver of economic growth, highlighting the importance of investment in research and development (R&D) for sustained economic advancement. Governments invest in technology infrastructure, research, and development, which is crucial for stimulating technological progress and economic growth. Mazzucato (2013) argues that government spending on technology not only supports direct innovation but also catalyses private sector innovation, emphasising the symbiotic relationship between public investment and technological advancement. Technological advancements enhance a nation's competitiveness in the global market by enabling the production of high-quality, innovative products and services that can be exported. Grossman and Helpman (1991) demonstrate that technology plays a pivotal role in determining trade patterns, with technologically advanced countries tending to export high-technology goods, thereby improving their trade balance.

Technological growth is integral to both economic and social advancement. By fostering innovation and improving efficiency, technological advancements drive productivity and create new industries and employment opportunities. The benefits extend beyond economic gains to include significant improvements in healthcare, resource management, and access to information,

thereby enhancing overall social well-being. However, sustainable technological progress necessitates internal innovation and the development of robust absorptive capacities within economies. This underscores the importance of investments in education, training, and research and development. Policymakers must support these areas to ensure that technological growth translates into long-term economic benefits and improved living standards. The synergy between public and private sector investments in technology can catalyse a nation's competitiveness in the global market, highlighting the critical role of strategic governance in fostering sustainable development.

4.5. Equality

The concept of social exclusion emerged in the 1970s and efforts to measure the processes of social inclusion and exclusion showed that a meaningful life in any society, is dependent on a larger set of social dimensions than simply economic and employment security and that even economic considerations are more than simple income poverty (Vesic et al., 2019). In their review of literature and models, Labonté et al. (2011), identified nine domains that capture processes of social exclusion or inclusion, namely employment and work, income and economic resources, material resources, education and skills, health, housing, social resources, community resources, and personal safety. According to Cingano (2014), the single biggest impact on economic growth is the widening gap between the lower middle class and poor households compared to the rest of society. The econometric analysis suggested that income inequality has a negative and statistically significant impact on subsequent growth. Cingano (2014) found that education is the key factor, a lack of investment into education for the poor, was the main factor behind income inequality and reduced growth. As stated, Hakura et al. (2016) found that both income and gender inequalities, including those from legal gender-based restrictions, are jointly negatively correlated with per capita GDP growth. Income and gender inequality are found to jointly impede growth, mostly in the initial stages of development, resulting in large growth losses in SSA. In addition, although the high levels of income inequality in SSA are partly driven by the structural features and stage of economic development of the individual countries, gender inequality and the low shares of working age population to the total population play significant roles. Hakura et al. (2016) also note that policies influencing access, for women and low-income households, to education and finance, also contribute to reducing inequality and growth.

The gap between male and female labour force participation rates in SSA are lower on average than in the rest of the world, often because economic necessity drives women to work regardless

of their status, particularly in low-income or unstable areas. At higher income levels, the gap increases. Despite relatively low gender differences in overall labour force participation rates, this would suggest that at higher income levels, other aspects of gender inequality are at play such as education, occupational segregation, wage gaps and barriers to entrepreneurship (ILO, 2016).

Greater economic equality tends to increase consumption levels across the economy. When income is more evenly distributed, a larger portion of the population has access to disposable income, which can lead to higher overall consumption. Galor and Zeira (1993) demonstrated that income distribution significantly affects consumption patterns, with more equal societies likely experiencing higher aggregate consumption. Economic equality can influence investment in two main ways. First, by reducing income disparities, a broader base of the population may have access to savings and credit, facilitating investment into small businesses and personal ventures. Second, economic equality can lead to a more stable socio-economic environment, which encourages both domestic and foreign investment. Aghion et al. (1999) argue that reducing income inequality is conducive to economic stability and growth, partly by encouraging investment. Governments in more equal societies may spend less on social welfare programs, given the reduced need for redistributive policies. However, such governments might also invest more in public goods that promote equality, such as education and health care, which can have positive effects on economic growth. Engerman and Sokoloff (2000) suggest that investments in public education, in particular, are both a cause and a consequence of income equality, contributing to economic growth. Economic equality can indirectly impact a nation's trade balance by fostering a more skilled and competitive workforce, leading to the production of higher value-added goods and services that are competitive in the global market. Stiglitz (2012) notes that inequality can undermine economic growth and stability, which in turn can affect a country's trade performance by limiting its ability to innovate and compete internationally.

In summary, the role of social inclusion and its critical impact on economic growth is clear. Highlighting key dimensions such as employment, education, and health, it can be shown that income and gender inequalities hinder growth. Greater economic equality enhances consumption, fosters investment, and promotes stability, driving overall economic progress. The conclusion is the necessity of inclusive policies and investments into public goods for sustainable development.

4.6. Trade and African Value Chains

African value chain development entails the integration of markets developed within Africa, between African suppliers and consumers. Engagement in trade and value chain development can

lead to greater economic growth, which, in turn, boosts disposable incomes and consumption. By specialising in certain stages of production where they have comparative advantages, African countries can enhance their efficiency, leading to lower prices for goods and services. This makes products more affordable to the local population, thereby increasing consumption. De Melo and Tsikata (2015) emphasize the importance of trade liberalisation in Africa for improving access to goods and reducing costs. Participation in global value chains encourages investment, both foreign and domestic, in sectors where countries have competitive advantages. Investments are often directed towards infrastructure, technology, and skills development, which are necessary for effective participation in global value chains (GVCs). According to the African Development Bank (2014), enhancing regional value chains is crucial for attracting investment and promoting industrialization in Africa. Governments may increase spending to support integration into global value chains and regional trade, investing in critical infrastructure like roads, ports, and telecommunications, as well as in education and healthcare to improve the workforce's productivity. This form of expenditure not only facilitates trade but also has a multiplier effect on the economy, stimulating further economic activity. Rodrik (2018) highlights the role of smart industrial policy in leveraging trade and investment for economic transformation. By efficiently integrating into global value chains, African countries can boost their exports, particularly of value-added goods. The African Continental Free Trade Area (AfCFTA), aimed at creating a single market for goods and services, is expected to increase intra-African trade, improve the trade balance, and encourage the production of value-added products. Signé (2018) argues that AfCFTA has the potential to significantly enhance trade and economic growth within the continent, impacting the net exports positively.

The Eclectic Paradigm, developed by Dunning (1979), provides a framework for understanding FDI by integrating various economic theories into a single comprehensive approach. It posits that for a company to engage in FDI, it must have unique competitive advantages labelled Ownership advantages, see benefits in exploiting these advantages within a foreign country labelled Location advantages, and find it more profitable to manage these advantages internally rather than licensing them to others, labelled Internalization advantages. Ownership advantages in the African context include unique resources, technological innovations, or brand reputations that local or foreign firms can leverage internationally (Dunning, 1979). For instance, African firms with proprietary access to local resources could use these as a competitive edge in global markets. Location advantages consider the geographical, political, and economic features that make investing in certain African countries attractive. These could range from natural resources to strategic trade positions or regional market access (Dunning & Lundan, 2008). However, challenges such as political instability or infrastructural gaps also play a significant role in shaping these advantages.

Internalisation advantages address the decision-making process regarding whether to manage operations directly or license them to third parties. In the African economic landscape, companies might internalise to protect proprietary information or navigate market imperfections (Dunning, Lundan, 2008). This is particularly relevant given the continent's diverse regulatory environments and market needs.

Examining these paradigms in the context of African economies can highlight the dynamics of FDI flows into the continent, and the opportunities and challenges faced in regional development and global integration (UNCTAD, 2020). From an economic perspective in Africa, there has been a significant focus on global markets, while ignoring the enormity of Africa as its own market. For illustration purposes, consider briefly the example of remote sensing in the comparative contexts of Nigeria and South Africa. NigeriaSat-2, launched in 2011, is a high-resolution Earth observation satellite designed for various applications including resource management, mapping of Nigerian territory, and disaster monitoring. It offers imaging capabilities with a maximum Ground Sample Distance (GSD) of 2.5m in panchromatic and 5m in multispectral across a 20km swath width. This satellite is part of the efforts by the Nigerian National Space Research and Development Agency (NASRDA) to support the country's geospatial infrastructure development. The contract for the development and construction of NigeriaSat-2 was awarded to Surrey Satellite Technology Ltd. (SSTL) in the United Kingdom, and it included the related ground infrastructure and image processing facilities. Alongside the technical aspects, an extensive training program was conducted to further develop indigenous space capabilities within Nigeria. This approach suggests that while Nigeria possesses the capability to produce satellite data through NigeriaSat-2, there was an acknowledgement of the need to develop local expertise in data processing and analytics, which is a crucial step in fully exploiting the data gathered by such satellites. The training component of the NigeriaSat-2 project indicates efforts towards building the necessary local expertise for data processing and analysis. The specific extent to which Nigeria currently relies on external expertise from outside of SSA for data analytics and software development is unclear. 46 percent of organisations surveyed in Nigeria have no data science professionals. In Nigeria, there were only 74 secure internet servers per million people in 2019, falling from 184 in 2017 and 222 per million people in 2018 (IFC, 2020). This is well below the average of 841 per million people for SSA. South Africa, on the other hand, has one of the largest ICT markets in SSA (Fitch, 2021), and is a strong competitor in data processing, analytics and software development, but is unable to produce its satellite data, and as such procures the data required from outside of SSA. Nigeria and South Africa had an opportunity to exploit this collaborative opportunity but the value chain was lost to SSA, and the revenue was directed elsewhere. Faster growth cannot be secured with low levels of private investment in SSA, the levels of which are well below that of other regions (IMF,

2013). The low level of private investment could be largely attributed to the investor perceptions of high risk and low returns on capital. Reducing the level of risk would improve the attractiveness of holding assets in the region, and would help to raise domestic savings as well as investment rates, reversing the trend towards capital flight. Many SSA countries have been driving changes in transparency and accountability within public sector resource management by taking measures to promote a sound and efficient civil service and implementing legal frameworks and measures to eliminate corruption.

The structure of global demand and trade has changed significantly over recent history, posing new challenges and opening new opportunities to developing and transitional countries. In this context, strengthening the role of domestic demand as a driver of growth would make many developing countries more resilient to external shocks propagated through trade links. This could also help boost domestic investment opportunities (UNCTAD, 2013). The United Nations Conference On Trade And Development (UNCTAD) together with other United Nations departments and agencies, measure progress by the Sustainable Development Goals, as set out in Agenda 2030. UNCTAD also supports the implementation of Financing for Development, as mandated by the global community in the 2015 Addis Ababa Agenda, together with four other major institutional stakeholders: the World Bank, the International Monetary Fund, the World Trade Organization, and the United Nations Development Programme. They propose that strengthening domestic demand could also support diversification within the economies and increase their resilience to sector-specific shocks. As the international financial system remains prone to instability and presents a cyclical bias, a number of developing countries have applied policies to reduce their exposure to external financial shocks and mitigate their domestic impact. These include the accumulation of foreign reserves, the reduction of the ratio of foreign debt to gross domestic product (GDP), capital flow management, the development of domestic debt markets and the broadening of the investor base. However, more comprehensive multilateral arrangements and internationally coordinated financial regulation could contribute to the prevention of financial shocks (IMF, 1984).

As mentioned, the official start of free trading under the African Continental Free Trade Area (AfCFTA) began in January 2021. The planned steps are: finance and trade facilities to be implemented to support SMEs especially those managed by women and young people; the second is launching the African Trade Gateway, a digital platform; and the third is an adjustment facility, which is expected to cushion the fiscal effects of tariff loss in countries; while the fourth will be the rollout of the Pan-African Payment and Settlement System (PAPSS); and the last area of focus is ensuring compatibility with Africa's Special Economic Zones (SEZs), (Siba, 2022).

By integrating markets within Africa and fostering trade, countries can leverage their comparative advantages, lower production costs, and enhance consumption. Participation in global value chains additionally attracts investment into infrastructure, technology, and skills, promoting industrialisation. The Eclectic Paradigm's application to African FDI emphasises the importance of competitive, locational, and internalisation advantages and so the necessity for strengthening domestic demand and implementing sound policies to mitigate financial shocks and foster sustainable growth is underscored.

5. Unique Economic Considerations

5.1. Economics of Culture

An early link between culture and economic development was proposed by Weber (1930). He hypothesised that the origins of industrialisation in Western Europe could be traced to the Protestant Reformation and particularly the rise of Calvinism. In his view, the set of beliefs embedded in Protestantism was crucial to the development of capitalism (Acemoglu, et al., 2005). Protestantism instilled a set of beliefs which emphasised hard work, thrift and saving, whereby economic success was interpreted as consistent with being chosen by God. Weber (1930) contrasted these characteristics of Protestantism with those of other variations of religious faith, such as Catholicism, which he claimed did not promote capitalism. In his book on Indian religions, he argued that the caste system blocked capitalist development (Weber, 1958). Similarly, Harrison (2006) distinguishes between progress-prone cultures and progress-resistant cultures. Harrison asserts that progress-prone cultures are characterised by a high emphasis on work and achievement, with moderate levels of frugality, risk propensity, acceptance of competition and an emphasis on innovation as well as advancement based on merit. Progress-resistant cultures do the opposite (Kuada, 2020).

Another religious impact on economic activity is *riba*—the charging of interest on savings or investments—which is explicitly forbidden in Islamic teachings. Many Muslims therefore avoid earning income through interest, shaping the financial behaviour of individuals and the structure of financial institutions in Islamic countries. While the Christian tradition historically also viewed usury with suspicion—particularly in medieval Catholicism—the interpretation evolved over time, especially in Protestant contexts where interest became an accepted component of economic activity. It's important to note that *riba* is a theologically specific concept, and its prohibition is distinct from Christian notions such as penury (extreme poverty), which is not equivalent either in concept or economic function.

Acemoglu and Robinson (2012) classify institutions into two broad categories – inclusive and extractive institutions. They argue that inclusive economic institutions create the incentives and opportunities necessary to harness the energy, creativity and entrepreneurship in society. Such institutions also protect private property rights, enforce the principles of the rule of law and maintain predictable enforcement of contracts. Extractive institutions do the opposite, so essentially those who control such institutions, use their power to extract incomes and wealth from one subset of society to benefit another subset. Harrison's (2006) progress-prone and progress-

resistant cultures therefore find their parallels in Acemoglu and Robinson's inclusive and extractive institutional categories. Progress-prone cultures tend to develop inclusive institutions whereas progress-resistant cultures tend to cultivate extractive institutions (Kuada, 2020).

(Grondona, 2000) notes that without development-oriented values and mindsets, nations will find it significantly difficult to develop efficiently and that some sort of cultural change will be needed in these nations in order to reduce poverty.

In African societies, the family is the primary social unit in relation to individuals (Assimeng, 1989). Individual members of the family are bound to one another by the collective moral rules and obligations of the family. The family therefore limits, influences and can in some situations, determine the individual's activities in society. The division of labour and distribution of power within the family is determined by age, the size of financial contribution, genealogical placement and gender. Poverty and inequalities in income distribution in African societies further accentuate the need for relying on traditional family structures and the acceptance of moral obligations to help the less advantaged family members. Sociologists use the term "familism" to describe these relationships (Bigombe & Khadiagala, 1990).

It was found that strong family and ethnic ties also tend to discourage Africans from developing trust-based non-kin relationships (Kuada, 2019). Trust deficiency is therefore viewed as an impediment to economic growth in Africa. For example, Fafchamps (1996) found in his empirical investigation of the operational environment of manufacturing firms in different African countries that most business relationships were characterised by distrust. In trust-embodied economic environments, interacting partners are willing to suspend their self-interests, thereby reducing monitoring and other similar costs of transactions. In trust-deficient economies, there is a short-term temptation to deviate from agreements and to engage in opportunistic behaviour, thereby creating self-perpetuating distrustful relationships among people.

The ability of institutions to facilitate growth also depends on the degree of trust that key actors within the society rest in the institutions. Kuada (2015) notes that public institutions are considered by the business community in Africa to be excessively bureaucratic and managed by corrupt and poorly motivated officials who deliberately impede rather than facilitate business activities. The low level of trust between public institutions and the business communities has its roots in the post-independence economic policies pursued in many African countries.

Technological developments in some high-growth African countries, have included rural electrification in order to facilitate knowledge dissemination through radio and television. These have also introduced changes to individual mindsets and behaviours, as has increased internet access. For example, in Kenya, the mobile phone has become a preferred mode of money transfer competing effectively with conventional banks (Kuada, 2018). Indigenous medicine in SSA plays

a significant role in shaping cultural practices and economic growth. Traditional healing practices, which include herbal medicine, spiritual healing, and the use of indigenous knowledge, are deeply rooted in African cultures and provide both health care and economic benefits. The widespread use of traditional medicine in rural and urban areas alike highlights its cultural significance and economic impact (World Health Organisation, 2013). The integration of traditional medicine into the broader health care system can promote economic growth by supporting local economies, preserving indigenous knowledge, and fostering innovation in pharmaceuticals. For instance, many plants used in traditional medicine are harvested, processed, and sold locally, providing income for rural communities (Gurib-Fakim, 2006). Additionally, the commercialisation of herbal remedies and the formal recognition of traditional healers can create new economic opportunities and enhance public health (WHO, 2002). Moreover, the preservation and promotion of indigenous medical practices contribute to cultural identity and social cohesion, which are essential for sustainable development. Incorporating traditional medicine into national health strategies can improve access to health care, particularly in remote areas where conventional medical facilities are scarce (Mwangi, 2004). This holistic approach to health care not only addresses physical ailments but also strengthens the social fabric and economic resilience of communities.

Thus, policy prescriptions for a given country at a given point in time must be anchored in an understanding of the characteristics of that economy as well as its historical growth path. In other words, policymakers must bear in mind that what is good for one phase of the development process may not be ideal for the next development phase, and equally important is that SSA countries cannot follow one simple development recipe. The fact that they are faced with different challenges at different points in time, with different societal structures, implies that they need to adopt different policies and strategies at different stages in their developmental trajectory.

Pierre Bourdieu (1984) developed the idea of cultural capital as a way to explain how power in society was transferred and social classes maintained. Karl Marx (1867) believed economic capital dictated your position in a social order, while both Marx and Bourdieu held that the more capital one has, the more powerful one is. Bourdieu (1984) defines cultural capital as association with the legitimate culture within a society, or what is colloquially referred to as 'high culture'. He noted families passing on cultural capital to their children by introducing them to dance and music, taking them to theatres, galleries and historic sites, and by discussing literature and art in the home environment. Bourdieu (1984) identified three sources of cultural capital, namely; objective cultural capital or literature and art, embodied cultural capital incorporating language and mannerisms, and institutional cultural capital which refers to qualifications, education, and credentials. More recent work on the idea of cultural capital has added several sources of transmission, including technical or skills, emotional, national or traditional and popular culture. These contribute to a sense of

social belonging but do not necessarily add to profit, it is rather its lack that is a handicap (Bennett, et al. (2009) and subsets of cultural specifics of cultural capital. Cultural consumption has changed over time, and some more recent prominent academic researchers have coined the term ‘cultural omnivore’ (Peterson & Kern 1996) as someone who mixes interests in a wide range of cultural forms, both those seen as historically ‘legitimate’ by society, as well as more emerging, ‘alternative’ forms. Studies (Sutton Trust, 2019) have probed the issue of how certain types of education and family background confer advantages to some children. Projects such as The Class Ceiling have shown how entry into top professions, such as banking and law, can be made easier by the level of cultural capital of the applicants.

In financial terms, social capital comprises the value of social relationships and networks that complement the economic capital for economic growth of an organisation. Strong social networking, coupled with efficient performance by the workforce, signifies a healthy state of affairs for the company. The notion of social capital highlights the importance of these social networks and relationships, and aims to use it in the best possible way for optimising the achievement of organisational objectives.

Further examples to consider, it is unclear what people consume when they visit a museum. Is it the aesthetic experience, or the intellectual challenge? or is it a way of passing time? Consuming a museum seems to be more like an activity. The satisfaction that visitors achieve appears to depend on what they bring to the museum in terms of knowledge and capabilities to experience the art. As pointed out by Becker (1996), the taste for art requires an investment. In that sense, the ability to enjoy the consumption of art appears to be a return on an investment. Acquiring taste involves work, and so we are led to think of the productive dimension of consuming art, the experiences of the consumers themselves contribute to the value derived. Cars are not just vehicles for the transport of people, they are also symbols and conduits for experiences. That is why many people are willing to pay a great deal more than is needed to get them safely from one point to another. A glass of wine is more than a drink to satisfy the need for refreshment; it is foremost an experience that depends a great deal on where it is ‘consumed,’ and with whom. The material and physical aspects of consumption appear to lose out against the cultural, symbolic, and other non-material aspects. So many goods, and especially cultural goods, are ‘experience goods’ (Caves, 2000). Cultural goods are, in that sense, also social goods (Hirsch, 1978).

Contemporary approaches to economic modelling and planning encounter significant challenges in their application to developing African nations, and a new approach is needed to account for the translation of cultural value and the cultural utility of time into mathematical modelling. This will vastly improve the economic modelling, strategy and planning for these economies. It is worth considering whether the difficulty is rooted in the issue of data, known colloquially as ‘garbage in

garbage out’, since the data available is insufficient and not measuring the required characteristics; or whether it is a problem that the economic models are based on a different set of objective, designed for the characteristics and cultural objectives of developed nations, and are not directly applicable to developing nations.

Moreover, we can investigate the literature around the broad area of the culture of technology. Firstly, there are the cultures and communities being developed within different spheres of technology interaction such as online gaming, dating, e-commerce and many other areas. In addition, there is the impact that technology is having on cultures and economics – both of which are in a constant state of evolution. There is a spectrum of perceptions in developing nations from the view of technology development as a driver of new growth and development in Africa, to the view that technology is a driver of cultural destruction: “Western technology exposed young people to adult issues, hideous violence, indecent dressing, immorality and build negative attitude that are contrary to African cultural values. It is recommended that the Government should regulate the influx of Western technology and promote the indigenous technology in order to protect African society from the adverse effects of Western technology” (Abanyam, 2013, Pg.26). Secondly, there is the culture that is shaping technology. Technology is either shaped by economic and government or military concerns or it is uncontrolled and for use by everybody. Technology policy, on the other hand, has been a pragmatic area where the basic tenet has been to leave technology on its own, or rather, to the forces of the market. If problems should occur, they may be managed through the use of the economic and legal instruments that governments have at their disposal. The idea of a cultural politics of technology is a methodology to explore the relationship between culture, politics, and technology that emphasises the cultural work that is performed in the conception, development, and implementation phases of new technologies, as well as in efforts to do business when engaged in the production of providing technological visions (Sorenson, 2004).

The importance of this section to this research is not to resolve the many complexities pertaining to the impact of culture on economics, but rather to show that culture does impact economics and in particular, the unique and diverse characteristics of African culture, impact the modelling of economic development in Africa and thus cannot be excluded.

5.2. Economics of Regime and Regime Change

To date, empirical studies have yielded mixed results in answering the question of whether or not the type of regime governing an economy impacts economic growth. Democracies have fared much better than the worst dictatorships, but not as well as some of the most successful dictatorships (Alesina & Perotti, 1994). A significant amount of literature on the determinants of the economic success of political regime type focuses on structural factors that are thought to be more conducive to either authoritarianism or democracy. The levels of socio-economic conditions that are indicative of particular stages of economic development – such as per capita income and educational attainment – have been assumed to be conducive to authoritarianism or democracy, although this relationship is not necessarily causal but often correlates.

Authors have argued that economic development creates growing social pressure for democratisation (Cheibub & Vreeland, 2018). Structural factors that can affect political regimes tend to be embedded in the type of political institutions. Under democratic regimes, institutional features that promote stability and compromise, are widely thought to facilitate the persistence of democracy. These include the extent of institutionalisation, party systems, and parliamentary rather than presidential systems of government. There are also international political and economic conditions that may affect political regimes such as colonial legacies, economic dependence, and other aspects of the international political-economic environment. However, theories of regime change that focus solely on structural factors are inherently problematic. While they can help identify factors that may facilitate regime change, they do not identify the actual processes that bring about the change itself, and thus the causes of said change (Rustow, 1970).

Gasiorowski (1995) notes that there are two types of causes for regime change, namely development-related socioeconomic factors, and the contagion effect of democratic neighbours. Some studies argue that regime change is likely to occur when triggering events occur in the environments with the structural factors that create conditions for transition, and thus magnify the effect of the events on regime change.

A serious challenge to research on this topic is the great variation within regime types – consider, for example, that both Great Britain and Mauritius are democracies, and both Zaire and Singapore are authoritarian regimes - these countries are vastly different in terms of economic development and one cannot conclude correlation purely due to regime labels. Similarly, the economic problems faced by governments as they democratise are different. In Ghana, where per capita income is USD 2, 500.00 (2021), and South Korea, where per capita income is USD 35, 000.00 (2021), it is difficult to offer a data-driven judgement about the comparative advantages of democratic

economic management (Rakner, 2003, Herbst, 1996). Regime type has an impact on economic performance but it is not alone as a cause or inhibitor of economic growth.

Other areas of research relate regimes to economic growth through property rights, the pressures for immediate consumption, and the autonomy of dictators. Although it can be assumed that secure property rights foster growth, one cannot so easily discern whether democracies or dictatorships better secure these rights. The pressure for immediate consumption through the cyclical nature of general elections can contribute to reduced saving and investment, and may form a mechanism by which democracy slows growth. On the other hand, the main argument against dictatorships is that authoritarian rulers have no interest in maximising total output. Reynolds (1983) reviewed the historical experience of several countries, concluding that spurts of growth are often associated with major political transformations. Research that has examined the impact of government spending on growth, finds in general that the size of government is negatively related to growth, but that the increase of government expenditures has a positive effect. In their study, Bergh and Henrekson (2011) noted that in wealthy countries, although statistically an increase in government size by ten percent is associated with a 0.5 to 1 percent lower annual growth rate, though this correlation is not necessarily causal. Several countries with high taxes seem able to enjoy above-average growth and a reason is that countries with higher social trust levels are able to develop larger government sectors without harming the economy. In addition, countries with large governments compensate for high taxes and spending by implementing market-friendly policies in other areas (Bergh & Henrekson, 2011).

In examining whether technological growth is a determinant of economic growth within a particular developing country, it becomes clear that the political will behind the technological growth is an important factor. National policies towards technology development echo the political will of a national government, which may vary from driving determinants of economic growth, to improving national pride and strengthening collective identity, or even to exerting regional dominance and defence. It can be the case that an authoritarian regime is more conducive to the implementation of a large-scale science and technology project. The obvious examples are countries dominant in the space sector – China, India, Russia and the USA. Each of them leads in SST, yet they are countries with different political regimes.

In the case of authoritarian leadership embarking on technology projects of megaproject size and nature, the regime may be able to overcome challenges to resource allocation, risk mitigation or the lack thereof, as well as other hurdles that may be more challenging to address than through more democratic, parliamentary systems with more stringent transparency and governance requirements.

Cowhey (1990, Pg. 169) states, “The international telecommunications regime provided a multilateral framework that reinforced domestic monopolies and bilateral agreements in the global market and thereby created one of the most lucrative and technologically significant international cartels in history.” This regime type and framework has split over into the space sector internationally. This is beyond the scope of this research, suffice to say that the regime type is not a significant factor as an indicator on its own but rather in the model proposed by this thesis, it is a factor to consider in a case-by-case application to a particular country in terms of the impact on the development of labour, capital formation and technology growth environments.

In the African context, the political situation may not always align with democratic norms; however, it can still create a conducive environment for investment in space science and technology. This paradox arises because certain non-democratic regimes may prioritize strategic investments in high-tech industries, including space science, to foster economic growth, enhance national prestige, and strengthen military capabilities. The centralized control characteristic of such political systems can facilitate the mobilization of resources towards large-scale scientific projects, bypassing the bureaucratic and fiscal constraints more common in democratic settings.

Non-democratic regimes may prioritise space science and technology as a strategic sector for national development. This prioritization can stem from a desire to leapfrog to advanced technological capabilities, reduce dependency on foreign technology, and assert national sovereignty in strategic areas. Muehlenbeck and Adam (2017) highlight how investments in space technology are not just about scientific exploration but also about asserting a country’s strategic independence and capabilities on a global stage.

The centralised decision-making process in non-democratic regimes can enable quicker mobilisation of financial and human resources towards space science and technology investments. Unlike democratic systems, where funding for such projects might require extensive deliberation and approval from multiple stakeholders, non-democratic systems can allocate resources more directly and efficiently, albeit at the cost of reduced public accountability. Fayomi, et al. (2019) argue that the streamlined governance structures in some African countries have facilitated significant investments in space technology, demonstrating a commitment to harnessing space for developmental purposes.

Non-democratic regimes often engage in long-term planning, unencumbered by the short-term electoral cycles that characterise democracies. This allows for sustained investment in space science and technology projects, which typically require long-term commitment and substantial financial investment before yielding tangible benefits. Johnson-Freese (2017) notes that the long-term vision required for space exploration and technology development often aligns better with the

governance models of non-democratic regimes, which can plan and execute long-term strategic initiatives without immediate pressure for results.

Investment in space science and technology is often driven by military and security considerations, a trend observed across both democratic and non-democratic regimes. The dual-use nature of space technologies—serving both civilian and military purposes—makes them attractive to governments seeking to enhance communication, surveillance, reconnaissance, and strategic capabilities. In African contexts, non-democratic regimes may particularly emphasise these uses as tools for regime stability, territorial control, or political legitimacy (Burgess & Mules, 2015). However, it is increasingly evident that democratic governments also prioritise security-focused space investments, especially in the face of growing geopolitical competition, cyber threats, and the weaponisation of space. The key distinction lies not solely in the regime type but in how and why these investments are pursued and managed.

While democracies generally perform better than the worst dictatorships in development outcomes, authoritarian regimes have sometimes achieved significant economic growth, particularly when paired with strong state capacity and institutional discipline. Empirical studies show that institutional quality—rather than regime type alone—is the more consistent driver of long-term economic performance, facilitating secure property rights, reducing transaction costs, and ensuring effective governance.

Additionally, this research highlights the potential for non-democratic regimes to mobilise resources and implement large-scale projects, such as those of SST, which can drive economic growth and enhance national prestige. Ultimately, the suitability of political regimes for fostering technological and economic development depends on various contextual factors, including political stability, governance quality, and strategic priorities. It is for these reasons that this research refers to political suitability as opposed to political stability or regime when considering SST investment and its impact

6. Time Valuation of Money

The most important asset we own is our time. We prioritise aspects of our lives by allocating time to what we perceive as most important to us. The term ‘perceive’ is used here as many of us take for granted what matters most to us, supplanting its time with the time needed to meet the many pressures and demands of life. We work and we are remunerated for our time – the time we sacrificed to earn that money. The overall limit of our time, i.e. the scarce and constantly diminishing nature of time in the context of the human lifespan, assigns importance to money, its utility to us and hence the satisfaction derived from it. Without delving into a philosophical debate on time and its importance, the key point here is that money’s importance is based on time and not vice versa. This may seem logical, but awareness of this relationship can be easily obscured in day-to-day life.

In economics, the key concept we start with is the time value of money. Simply put, an amount of money is worth less in the future than the same amount is worth now, due to its earning potential in the interim. Time is an essential element to the value of money. Nevertheless, how we value time also has an impact on how we value money. Within the plethora of distinguishable cultures on Earth, and in particular, within Africa, there are differing views, traditions and degrees of importance placed on time. Different approaches and conceptions about time, such as time discipline, the idea of infinitude and other cultural perceptions of time, impact its worth. This impact equally affects the perception of money and ultimately the economy.

Classical economics is based on the interaction of rational actors making decisions in order to maximise utility for various resource constraints. Ultimately, their marketplace, made up of utility-maximising agents, is striving towards a general economic equilibrium. However, more recent research has shown that economies are not filled with rational actors, and if the goal is to maximise utility, we need to understand the utility itself – or rather the utility of time and of money.

Smelser (1963:7) defines values as “beliefs that legitimize the existence and importance of specific social structures and the kind of behaviour that transpires in social structures.” In simpler terms, values define the “dos and don'ts” in any given society and therefore serve as a compass that guides individuals’ lives as members of a given society. In this way, values tell people what to expect from others in their society, thereby furnishing them with a degree of mastery and confidence in most social situations. Cultural attributes such as belief in the importance of individual effort, trust, commitment, autonomy, ethic of hard work, and thrift are important for enterprise development and economic growth (Romer, 1990). Nnajofofor (2016) noted that it appears to be the general

observation that in Africa there can be a disregard for time and schedule and he stated that ‘African time’ is seen as the contributor “to the continuous cycles of poverty, bad governance, and a seemingly perpetual over-dependence on other economies of the world. This, however, cannot be read to mean that Africans lack the idea of time or of infinitude, but what we can say is that they lack time-discipline.”

However, this thesis would propose that it is not an issue of time-discipline, but rather an issue of a different standard of time valuation. Perhaps a better descriptor would be a value conflict, where a value conflict is defined as occurring when individuals or groups of people hold strong personal beliefs that are in disagreement with the values of others or institutions. These may include religious differences, cultural differences or differences in upbringing – and, in this case, the prioritisation of time.

In many African cultures, time is prioritised for family and community, traditional commitments, and activities outside of the workplace. There may not be a prioritisation for additional money beyond absolute necessity and thus no money value is assigned to additional work time that encroaches on other time priorities. This may give the impression of inefficiency or a lack of commitment or time-discipline – or what is colloquially referred to as ‘African time’.

Kalliath and Brough (2008) offer the following definition of work–life balance. Work–life balance is the individual perception that work and non-work activities are compatible and promote growth in accordance with an individual’s current life priorities.

The direct comparison of the consequences of the types of work-life balance policies – such as flexible working hours, paid or unpaid leave, dependent care, and access to resources, is difficult to quantify due to cross-cultural variations in government regimes, employment policies and labour-market conditions (Ackers, 2003). However, there is increasing evidence that work-life balance has a direct impact on societal issues, such as delayed parenting, declining fertility rates, ageing populations and decreasing labour supply (Brough et al., 2008). Given the challenges associated with maintaining a work-life balance, as well as the challenges associated with addressing varying standards for individual contentment, there has been an increase in research on the topic since unbalanced work–family relationships can result in reduced health and performance outcomes for individuals, families and organisations. In developed nations where work and money are a time prioritisation, and lead to significant social challenges, perhaps ‘African time’ has its merits, although it can be frustrating to time-disciplined or time-oriented partners.

Examination of the literature shows that there are vast cross-cultural differences in the conception of time. In some cultures, for example, the United States and Western Europe, it is a common cultural norm that silence – particularly in the presence of others – tends to make people uncomfortable. It may denote that nothing is happening, or that something is going wrong. The

usual response is to say something, to fill the silence or to keep the meeting or conversation going. People in other cultures, including many Asian and Pacific Island nations, are quite comfortable with silence. It is seen as an opportunity to focus inwardly and to gather one's thoughts before speaking. Brislin (2000) has described how cultural misunderstandings and counterproductive decisions often arise from ignorance of these decisions.

The value of time can be even further analysed. For example, there are individual and cultural differences in people's orientation toward the past, present, and future. Zimbardo and Boyd (2008) developed a scale that distinguishes between six types of temporal frames, finding large individual and cultural differences on both the individual subscales and the patterns of the subscales taken together. They describe a wide range of consequences of these differences. Time perspective affects political, economic, personal, social, environmental, and other domains of life and civilisation.

Industrial psychologists emphasise the significance of monochronic versus polychronic work patterns (Bluedorn, 2002). People and organisations operating in clock-time cultures are more likely to emphasise monochronic (M-time) approaches, meaning they prefer to focus on one activity at a time. People in event-time cultures, on the other hand, tend to emphasise polychronic (P-time) approaches, meaning they prefer to do several things at once. These labels were originally developed by Hall (1983). M-time people tend to demonstrate a preference for working from start to finish in a linear sequence: one begins and completes the first task before turning to another, which is then begun and completed. In polychronic time, however, one project goes on until there is an inclination or inspiration to turn to another, which may lead to an idea for another, then back to first, with intermittent and unpredictable pauses and reassuming of one task or another. Progress on P-time occurs a little at a time on each task (Levine, 1997).

Just as values and norms are a culture's learned behaviours, so is time perception. Time perception may be based strongly on a society's values. Those from monochronic cultures may be inclined to value relationships above all else. So, if they miss a deadline instead of putting time into a family matter, their lateness is a nonissue. Just as children learn values during their primary socialization, so they are oriented toward a specific time cognitivism based on those values, known as, 'time orientation'. There are four different types of time orientation, the first being past-oriented cultures where the past and the present are interchangeable in that they often do not fully grasp elapsed time. The second type is labelled the time-line orientation, this type of time cognitivity is a detail-oriented linear concept of time. However, time-line cognitivity does not lend itself to multitasking. The third type is present-oriented – one could think of a thrill-seeking person when considering present-oriented cognitivity, and these tend to occur in low-risk aversion cultures. The fourth type is future-oriented - the goal-setting, forward-thinking cultures are future-oriented. Those with

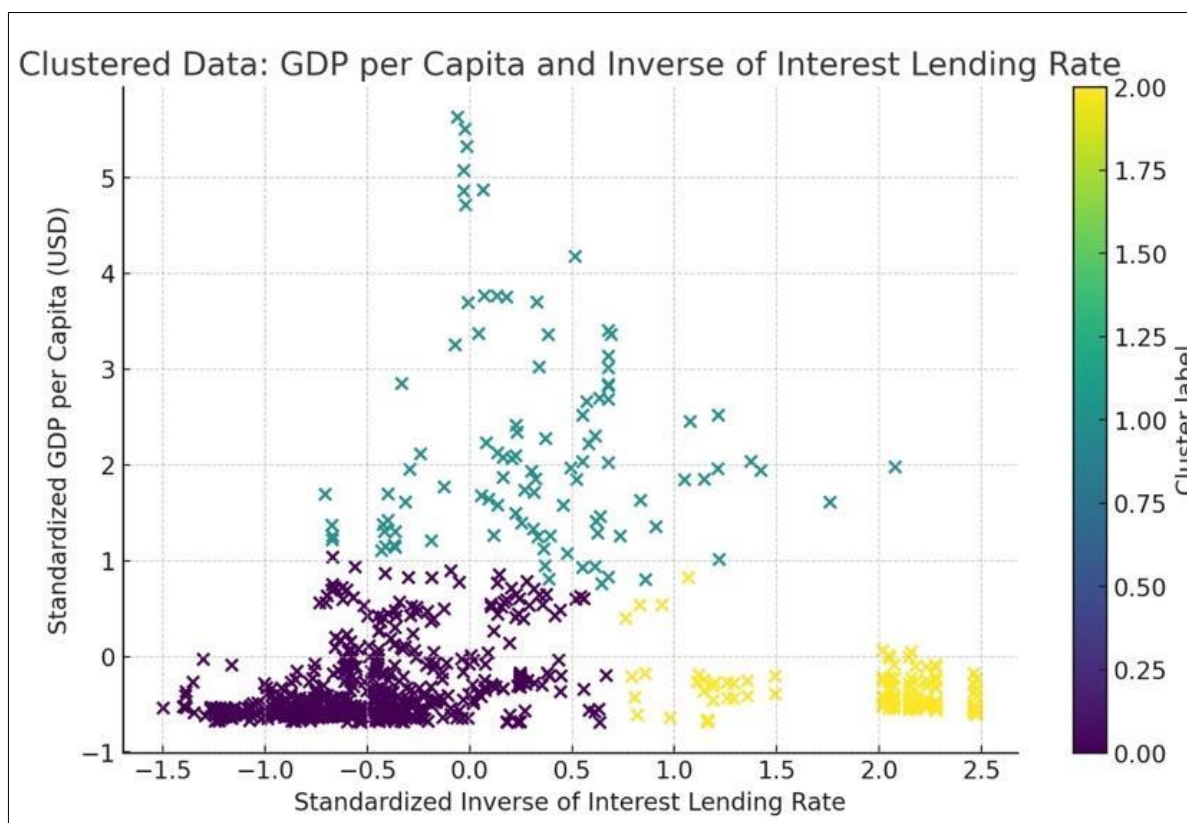
future-oriented cognitivity look at the bigger picture and follow through with their plans to achieve that picture.

Building on the observed differences in cultural perspectives on time across our global society, it makes sense to examine the time value conflict further, and to ascertain whether it leads to wider economic impacts. Further examination is beyond the scope of this research but this thesis does propose a simple quantitative measure for tracking the propensity to value time in terms of money. By utilising such a measure, further studies can examine and identify the elements of this proxy, in order to fully understand the economic impacts of the valuation of time.

6.1. Propensity to value time in terms of money

6.1.1. Interest Rates

Interest rates are a key quantitative representation of the time value of money. This is because money has a time value, which gives rise to the concept of interest. The most fundamental formula for the time value of money takes into account variables representing the future value of money, the present value of money and the interest rate. Saving and investment are two of the most important tools for economic growth and the interest rate has always been considered an important determinant of saving and investment. The lending interest rate captures the risk associated with a loan – and the corresponding reward paid to the lender for assuming the risk – thus a higher interest rate will represent a higher risk of defaulting on the loan repayment. The interest rate also accounts for the opportunity cost of the loss of the use of the money during the loan period. The time value of money or conversely, the money value of time, is an established norm in the developed world, but this research explores this concept further within the SSA context to define the factor, Propensity to Value Time in terms of Money (PVTM). The starting point for the statistical examination of the PVTM factor was an examination of the data in terms of indicators immediately relevant to the time value of money, that is GDP per capita, the interest lending rate and the inverse of the interest lending rate. The analysis for the SSA dataset did not reveal any significant information in terms of the PVTM factor. The data visualisation can be seen below in Graph 3.1 after using K-Means clustering (Hartigan & Wong, 1979), using partitions of similar levels of GDP per capita. K-Means Clustering is an algorithm which groups the unlabelled dataset into different clusters. The clustering for the years 2010 and 2020 was then selected for visualisation as the data is too voluminous over annual periods with countries appearing in more than one cluster, as can be seen in Graph 3.1.



Graph 6.1.1SSA Countries: Clustered Data by GDP per capita and Interest Lending Rate

The results along with the respective scatter plots after clustering by years 2010 and 2020 are displayed in the tables below and in graph 6.1.2. The clusters for 2010 are as follows:

Cluster 0	Botswana, Eswatini, Mauritius, Namibia, Seychelles, South Africa
Cluster 1	Benin, Burkina Faso, Cote d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal, Togo
Cluster 2	Angola, Burundi, Cabo Verde, Comoros, Congo, Dem. Rep., Gambia, The, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mauritania, Mozambique, Nigeria, Rwanda, Sao Tome and Principe, Sierra Leone, Tanzania, Uganda, Zambia

Table 6.1.1Clusters for 2010

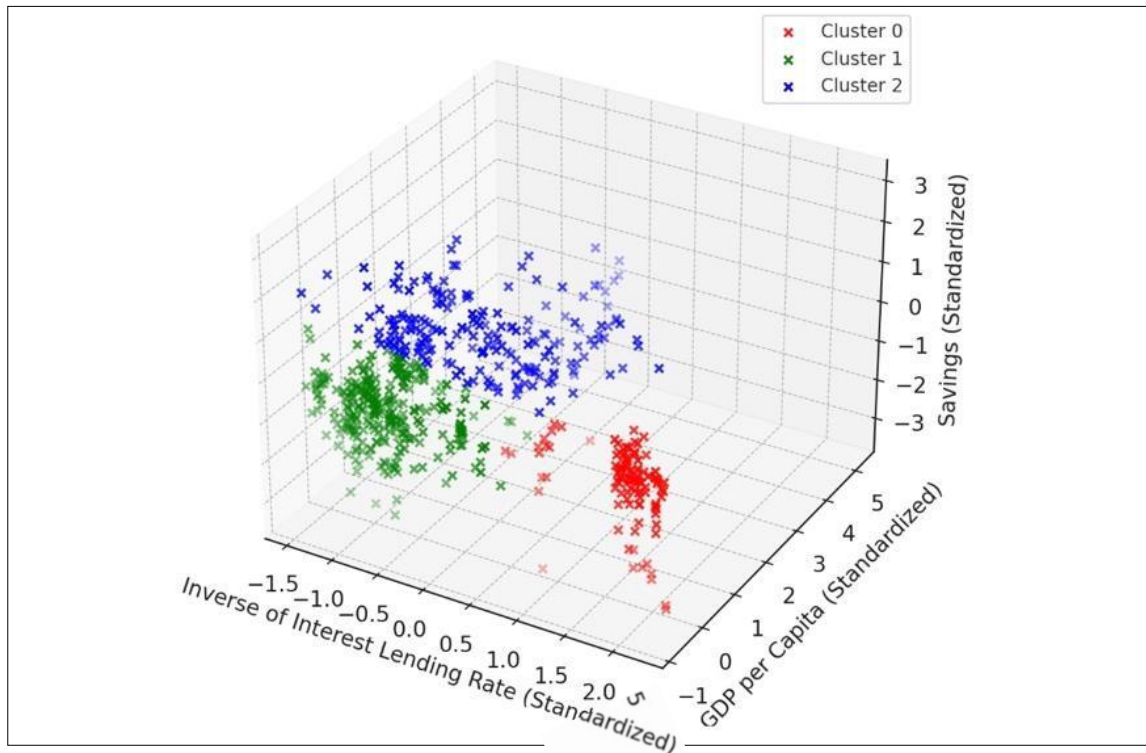
The clusters for 2020 are as follows:

Cluster 0	Botswana, Mauritius, Seychelles, South Africa
Cluster 1	Angola, Burundi, Congo, Dem. Rep., Gambia, Kenya, Madagascar, Malawi, Mozambique, Nigeria, Rwanda, Sao Tome and Principe, Sierra Leone, Tanzania, Zimbabwe
Cluster 2	Benin, Burkina Faso, Cabo Verde, Comoros, Eswatini, Lesotho, Namibia, Zambia

Table 6.1.2 Clusters for 2020

The clustering analysis suggested that there is not a strong linear relationship between the inverse of the interest lending rate and GDP per capita. Clusters that contain countries with higher GDP per capita generally seem to have lower interest lending rates. This aligns with economic theories that suggest more developed economies often have more stable financial systems, which are associated with lower interest rates. The clustering for both 2010 and 2020 shows that countries like Botswana, Mauritius, Seychelles, and South Africa tend to be grouped together, suggesting a pattern of higher economic development and lower interest rates.

Conversely, clusters that have countries with lower GDP per capita, generally have higher interest lending rates. These countries could be characterised by less stable financial systems that require higher interest rates to compensate for higher risks or by central bank policies that keep rates high to control inflation or stabilise the currency. Comparing the clusters from 2010 to 2020 reveals economic progress or decline. For example, if a country moves from a cluster with lower GDP per capita to one with higher GDP per capita, it would indicate economic improvement. Similarly, a shift in the opposite direction would signal economic challenges. Countries with a high GDP per capita may still maintain high interest rates, or countries with low GDP per capita may have surprisingly low interest rates. These anomalies warrant further investigation into country-specific factors such as monetary policy, economic crises, or unique economic structures. For policymakers, understanding the relationship between interest rates and economic performance is crucial. Lowering interest rates might be a strategy to stimulate economic growth, but only if the financial system is robust enough to handle the potential risks.



Graph 6.1.2 3D scatter plot of clusters

Graph 6.1.2 above is the 3D scatter plot that visualises the clusters formed by including the inverse of the interest lending rate, GDP per capita, and savings. Each colour represents a different cluster, showing how countries are grouped together based on these three standardised variables.

This visualisation aids in understanding how these economic indicators relate to each other and to the concept of valuing time versus money in different economies. The characteristics of each cluster provide insights into the economic behaviours and priorities of the countries within the cluster. The relevance in this context is that a lower propensity to value time in terms of money has a significant impact on the success of SST programme investments, or in fact any project investments. A low propensity to value time in terms of money will negatively impact schedule and budget – two key failure points identified in an assessment of failed programmes (See Appendix A). By assessing the indicator, the lending interest rate of a country, one has a picture of a part of its institutional and economic position. World Bank (Nd) notes that the development relevance of this indicator is in the fact that both banking and financial systems enhance growth, the main factor in poverty reduction. At low levels of economic development commercial banks tend to dominate the financial system, while at higher levels domestic stock markets tend to become more active and efficient. The argument can be made that the level of the interest lending rate provides an indication of the propensity to value time in terms of money – that is, a lower interest rate would indicate a higher propensity to value time in terms of money. The inverse of

the interest lending rate provides a larger differential for comparison and is thus used for practical analysis. The growth in real GDP per capita indicates the pace of income growth per person in the population, and as a single composite indicator, it is a reliable summary indicator of economic development.

Understanding the proposed PVTM in SSA requires a nuanced approach that incorporates cultural perspectives on time. In SSA, differing views on time, influenced by cultural and social norms, significantly impact economic behaviours and growth. This research aims to quantify these cultural attitudes and their economic implications through the concept of PVTM. In many SSA cultures, time is often valued differently compared to Western norms, with a stronger emphasis on community and family over strict adherence to schedules. This cultural inclination can influence financial behaviours, such as saving and investment patterns, and subsequently, the interest rates observed in these economies. Higher interest rates in some SSA countries may reflect not only economic instability but also a lower cultural propensity to value time in monetary terms.

By integrating cultural perspectives and time perspectives with traditional economic indicators, this research highlights the importance of further exploration into the proposed PVTM in understanding economic behaviours in SSA. Further studies could deepen this understanding, exploring specific cultural practices and their direct impact on economic growth. Although this concept is incorporated into this research, further study on this topic is beyond the scope of this research.

Part 3

Data Analysis

7. Data Analysis

7.1. Introduction

One of the most difficult elements of obtaining funding allocations for SST programmes, within the African context, is demonstrating and quantifying the socio-economic impact from the investment. The quantitative analysis is challenged by the lack of availability and quality of data for socio-economic impacts and spill-over effects, particularly in the African context, as well as the often difficult-to-track indirect and time-lagged benefits from this kind of investment. Based on the literature and statistical analysis, the economic indicator or proxy chosen to quantify the socio-economic impact of investment into SST, and the dependent variable of the econometric testing in this research, is labour productivity – defined as the amount of output or real gross domestic product (GDP)²⁶ produced by an hour of labour, it can also be defined as the output per worker. Due to the potential for double counting, output per hour worked is deemed more accurate than output per worker. It is normally determined by dividing the total output produced by the total number of labour hours worked. The formula is as follows:

$$\text{Labour Productivity} = \text{Total Output} / \text{Total Labour Hours}$$

Equation 7.1.1

In terms of labour, the output of an economy can be increased by adding more workers, increasing working hours, or raising worker productivity, and worker productivity can be increased by interventions such as technological advances (IMF, 2018). Economic growth broadly depends on three main factors as laid out in the literature review, namely saving, investment into both physical capital and new technology, and human capital (Solow, 1956). As such, labour productivity is a measure for assessing the socio-economic impact of various factors and policies within an economy. It provides insights into the efficiency and effectiveness of labour utilisation, which has significant implications for the overall well-being of individuals, businesses, and societies (Sharpe, 2002)). Labour productivity can indeed then be used as a proxy for the socio-economic impact of investments in sectors such as the SST sector. This is based on the premise that such investments

²⁶ Gross domestic product (GDP) is the standard measure of the value added through the production of goods and services in a country during a certain period (OECD).

typically lead to enhancements in knowledge, innovation, infrastructure, and human capital, all of which are key factors that contribute to increasing labour productivity. In other words, labour productivity serves as a measure of socio-economic impact in terms of economic growth; higher labour productivity allows for the production of more goods and services with the same or fewer labour inputs (Schreyer & Pilat, 2001). This leads to increased output, higher incomes, and improved living standards. Countries with higher labour productivity tend to experience stronger economic growth and have greater potential for socio-economic development (Bloom et al., 2004). As labour productivity increases, businesses can produce more output with the same labour input, potentially leading to increased job opportunities, which may contribute to reducing unemployment rates and creating more secure and sustainable employment, positively impacting individuals and society as a whole. The reasons for this include that businesses can produce more output with the same amount of labour which often results in lower unit labour costs and increased competitiveness can lead to higher sales, expansion of operations, and the need for more workers to meet growing demand. Productivity gains can lead to economic growth and a growing economy typically requires more workers, which can lead to job creation. Firms that benefit from higher productivity might reinvest their profits into new technologies, processes, or business lines. This reinvestment can lead to the creation of new jobs. Moreover, as companies innovate, they may develop new products.

It is worth noting that increased labour productivity is generally associated with positive economic outcomes, particularly over the long term, however the effects can vary depending on the specific economic context. Some economists argue that increased productivity can lead to job displacement, at least in the short term, as firms may not need as many workers to produce the same level of output. This can lead to structural unemployment, where the skills of the workers do not match the needs of the new, more productive economy (Autor, 2015). This displacement can be more pronounced in industries where automation and technological advancements play a significant role (Acemoglu and Restrepo, 2018). Increased productivity might also cause shifts in employment from one sector to another. While jobs may be created in new, high-productivity sectors, there may be a loss of jobs in traditional sectors that cannot compete. This transition may lead to temporary increases in unemployment if workers cannot quickly adapt to new roles or industries (David, 2013). Investments in SST often require advanced skills and knowledge, leading to improved educational opportunities and workforce skills. As workers become more skilled, they can perform tasks more efficiently and with higher quality, which enhances labour productivity (Becker, 1964).

The development of new technologies can spill over into other industries, leading to productivity gains as these technologies are adopted elsewhere. New technologies can automate tasks, improve

processes, and lead to the creation of new products and services (Solow, 1956). R&D investments, which are often a significant component of SST investments, can result in innovations that streamline production processes, reduce costs, and improve product quality. The resulting increases in output per worker are directly observable as increased labour productivity (Barro & Sala-i-Martin, 2004). Space technology contributes to the development of infrastructure such as satellite communication, navigation, and remote sensing and these technologies can boost productivity by improving logistics, reducing transaction costs, and enabling more efficient resource management. The space industry and space science institutions can create jobs both directly and indirectly through multiplier effects, as increased demand for space-related goods and services spurs growth in other sectors, thereby potentially raising overall labour productivity (Barro & Sala-i-Martin, 2004). Engagement in SST can position a country favourably in the global economy, promoting sectors that contribute to high-value-added products and services, which in turn supports high labour productivity levels.

In summary, labour productivity can serve as a meaningful indicator of the socio-economic benefits derived from SST investment because it reflects the culmination of improvements in human capital, technology, R&D, infrastructure, and more, which are all critical components influenced by such investments. The utilisation of labour productivity as a proxy for assessing the socio-economic impact of investments into SST, within the African context, thus serves as a practical measure to gauge the tangible outcomes and contributions of such investments towards economic growth and development. It is imperative to acknowledge the multi-faceted nature of socio-economic impacts, and labour productivity alone may not capture the entirety of these effects, however, the inputs and outcomes derived from investments into SST are most likely captured in labour productivity as an overall benefit to the economy. The transformative potential that investments in SST hold for Africa's socio-economic development under investigation requires an examination of labour productivity together with other indicators, to provide a holistic understanding of the mechanisms at play. The integrated approach provides an empirical foundation for policy-making but also ensures that the benefits derived from space-related initiatives are maximised and equitably distributed.

7.2. Methodology

The empirical investigation in this research of socio-economic benefits from SST investment examined the correlations of indicators in an attempt to identify causality between them. This causality, if identified, addresses the underlying trends and relationships within the dataset that

lead to change in the indicators. Econometric analysis was undertaken on the panel dataset of economic development indicators in Sub-Saharan Africa (SSA). The SSA dataset is comprised of 48 panels representing 48 SSA countries for the years spanning 1996 to 2021, with the labour productivity indicator as the dependent variable being estimated. The study employs the fixed and random effect model, panel two-stage least squares, and general method of moments regression model on an unbalanced panel. The original analysis utilised 50 economic indicators to explore the relationships between economic growth, labour productivity and SST investment. Ultimately 10 indicators were selected to make up four exogenous composite variables. The data utilised in this research was predominantly obtained from the World Bank database and the ILOSTAT database. The panel dataset, which combined cross-sectional and time-series data, is considered a sufficient framework to explore both inter-country variations and longitudinal trends. This approach enabled the analysis to capture the heterogeneity among the 48 SSA nations and to account for the dynamic nature of economic processes over time.

In this chapter, the key elements of model specification, and the rationale behind the econometric techniques are laid out. Subsequently, the variables of interest are discussed, as well as their analysis, and the econometric models that were employed to examine the socio-economic impacts of investments in SST.

In the context of the regression analysis performed throughout this chapter, hypothesis testing is used to determine whether the particular predictors have a statistically significant relationship with the dependent variable, labour productivity, and vice versa or in some cases, with each other.

The primary hypotheses for the predictor in regression are as follows:

1. Null Hypothesis (H_0): There is no relationship between the predictor variable/s and Labour productivity or vice versa. In the context of regression coefficients, the slope of the predictor is equal to zero.

Mathematically: $H_0: \beta_i=0$ (where β_i is the coefficient of the predictor variable).

2. Alternative Hypothesis (H_a or H_1): There is a relationship between the predictor variable/s and labour productivity, or vice versa. The slope of the predictor is not equal to zero.

Mathematically: $H_a: \beta_i \neq 0$

After running the regression, if the p-value associated with a predictor is below the chosen significance level of 0.05, the null hypothesis is rejected in favour of the alternative hypothesis, suggesting that the predictor has a significant relationship with labour productivity.

The main limitation of this study is data related, either all the required SSA data is not available, unreliable or there are large gaps in the data for many of the economic indicators, which has the impact of reducing the accuracy of the results, the number of indicators available for use, and a reduction in the time periods available for comparison.

Acknowledging these constraints to the data analysis, the methodology does still provide a structured approach to the analysis of the data in order to investigate the impact of SST investment on labour productivity. The statistical analyses aimed to yield valuable insights into the relationship, contributing to the broader understanding of socio-economic impact determinants.

8. Exploring Labour Productivity in the African Context

8.1. Labour Productivity as a Contributor to Economic Growth

The initial step in the data analysis of this research was to test the SSA data set in order to determine alignment and departures from standard economic theory as was highlighted in the literature review. Below are the results from the regression analysis that was applied to the SSA panel dataset, utilising the standard Cobb-Douglas Production Function with technology, based on the Solow–Swan model (Solow, 1956);

$$Y(t)=K(t)^\alpha (A(t)L(t))^{1-\alpha} \tag{Equation 8.1.1}$$

where t denotes time, $0 < \alpha < 1$, α is the elasticity of output with respect to capital, and $Y(t)$ represents total production. A refers to labour-augmenting technology, thus AL represents effective labour. The number of workers, labour force, as well as the level of technology grow exogenously at rates n and g , respectively; $L(t)=L(0)e^{nt}$, $A(t)=A(0)e^{gt}$.

For the regression analysis:

$$Y_{it} = c_0 + c_1(X_{1it}) + c_2(X_{2it}) + c_3(X_{3it}) + u_i \tag{Equation 8.1.2}$$

Thus Let $Y = \ln \text{GDP}$, $X_1 = \ln \text{Capital Formation}$, $X_2 = \ln \text{Labour Force}$, $X_3 = \ln \text{TFP}$ ²⁷

Hypothesis Test:

H0: (The coefficients are zero). The independent variables have no effect on the dependent variable

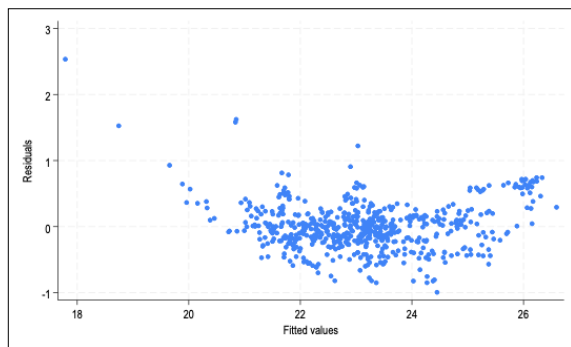
H1: (The coefficients are not zero). The independent variables have an effect on the dependent variable

²⁷ Ln=Natural Logarithm.

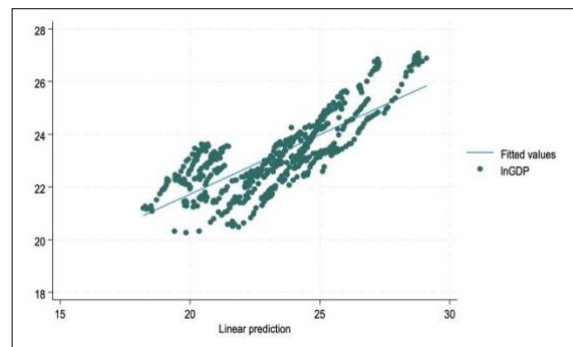
Root MSE	0.1795	F(3,560)	1765.51	No. of Obs
R-squared	0.9044	Prob>F	0.0000	589
Variable (Log-Log)	Coefficien t	Std Error	t	P>|t|
GDP	1			
Capital Formation	0.307	0,019	16.54	0.000
TFP	0.711	0,072	9.87	0.000
Labour Force	1.606	0,076	21.07	0.000
Constant	-7.665	0,869	-8.82	0.000

Table 8.1.1 Fixed Effects Regression on SSA Panel Data: Economic growth model

Based on the 5% significance level, H0 is rejected. 90% of GDP can be described by capital formation, TFP and the labour force, as expected. The residual scatter plot of the GDP versus the regression residuals can be seen in Graph 9.1.1 below.



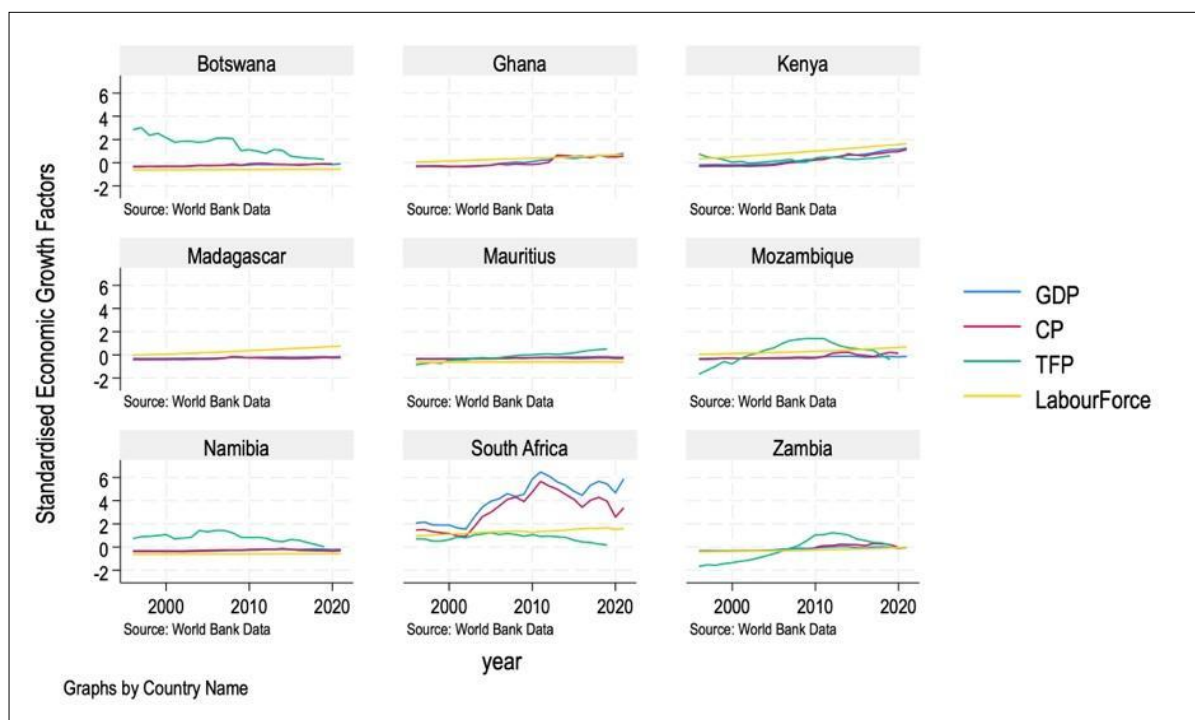
Graph 8.1.1 Residual plot versus fitted values



Graph 8.1.2 Scatter plot of actual versus predicted values

Before running the fixed effects regression, a standard regression was run on the data, the results of which showed that the coefficient for TFP was not significant at the 5% level. The data was then re-analysed with the fixed and random effects regressions and the appropriateness of the fixed effects model was confirmed by the Hausman test (Hausman, 1978). The test evaluates whether the unique errors are correlated with the regressors, thereby providing a basis for model selection between fixed effects and random effects models. The fixed model allows for addressing unobserved heterogeneity, that is the presence of variables or characteristics that influence the outcome but are not observed or included in the model. Above in Graphs 9.1.1 and 9.2.2, the

predicted value plot and the residual plot show that the model adequately captures the relationships. Based on the first regression results it is worth understanding why it could be the case that the TFP may have a non-significant impact. There are several possible reasons for TFP not significantly impacting GDP in the SSA economies. The first would be structural barriers that prevent TFP from translating into economic growth, including poor infrastructure, inadequate governance, and underdeveloped financial markets, which can hinder the efficient allocation and utilisation of productive resources (Acemoglu & Robinson, 2012). The impact of TFP on growth is heavily influenced by the level of human capital, as such in regions where education and skill levels are low, the ability to adopt, adapt, and innovate technologies is limited, potentially leading to a negative impact on growth (Nelson & Phelps, 1966). Thirdly, SSA countries are more vulnerable to external shocks such as commodity price fluctuations, climate change, and global economic downturns. These shocks can disrupt economic activities and reduce the positive effects of TFP on growth (Rodrik, 1999). The ability of SSA countries to benefit from global technological advances is limited by their capacity to absorb new technologies. Lastly, TFP is difficult to measure accurately, especially in developing countries where data on inputs and outputs is less reliable. Errors in the measurement and the use of inappropriate proxies could also lead to misleading results (Hulten, 2001). The data from the SSA region is made up of indicators from 48 countries, which is challenging to represent visually. As such for the purposes of an illustrative visual representation, the nine SKA Africa Partner countries were selected, as laid out in the Introduction to the SKA.



Graph 8.1.3 Africa SKA Partner Countries: Standardised Economic Growth Factors with GDP, 1990 to 2022

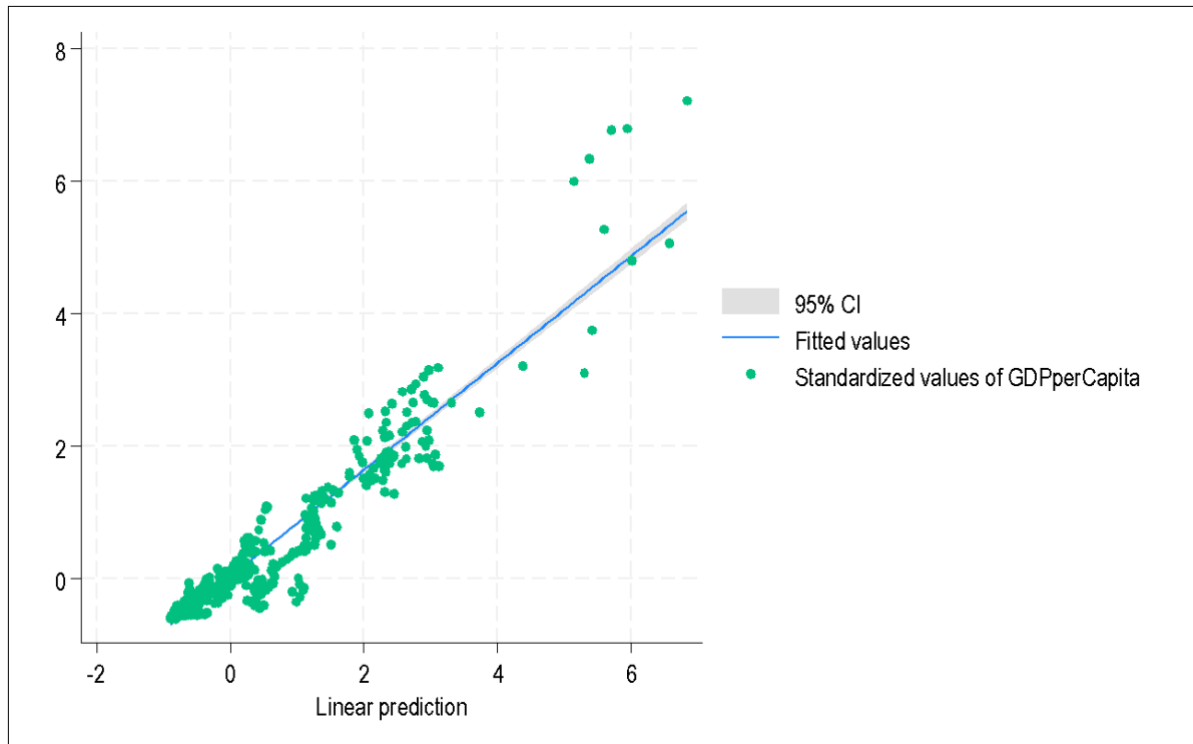
Labour productivity is assumed to be a key determinant of income and wage levels (Mankiw et al., 2017). When workers are more productive, they contribute more value to the production process, which can translate into higher wages and incomes. Improved labour productivity supports higher earning potential for individuals, reducing income inequalities and fostering socio-economic well-being (OECD, 2022). Thus labour productivity is instrumental in poverty reduction efforts and can lift individuals and households out of poverty by providing better income opportunities and improving the overall standard of living. The below regression results test whether by enhancing labour productivity, societies can promote growth and reduce poverty rates by utilising GDP per capita as a proxy for average individual earnings.

Root MSE	0.2131	F(1,644)	1057.80	No. of Obs
R-squared	0.6216	Prob>F	0.0000	687
Variable (Standardised)	Coefficient	Std Error	t	P>|t|
GDP per Capita	1			
Labour Productivity per Hour	1.217	0.037	32.52	0.000
Constant	0.084	0.008	10.34	0.000

Table 8.1.2 Fixed Effects Regression on SSA Panel Data: GDP per Capita and

The fixed-effects regression model whereby standardised GDP per capita was regressed on standardised labour productivity, shows that approximately 62% of the variation in standardised GDP per capita within countries over time, is explained by changes in standardised labour productivity. Standardisation of the variables was used as it adjusts different variables to the same scale, allowing for direct comparison of coefficients and simplification of the interpretation of the results. The model also explains a significant portion of the variation between countries. The Rho²⁸ value indicates a substantial part of the variance in GDP per capita is due to differences across countries, reinforcing the importance of considering fixed effects for this model. The regression results support the theory that changes in labour productivity are a driver of variations in GDP per capita within countries, highlighting productivity as a key focus for economic policy aimed at improving GDP per capita.

²⁸ Spearman's Rho is a non-parametric test used to measure the strength of association between two variables.



Graph 8.1.4 Scatter plot of actual versus predicted values

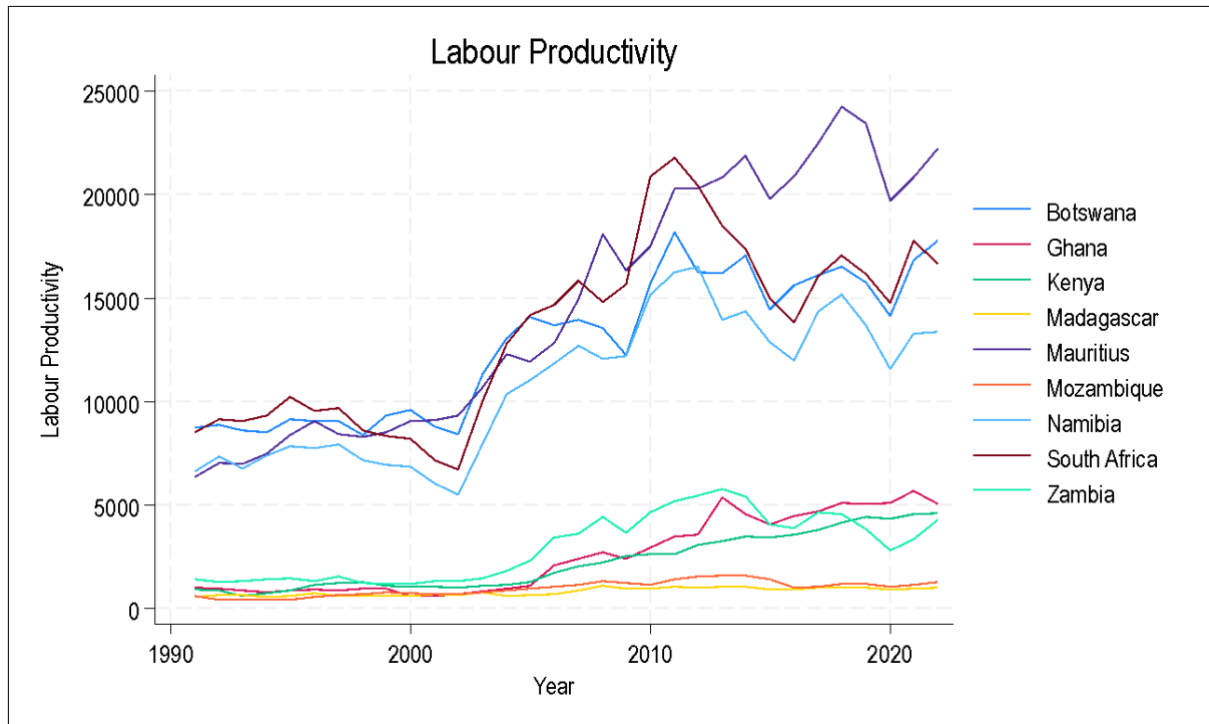
Hypothesis Test:

H0: (The coefficients are zero). Labour productivity is not a determinant of income levels

H1: (The coefficients are not zero). Labour productivity is a determinant of income levels

H0 is rejected at the 5% level, and the Root MSE and R-Squared values support the accuracy and predictive quality of the model. The panel data for SSA countries supports the claim that labour productivity is a determinant of income levels.

Higher labour productivity leads to increased incomes as businesses can afford to pay their workers more due to higher output per worker. This increase in income boosts consumer spending because individuals have more disposable income. According to Keynesian economics, consumption is largely a function of income; thus, as labour productivity increases, it leads to a rise in consumption levels (Blanchard & Fischer, 1989). Improved labour productivity makes investment more attractive to firms. Higher productivity can lead to greater profitability, encouraging firms to invest in new technologies, expand operations, and enter new markets. Lucas (1988) argues that the accumulation of human capital is critical for an increase in the economic growth rate, suggesting that investments in education and training that enhance labour productivity are particularly beneficial.



Graph 8.1.5 SKA Africa Partner Countries: Labour Productivity, years 1990 to 2022 (Data Source: World Bank Data)

As labour productivity increases, it can lead to higher tax revenues without increasing tax rates, due to higher incomes and profits. This increase in revenue gives governments more flexibility to spend on public services, infrastructure, and social programs. Barro (1990) has shown that government spending on productive services can further enhance economic growth, creating a cycle of productivity and growth. Higher productivity enhances a country's competitiveness in the international market by lowering production costs and allowing for the production of higher-quality goods. This can lead to an increase in exports as domestically produced goods become more attractive to foreign buyers. Krugman (1987) presented how productivity improvements can alter trade patterns and improve a country's trade balance by making its exports more competitive. This section has demonstrated, both theoretically and empirically, that labour productivity is a foundational driver of economic growth and socio-economic progress in Sub-Saharan Africa (SSA). Using the Solow-Swan production framework and panel data regression models, it was shown that capital formation, labour force growth, and total factor productivity (TFP) together explain a substantial portion of GDP variation across SSA countries. Yet, the muted role of TFP in some models signals the need for more nuanced understandings of how innovation, technology adoption, and institutional environments shape productivity outcomes in the region.

The results further affirm the strong association between labour productivity and GDP per capita, suggesting that productivity gains translate directly into higher incomes, improved standards of living, and broader development benefits. This is consistent with mainstream economic thought,

where productivity improvements foster increased wages, greater consumption, higher investment, and fiscal space for public investment. However, the SSA context reveals added complexities—such as structural constraints, informality, education gaps, and uneven technology absorption—that can temper the full realisation of these benefits.

Importantly, the findings also highlight the heterogeneity across SSA economies. While some countries show stronger productivity-led growth, others face challenges in translating output efficiency into income gains due to weak institutions or underdeveloped markets. This reinforces the importance of contextualised, country-specific policy interventions that target human capital development, technological capacity, financial inclusion, and the integration of informal labour into more productive and formal structures.

Overall, the analysis in this chapter supports the central proposition of this thesis: labour productivity can serve as a practical and robust proxy for socio-economic benefit, especially when assessed alongside capital investment, innovation, and institutional quality. These insights lay the foundation for the next chapter, which builds a comprehensive model linking Space Science and Technology (SST) investment to labour productivity and, ultimately, socio-economic transformation in Africa.

8.2. Labour Productivity and Business Competitiveness

Labour productivity is also a crucial factor in determining the competitiveness of businesses and industries. Competitiveness in the context of this research may be seen to exist between businesses, sectors and even at the level of a nation's international competitiveness. For the purposes of this research and derived from thematic analysis; business competitiveness is defined as the propensity of a firm, industry sector or a national economy to efficiently and sustainably generate superior value in the production and delivery of goods and services. This competitive stance is premised on the ability to innovate, leverage human capital, employ advanced technologies in production processes, and optimise resource allocations to meet and exceed the quality expectations of the local or global marketplace, thus securing and expanding market share. Factors such as labour productivity, technological advancement, and entrepreneurial impact are instrumental in shaping the competitive contours of a business ecosystem. As stated, labour productivity enables companies to produce goods and services more efficiently and at lower costs (ILOSTAT, 2021). This enhances their ability to compete in domestic and international markets, supporting industrial development, attracting investments, and creating socio-economic opportunities.

Labour productivity is widely regarded as a causal factor for business competitiveness rather than the other way around. This causality stems from the principle that higher labour productivity—meaning more output per unit of labour—directly contributes to lowering production costs, improving product quality, and enhancing service delivery, which are all critical components of business competitiveness. Businesses with higher labour productivity can produce goods and services at lower costs, giving them a competitive edge in pricing. Krugman (1994) emphasises that productivity is the most important factor in determining a nation's living standards and its ability to offer goods and services at competitive prices. This ability to lower costs through increased productivity enables businesses to compete more effectively both in domestic and international markets. Porter (1990) argues that competitive advantage derives from the ability to offer superior value to consumers, either through lower prices or higher quality products and services. Thus, labour productivity enhances competitiveness by enabling businesses to improve the quality of their offerings. Increased labour productivity can also translate into better customer service and faster delivery times, making a business more competitive. This is particularly important in service-oriented sectors where efficiency and speed are closely linked to customer satisfaction. Loveman (1998) found a positive relationship between productivity improvements and service quality in the banking industry, suggesting that labour productivity enhancements lead to better service delivery and, consequently, higher competitiveness.

The reverse relationship, where business competitiveness drives labour productivity, does hold in certain contexts—especially in highly competitive industries where firms must continually improve efficiency to survive. However, the primary causality generally flows from labour productivity to competitiveness. Firms and industries that manage to increase their labour productivity can reduce costs, improve quality, and enhance service delivery, which are all essential for gaining and maintaining a competitive edge. Competitive businesses often lead to lower prices and higher quality goods and services, which can increase consumer satisfaction and spending. Lower prices make goods and services more accessible to a broader segment of the population, thus increasing consumption. Dunning (1993) argues that competitiveness enhances a country's attractiveness to both inward and outward investment, leading to increased capital formation and, subsequently, economic growth. While the direct impact of business competitiveness on government spending might be less apparent than on other components, competitive industries can contribute to a broader tax base, thereby increasing government revenues without raising tax rates. This can enable governments to spend more on public goods and services, infrastructure, and social programs, which in turn can support further economic growth. Rodrik (1996) suggests that government policies that support competitiveness, such as investments in education and infrastructure, not only bolster competitiveness but also facilitate increased government spending

on public goods. Increased competitiveness enhances a country's export potential by making its goods and services more attractive on the international market due to higher quality or lower prices. Furthermore, competitive businesses are better positioned to penetrate new markets and adapt to global market trends, improving the trade balance. Krugman (1989) has shown that competitiveness is crucial for improving a country's trade performance, as it determines the ability to export more and import less, thereby positively affecting the net exports component of the GDP equation.

This research has analysed the relationships between elements of business competitiveness and labour productivity on a country level, for the SSA region. In Appendix C is the visual representation of a System Equation Model (SEM) that shows the final selection of pathways of effect, from the analysis of the impact of labour productivity on selected business competitiveness indicators, and vice versa (Also see Appendix C for the full statistical output). The elements of business continuity were selected as proxies based on research and the availability of data. It is clear that the elements of business competitiveness impact labour productivity and can be considered causal, whereas labour productivity is not impacted by other elements directly and may in fact be regarded as causal to those elements. There is also evidence of a feedback loop to the interactions, thus the causality works both ways.

Table 9.2.1 below shows the regression output of the selected elements of business competitiveness and labour productivity from the SEM. The variables were standardised for the purposes of comparison and it is worth reiterating that the relationships can be derived from the regression, but causality cannot be inferred. The regression shows that ICT Service Exports and Net FDI Inflows are not significant as determinants of labour productivity in the model, however, the SEM shows a significant impact of labour productivity on ICT Service Exports, thus it is evident that this is a layered and perhaps cyclic relationship.

Root MSE	0.0611	F(4,203)	79.85	No. of Obs
R-squared	0.5703	Prob>F	0.0000	208
Variable				
Labour Productivity (Standardised)	Coefficient	Std Error	t	P>|t|
ICT Service Exports	-0.044	0.041	-1.06	0.291
Net FDI Inflows	-0.141	0.088	-1.61	0.110
New Business Density	0.531	0.039	13.51	0.000
High Tech Exports	0.157	0.033	4.70	0.000
Constant	0.029	0.040	0.71	0.481

Table 8.2.1 Regression of Standardised Elements of Business Competitiveness

Table 9.2.2 below displays the results of the instrumental variables regression with the general method of moments on SSA countries. The endogenous variable is ‘New Business Density’, the exogenous variables are ‘ICT Service Exports’, as well as the instruments ‘Patent Applications by Residents’ and ‘Domestic Credit to the Private Sector’. The Hansen J test for overriding restrictions provided a p-value of 0.1679 thus the null hypothesis is rejected and confirmation that the instruments are valid (Hansen, 1982).

Root MSE	0.032	Wald Chi2(2)	154.01	No. of Obs
R-squared	8.634	Prob>F	0.0000	92
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity				
New Business Density	2.544	0.206	12.32	0.000
ICT Service Exports	0.541	0.272	1.99	0.047
Constant	-2.274	1.782	-1.28	0.202

Table 8.2.2 GMM Labour Productivity and Business Competitiveness

Hypothesis Test:

H0: Business Competitiveness is not a determinant of Labour productivity

H1: Business Competitiveness is a determinant of Labour productivity

H0 is rejected at the 5% level, thus business competitiveness is a determinant of Labour Productivity. The Root MSE and R-Squared values support a low predictive accuracy of this result. The reasoning is that there are other impacts on labour productivity, such as education, that are not included in this equation as the purpose here was to isolate the system interactions of business competitiveness and labour productivity. This relationship can be considered as bi-directional as elements of business competitiveness impact labour productivity, as shown in the SEM, but equally labour productivity impacts other elements of business competitiveness and in fact, reinforces the effect. A case for further study can be made and further statistical analysis would likely reveal a multi-level feedback loop between business competitiveness elements and labour productivity.

For comparative purposes, the SEM was reproduced with the same variables for the World data set, and again for nine developed nations, where the indicator for Net FDI inflows is shown to be an invalid instrument and not statistically significant. It is reasonable to assume that the non-significance of net FDI inflows in the developed countries in relation to labour productivity is due to the different economic structures and stages of development compared to SSA countries. In

developed countries, the economy can be less influenced by foreign direct investments due to their well-established capital, technology, and infrastructure, which are typically the primary contributions of FDI in developing countries. Additionally, developed countries might also be net exporters of capital, which provides an explanation as to why FDI inflows do not show a significant impact on their labour productivity.

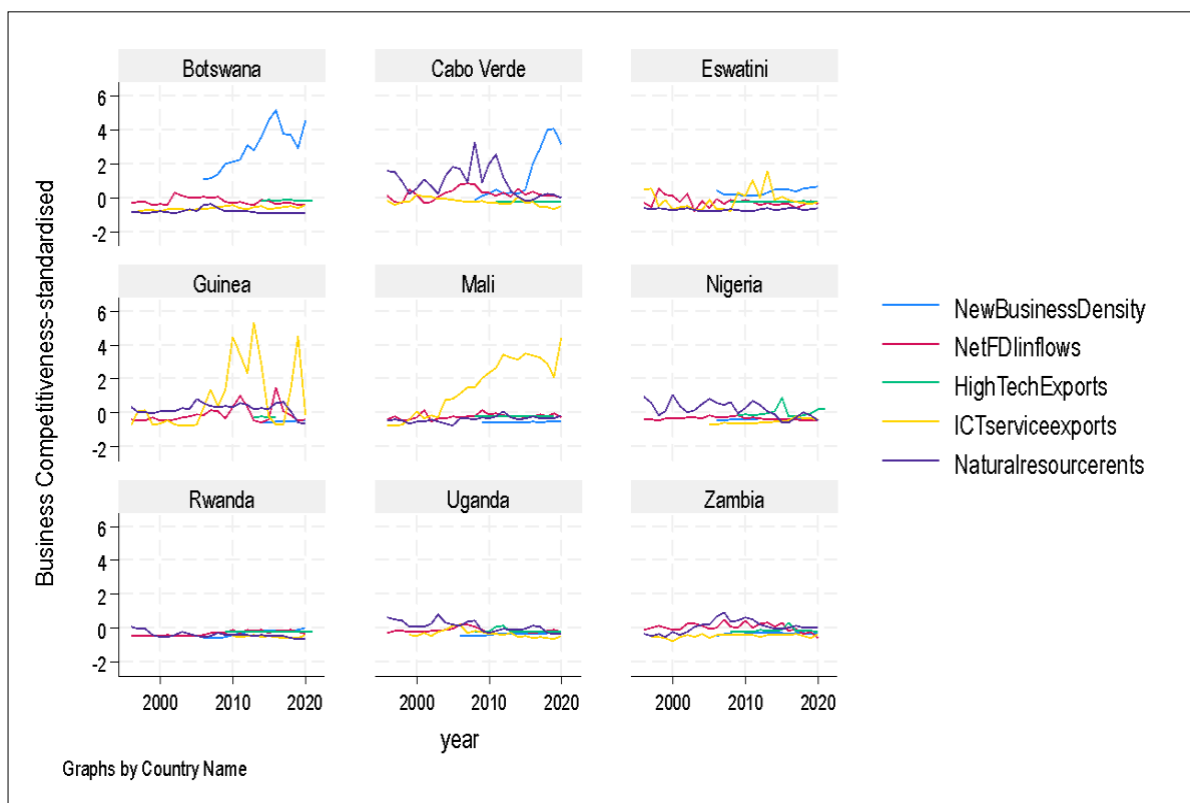
The panel data regression for SSA countries supports the claim that labour productivity is a determinant of business competitiveness, but the degree of impact is unclear due in part due to the lack of availability of appropriate indicators combined with insufficient data in terms of a low number of observations, to fully explore this relationship. The impacts of labour productivity on business competitiveness has been extensively studied in business literature. Notably, Porter's Diamond Model (1990) highlights the pivotal role of factors of production, including labour productivity, in shaping the competitive advantage of nations and industries (Porter, 1990). Moreover, Bartel et al. (1997) conducted an empirical examination that underscores the influence of information technology and worker skills on labour productivity and its subsequent positive correlation with firm competitiveness (Bartel et al., 1997). In a related study, Duflo and Pande (2007) demonstrated the constructive effects of irrigation technology and enhanced labour productivity on the competitiveness of agriculture-based enterprises (Duflo & Pande, 2007).

Below in Table 9.2.3, one can see the correlations of labour productivity with the business competitiveness indicators, and it can be seen that the data shows that New Business Density is most highly correlated to labour productivity.

	Labour Productivity per Hour Worked	High Technology Exports	New Business Density	Net FDI Inflows	ICT Services Exports
Labour Productivity per Hour Worked	1.0000				
High Technology Exports	0.4594	1.0000			
New Business Density	0.7476	0.3450	1.0000		
Net FDI Inflows	-0.2037	-0.1388	-0.1605	1.0000	
ICT Services Exports	-0.2133	-0.1073	-0.2254	-0.0628	1.0000

Table 8.2.3 Correlation table of Labour Productivity and the selected

Further investigation revealed unique cases within the Sub-Saharan African (SSA) context. Specifically, Botswana, Cabo Verde, Eswatini, Guinea, Lesotho, Mali, Nigeria, Rwanda, Togo, Uganda, and Zambia exhibit notable and unexpected outcomes regarding the influence of labour productivity on new business density. This outcome diverges from the anticipated results observed in more robust and sizeable economies within SSA and several factors warrant consideration in understanding these findings for labour productivity and new business density within the aforementioned countries.



Graph 8.2.1 Unique SSA Cases: Standardised Business Competitiveness Indicators,

Firstly, many of these countries predominantly rely on agriculture as a key economic sector, employing a substantial portion of the population. Several of these countries are rich in natural resources and have economies that are significantly influenced by the extraction and export of these resources, for example, Botswana in diamonds, Nigeria in oil, and Zambia in copper. There is also a push in these countries to diversify and stimulate growth in alternative industries. This shift towards diversification may enable these economies to have greater adaptability, fostering an environment more conducive to the emergence of new businesses. Conversely, countries with more diversified economies might offer more latitude for new enterprises to flourish in response to heightened labour productivity. The developmental stage of a nation significantly influences its

response to shifts in labour productivity as the availability and quality of physical capital, human capital, and technological change are key determinants in adaptation to productivity changes (Lumen Learning, n.d.). A nation can be in a developmental phase where augmented labour productivity more directly translates into the establishment of new businesses, in contrast to more mature economies where this relationship would be less pronounced. As an example, Nigeria has a vast oil sector, whereas Rwanda has invested heavily in becoming a service and technology hub in the region with the establishment of Kigali Innovation City, as part of the Government's Vision 2020 program (World Economic Forum, 2022).

The regulatory environment for initiating businesses can significantly impact the interaction between labour productivity and new business density. Countries such as Cabo Verde and Botswana rely substantially on tourism as a cornerstone of their economic vitality, while remittances from expatriates play a pivotal role in economies like Lesotho and Cabo Verde. These dynamics can exert profound influences on the respective business ecosystems. Another factor to consider is the youthfulness of these populations, which acts as both an opportunity and a challenge for new business growth. While it signifies the potential for a substantial labour force, it simultaneously underscores the need to generate sufficient employment opportunities to absorb this demographic. Several SSA countries have implemented development initiatives aimed at catalysing entrepreneurship, innovation, and business expansion to address this. These initiatives, encompassing training programmes, incubators, and improved access to finance, can significantly impact new business density.

The ease of accessing start-up capital emerges as a pivotal determinant, whether through local savings, FDI, or alternative avenues, the accessibility of capital profoundly influences the relationship between labour productivity and new business formation. In addition, labour mobility plays a role, enabling timely resource reallocation in response to fluctuations in productivity. This mobility can result in a more direct association between labour productivity and new business creation. Urbanisation dynamics must also be considered since rapid urbanisation often coincides with surges in new business formation, as individuals gravitate toward urban centres in pursuit of fresh economic prospects. Several of the aforementioned countries are members of regional trade blocs such as the Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC), which endeavour to foster trade and economic collaboration among member nations. Many of these countries receive substantial foreign aid, either bilaterally from developed countries or via international organisations, and it is the allocation of foreign aid that can significantly impact infrastructure development, including transportation, energy, and digital connectivity, all of which are integral to fostering an environment conducive to business growth.

Diversification of economies beyond traditional sectors such as agriculture and extractive industries often entails the promotion of industries like manufacturing, services, and technology. This requires addressing the common challenges in terms of infrastructure development, access to capital, and market access. It is worth noting that many of these economies boast a substantial informal sector and a culture of entrepreneurship, both of which can contribute to the proliferation of new businesses (Wodon et al., 2013). The research has shown that the unexpected regression results observed in the relationship between labour productivity and new business density in SSA are underpinned by economic, demographic, regulatory, and developmental factors.

The negative correlation between Information and Communication Technology (ICT) services exports and labour productivity in Sub-Saharan Africa (SSA) can be attributed to several factors, but it's important to note that this relationship is not necessarily causal. Instead, it reflects the complex dynamics of the region's economic landscape. Firstly, many SSA countries have traditionally relied on agriculture as a primary economic sector. When these economies undergo a shift towards ICT services exports, it might not immediately translate into significant improvements in labour productivity in the broader workforce. The transition from agriculture to ICT services can be gradual and uneven (Casper, 2012). Moreover, the digital divide remains a significant challenge in SSA, with limited access to high-quality internet services and a lack of digital infrastructure in many areas. Unequal access to ICT services can hinder their productive utilisation (Clarke, 2017). SSA countries may face a skills gap in the labour force and while ICT services exports require a skilled workforce, many regions within SSA might not have the necessary educational and training infrastructure to produce a labour force proficient in ICT-related tasks (African Union Commission, 2017).

Furthermore, a substantial portion of economic activity in SSA takes place in the informal sector, which often remains disconnected from the formal ICT services export sector. This division can limit the overall impact of ICT services exports on labour productivity (ILO, 2018). Moreover, the benefits of ICT services exports may not be evenly distributed across the population, potentially exacerbating income inequality. Unequal income distribution can impact overall labour productivity, particularly if large segments of the workforce do not benefit from the ICT sector (World Bank, 2021). SSA countries may face regulatory and policy challenges in effectively harnessing the potential of ICT services exports, issues such as inadequate intellectual property protection, restrictive regulations, and limited access to financing can hamper the growth of the ICT sector and its impact on labour productivity (ECA, 2019). Finally, inadequate physical infrastructure, such as reliable electricity supply and transportation networks, can hinder the expansion of ICT services and the integration of technology into other sectors of the economy, limiting its impact on labour productivity (World Bank, 2020).

While a negative correlation may exist, it does not imply that ICT services exports are inherently detrimental to labour productivity in SSA. Rather, it underscores the need for comprehensive policy measures, investments into education and digital infrastructure, and efforts to ensure that the benefits of the ICT sector are distributed equitably across the population.

This section has demonstrated that labour productivity is both a driver and a product of business competitiveness in Sub-Saharan Africa (SSA). Higher productivity enables firms to reduce costs, improve quality, and compete more effectively—key factors in fostering industrial growth, attracting investment, and expanding markets.

Regression and SEM analyses confirm that labour productivity positively influences elements such as new business density and high-tech exports, while also being shaped by competitiveness factors like innovation and entrepreneurship. Though causality primarily flows from productivity to competitiveness, the relationship is clearly bidirectional and context-dependent.

Unexpected results in certain SSA countries highlight the role of structural factors—such as economic diversification, regulatory environments, and youth demographics—in shaping these dynamics. The observed negative correlation between ICT service exports and productivity underscores the region's ongoing challenges in digital infrastructure, education, and equitable access. Overall, the evidence points to a complex but reinforcing relationship. Labour productivity and business competitiveness must be pursued together through coordinated investments in human capital, infrastructure, and innovation systems. These insights are critical in shaping SST policies that aim to unlock inclusive growth and sustainable development across SSA.

8.3. Labour Productivity and FDI

Labour productivity is typically understood to have a positive effect on Net FDI inflows for several reasons, which can be particularly pronounced in the African context. Higher labour productivity means that workers can produce more goods or services for each hour of work. This increased efficiency can lead to higher profit margins for businesses, which is an attractive proposition for foreign investors (Dunning & Lundan, 2008). In the African context, where labour costs might be lower compared to developed countries, high labour productivity can give an added competitive advantage to local firms and sectors. This can attract foreign companies looking to optimise their production costs by investing in high-productivity areas, thus increasing FDI inflows (Borensztein et al., 1998). Higher productivity is often associated with stronger economic performance. In African nations, which may be perceived as higher-risk environments, strong indicators of productivity can signal economic stability and potential for growth, thus encouraging FDI

(UNCTAD, 2012). Moreover, increases in labour productivity often lead to improvements in infrastructure and education because these factors are critical for enabling workers to produce more efficiently. Foreign investors tend to look for such improvements as indicators of a supportive business environment (World Bank, 2020). Higher labour productivity can lead to greater economic output, which in turn can increase the size and potential of the market. A larger and more dynamic market is a key attraction for foreign investors, as it promises better returns on their investments (Morisset, 2000). SSA countries that demonstrate high labour productivity may be more adept at adopting and integrating new technologies, and foreign firms seek to invest in regions where their technology can be utilised effectively, and high productivity levels can be an indicator of such capability (UNCTAD, 2012). A positive relationship between labour productivity and FDI can also reflect a favourable regulatory environment. SSA countries that have implemented reforms to improve labour productivity would likely have improved their business climates in ways that attract FDI, such as by protecting investor rights and streamlining business registration processes (World Bank, 2019).

Labour productivity and FDI inflows impact each other and causality is not unidirectional. Elmawazini (2014) investigated the hypothesis that FDI inflows yield positive productivity spillovers to 19 SSA countries during the period 1985–2010. His results showed that FDI inflows yield weak and negative productivity spillovers to SSA countries. In addition to this, he found that the growing technology gap in the SSA region negatively contributes to the productivity growth in SSA countries. These results are consistent with the observed internationalisation of capital and the international division of labour. He also noted that a significant challenge for SSA countries is attracting manufacturing and high-quality FDI (Elmawazini, 2014).

While it is generally assumed that higher labour productivity would attract more FDI due to higher efficiency and potentially higher returns, a negative effect of labour productivity on net FDI inflows in the SSA context could be a result of several complex factors. Higher labour productivity could be associated with higher wages, which in turn might deter FDI that is seeking cost advantages, particularly in labour-intensive industries (UNCTAD, 2021). Productivity increases may be the result of automation or other capital-intensive improvements that reduce the demand for labour, thus diminishing the labour cost advantage that many African nations possess (Rodrik, 2016). High productivity may indicate a maturing market where the opportunity for high returns typically sought by FDI might be lower compared to emerging markets with higher growth potential (World Bank, 2019). Investors might perceive high labour productivity as a sign of possible future wage inflation, increased bargaining power of workers, or impending regulatory interventions, all of which could impact long-term investment returns (IMF, 2020).

The relevance here is that the relationship between labour productivity and FDI is multifaceted and can be influenced by various other factors, such as political stability, infrastructure, the overall business environment, and the specific sectors of investment interest. These explanations are hypothetical when considering the relationship in the general sense, as the actual relationship between labour productivity and net FDI inflows varies based on the specific context of each SSA country.

In Section 3.3.2, the empirical analysis of business competitiveness data from the SSA panel showed that Net FDI inflows have a negative or even non-significant impact on labour productivity. The economic rationale behind the adverse effects of FDI on labour productivity can lie in the 'resource curse' phenomenon and the quality of FDI. In some African countries with significant natural resources, they might attract high levels of FDI, particularly in extractive industries. The 'resource curse,' is thus often observed in countries with abundant natural resources, and refers to the adverse consequences of heavy reliance on resource exports, which can crowd out other economic sectors and potentially reduce labour productivity in non-resource sectors. The impact of FDI on labour productivity can also vary depending on the quality and nature of the investments. The quality and nature of FDI investments play a pivotal role in determining the impact on labour productivity. High-quality FDI involves investments that foster technology transfer, skills development, and value-added activities, which can lead to enhanced labour productivity. On the other hand, if FDI is primarily in low-wage, labour-intensive industries, it may not lead to significant productivity gains. In addition, the effects of FDI on labour productivity may not be immediate. It may be the case that there is a time lag between the influx of FDI and its resultant impact on labour productivity, owing to factors such as technology transfer, skills development, or the expansion of production capacity. Reverse causality might be at play, wherein countries with initially lower labour productivity might attract more FDI to enhance productivity. This can lead to a negative correlation when examining the cross-sectional data.

Another aspect to the relationship between FDI and labour productivity that was revealed in the SEM presented in Chapter 5.4, is that FDI may not impact labour productivity directly, but rather indirectly through its impact on other economic areas such as new business density. In turn, if labour productivity is shown not to impact FDI directly, it can be demonstrated to impact other economic factors which do impact FDI impact. SSA countries are diverse in terms of their economic structure, institutions, and development levels and as such it is, of course, necessary to consider this heterogeneity when interpreting the results.

The relationship between labour productivity and foreign direct investment (FDI) in Sub-Saharan Africa (SSA) is complex and context-dependent. While higher labour productivity typically attracts

FDI by signaling efficiency, economic stability, and a capable workforce, this effect is not always straightforward in the African context.

Empirical evidence from this research suggests that in SSA, labour productivity may have a non-significant or even negative relationship with net FDI inflows. This could be due to factors such as the prevalence of low-quality, resource-based FDI, concerns over rising labour costs, or the effects of automation. Moreover, the ‘resource curse’ phenomenon highlights how FDI concentrated in extractive industries may crowd out broader productivity growth.

The analysis supports the idea that FDI’s impact on productivity may be indirect, occurring through pathways like new business formation rather than direct capital-to-labour improvements. Similarly, reverse causality may explain why less productive economies attract FDI aimed at boosting efficiency. In short, while labour productivity and FDI are linked, their interaction in SSA reflects broader structural, sectoral, and institutional conditions. Policy approaches should focus not only on attracting FDI, but on ensuring its quality, alignment with national development goals, and capacity to contribute to long-term productivity gains.

8.4. Labour Productivity and Education

Labour productivity is also closely linked to human capital development. Enhancing the skills, education, and training of the workforce contributes to improved labour productivity. Investments in education, vocational training, and lifelong learning programmes can enhance human capital and result in higher labour productivity, benefiting individuals, businesses, and society as a whole. Primary education forms the foundation of an individual's educational path and equips students with fundamental skills such as literacy, numeracy, and basic problem-solving. These skills are essential for communication and understanding instructions later in the workplace (Heckman & Kautz, 2012).

Secondary education builds upon the knowledge and skills acquired during primary schooling. It offers a more specialised curriculum and encourages critical thinking, analytical abilities and enables individuals to access entry-level jobs and prepares them for more advanced learning. Secondary education plays a pivotal role in providing individuals with a broader knowledge base and preparing them for diverse career paths (Hanushek & Woessmann, 2012).

Graduates are better equipped to adapt to changing job requirements and contribute to workforce productivity.

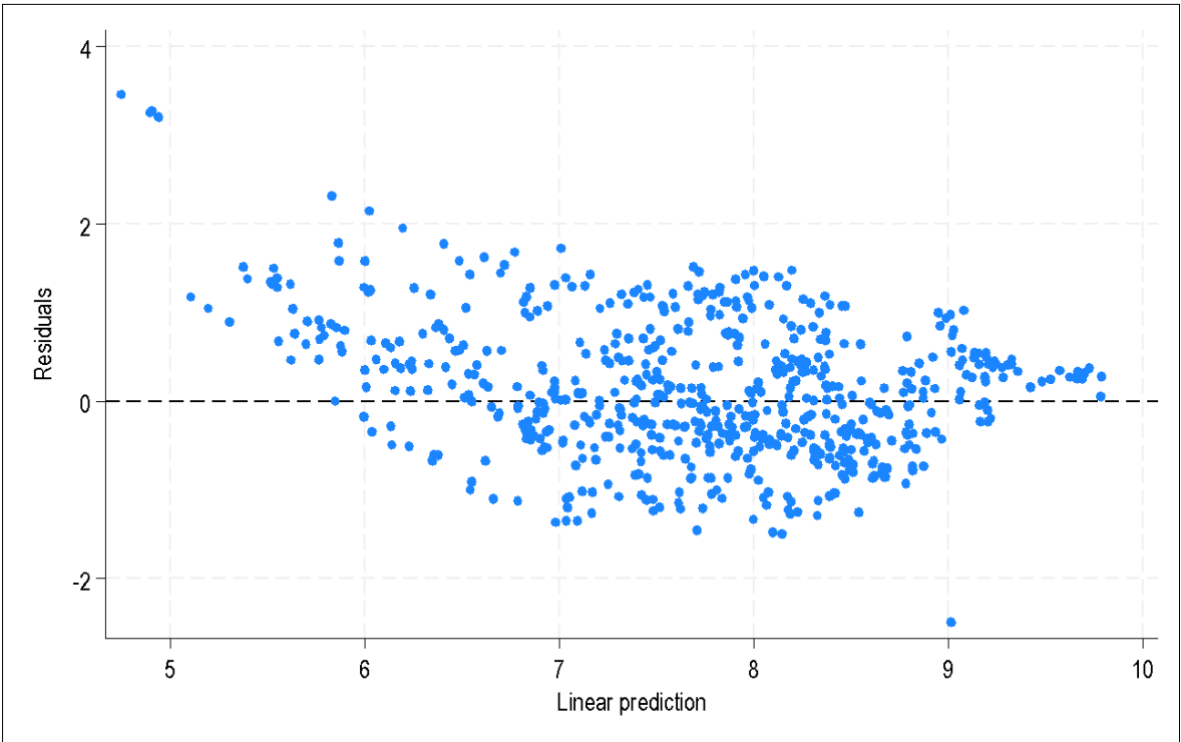
Tertiary education, including universities, colleges, and vocational training, fosters advanced expertise and specialisation. It equips students with specialised knowledge and skills relevant to

their chosen fields of study (Psacharopoulos & Patrinos, 2018). Tertiary graduates are often at the forefront of innovation, research, and leadership roles, driving productivity growth across industries. In a rapidly evolving job market, the importance of lifelong learning cannot be overstated. Continuous skills development, retraining, and upskilling through adult education programmes or professional development contribute to sustained labour productivity (Borghans et al., 2008). Lifelong learners are better prepared to navigate technological advancements and industry changes. The impact of education on labour productivity extends beyond individuals. Nations with well-educated workforces tend to experience higher economic growth and innovation (Hanushek, Woessmann, 2008). Education also has the potential to reduce income inequality and improve overall societal well-being, contributing to social cohesion and stability (Chetty et al., 2011).

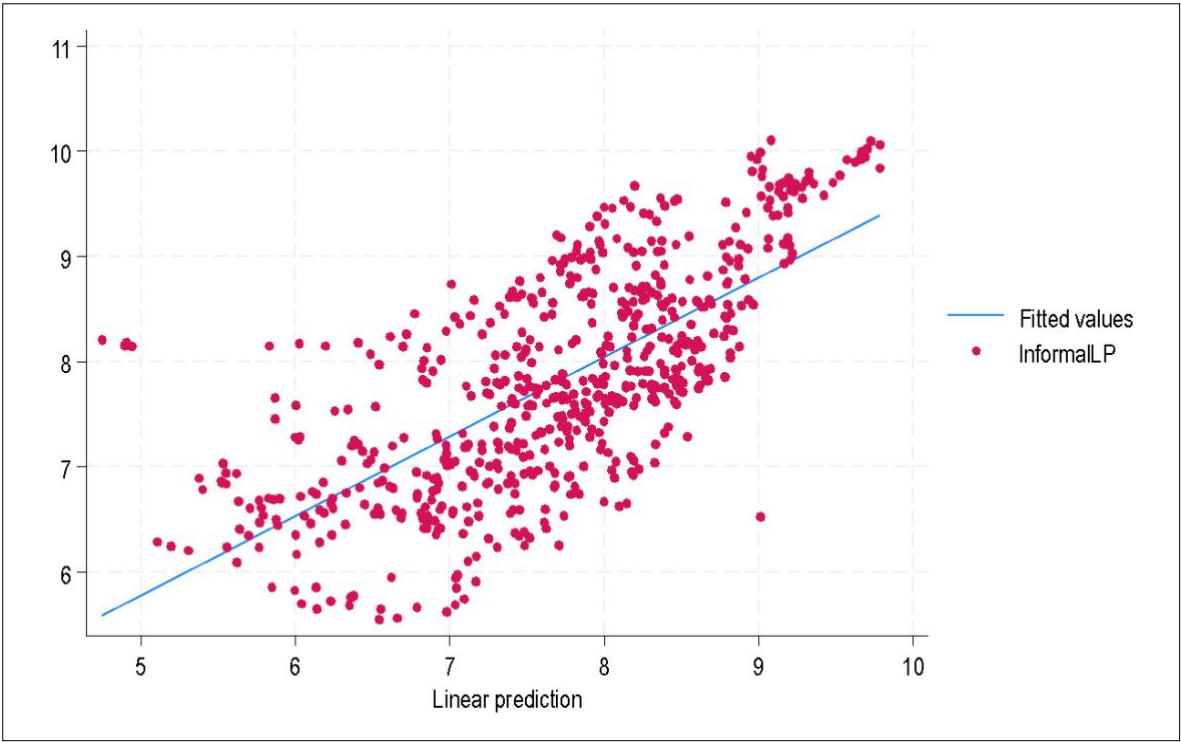
Root MSE	0.7506	F(4,217)	163.26	No. of Obs
R-squared	3.2609	Prob>F	0.0000	222
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Pre Primary Enrolment	-0.03645	0.0089	-4.06	0.000
Primary Enrolment	-0.05328	0.0099	-5.34	0.000
Secondary Enrolment	0.10171	0.0161	6.30	0.000
Tertiary Enrolment	0.46735	0.0471	9.91	0.000
Constant	3.15539	1.0156	3.11	0.002

Table 8.4.1 SSA Panel Data: OLS Regression Educational enrolment is a determinant of Labour Productivity

Although the results from the Ordinary Least Squares (OLS) regression in Table 9.4.1 seem acceptable, the theory suggests the data may have issues with simultaneity, that is the level of education at one stage is affected by the education levels at other stages due to simultaneous decision-making processes. Omitted variable bias is also a challenge as there may be factors that influence multiple stages of education that are not included in the model, such as socio-economic status, which could lead to correlations between the independent variables and the error term. Reverse Causality is also a cause for concern as educational outcomes at one level could influence educational decisions at another level.



Graph 8.4.2 Scatter plot of actual versus predicted values of Labour Productivity



Graph 8.4.1 Residual Plot versus Fitted Values for Regression Table 9.4.1

Root MSE	0.5112	F(4,1195)	968.96	No. of Obs
R-squared	0.7643	Prob>F	0.0000	1200
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Pre Primary Enrolment	0.0052	0.0006	7.67	0.000
Primary Enrolment	-0.0139	0.0012	-11.47	0.000
Secondary Enrolment	0.0226	0.0009	24.89	0.000
Tertiary Enrolment	0.0059	0.0008	6.87	0.000
Constant	1.6802	0.1271	13.82	0.000

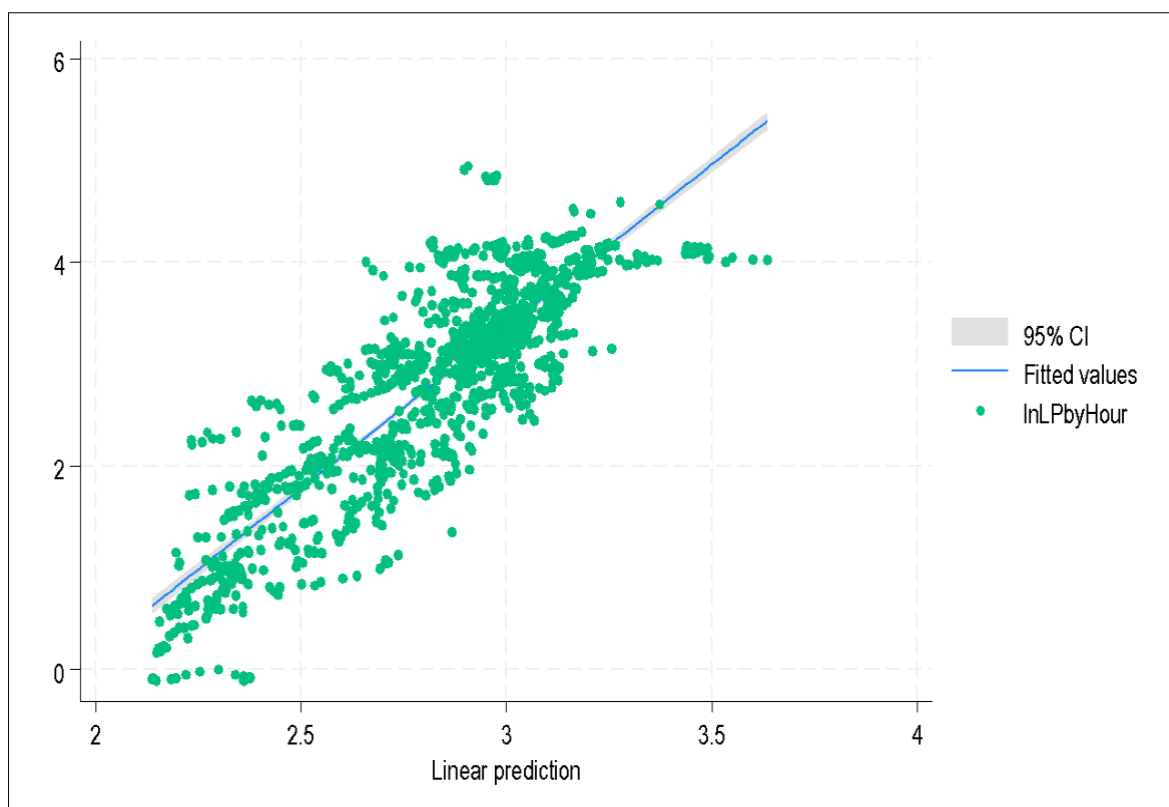
Table 8.4.2 World Panel Data: Educational enrolment is a determinant

Hypothesis Test:

H0: Education enrolment is not a determinant of labour productivity.

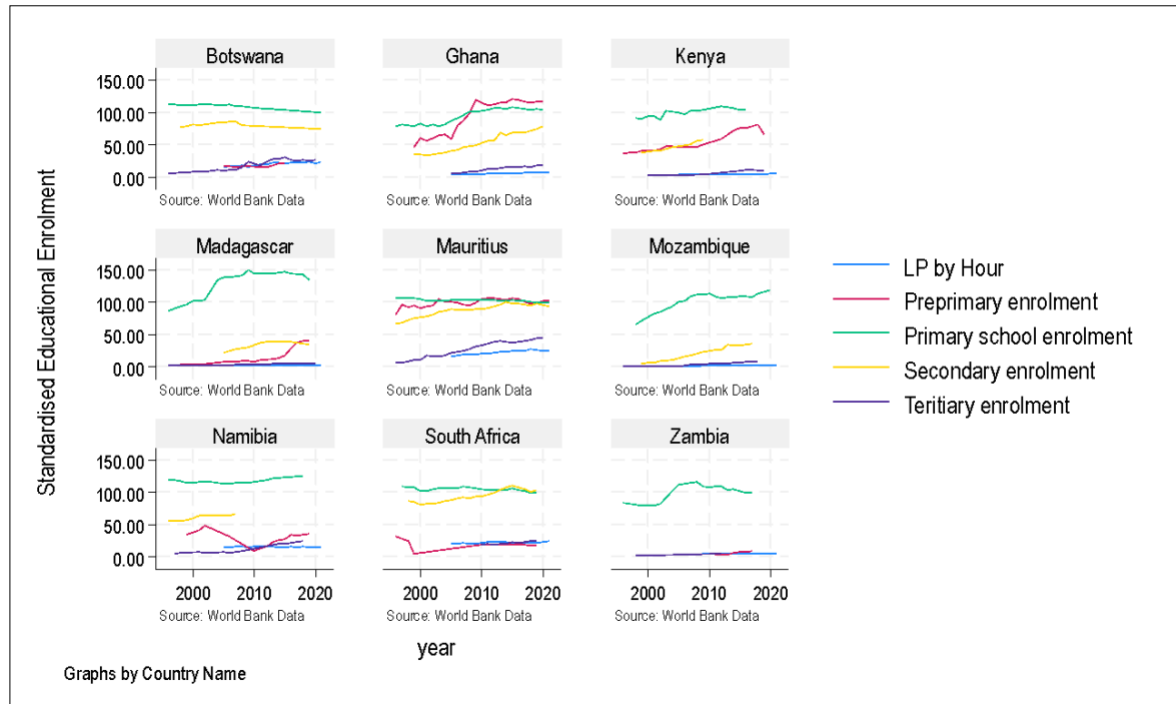
H1: Education enrolment is a determinant of labour productivity.

H0 is rejected at the 5% level, and education enrolment is shown to be a determinant of labour productivity. The fitted values line represents the relationship between the predicted labour productivity from the model, and the actual labour productivity. If the regression model were perfect, all points would lie on the line.



Graph 8.4.3 World Data: Scatter plot of actual versus predicted values of Labour Productivity Regression

This graph suggests that while the model captures some of the trends in the data, there is more complexity in the relationship between school enrolment and labour productivity that is not being accounted for in the current model. The model was run with standardised variables and the residual plot showed a relatively consistent spread of residuals across the range of fitted values, which suggests that the variance of the residuals is relatively constant, this is positive for the validity of the regression assumptions and this is sufficient for the purposes of this research.



Graph 8.4.4 Africa SKA Partner Countries: Standardised Educational Enrolment

It is clear that education at different levels significantly influences labour productivity, either directly or indirectly, by equipping individuals with the skills, knowledge, and adaptability needed in the workforce. This also contributes to economic development and social progress on a broader scale. The impact of pre-primary enrolment on labour productivity through the impact on tertiary enrolment in the SSA data set shown in the regression could be influenced by various factors and may not be a straightforward relationship. In some African countries, the quality of education in pre-primary and primary schools may be inadequate. Students may not receive a strong foundation in basic literacy, numeracy, and critical thinking skills (Mbiti & Mulligan, 2020). As a result, individuals may enter the workforce with limited skills and lower productivity. The curriculum and skills taught in schools may not align with the skills demanded by the labour market (Kingdon, Teal, 2010), and the lack of emphasis on practical skills and vocational training in early education

may not prepare students for employment (World Bank, 2018). If students are not adequately prepared for the types of jobs available, their productivity in the workforce may suffer.

In some regions, there are high dropout rates in primary education due to factors such as poverty, lack of access, and early marriage (Glick & Sahn, 2010). Those who do not complete primary education may face reduced employment opportunities and lower productivity prospects. Overcrowded classrooms and a lack of resources can hinder effective teaching and learning in primary schools (Glewwe et al., 2019), and this can result in lower educational outcomes and, subsequently, lower labour productivity among graduates. Malnutrition and health issues can affect children's physical and cognitive development, potentially leading to lower educational attainment and, later in life, lower labour productivity (Alderman et al., 2006). Poor infrastructure, including the lack of electricity, clean water, and sanitation facilities in schools, can create challenging learning environments, potentially impacting educational outcomes and, by extension, labour productivity. Gender disparities in education can lead to differential impacts on labour productivity. In some regions, girls may face greater barriers to education, limiting their future opportunities in the workforce (Filmer, Fox, 2014). Additionally, in many SSA countries, a significant portion of the labour force is employed in the informal sector, where educational qualifications may have less direct relevance (World Bank, 2019). This can result in lower returns on education and less impact on productivity (Teal, 2010). The structure of the economy and the availability of jobs in low-skill, labour-intensive sectors may mean that there is limited demand for highly educated workers. As a result, the productivity gains from primary education may be modest.

Indicator	Labour Productivity	Pre-primary Enrolment	Primary Enrolment	Secondary Enrolment	Tertiary Enrolment	Un-employment
Labour Productivity	1.0000					
Pre-primary Enrolment	0.4517	1.0000				
Primary Enrolment	-0.1122	0.1590	1.0000			
Secondary Enrolment	0.7460	0.6305	0.2215	1.0000		
Tertiary Enrolment	0.8204	0.6686	0.0384	0.8117	1.0000	
Unemployment	0.5724	0.0688	-0.1894	0.4614	0.2708	1.0000

Table 8.4.3 Correlation of Educational Enrolment at different levels and Labour Productivity

In Table 9.4.3 above one can see the correlations between the school enrolment data and labour productivity. The theory is clear that labour productivity plays a significant role in shaping the employment landscape. As productivity levels rise, firms can produce more output with the same amount of labour, leading to increased demand for workers. This can, in turn, lead to a reduction in unemployment rates (Loayza & Poplawski-Ribeiro, 2018). Conversely, low labour productivity can contribute to higher unemployment rates, as firms may be unable to absorb additional workers without compromising their competitiveness. Additionally, industries with low productivity levels are less likely to expand and generate employment opportunities. Therefore, policies aimed at enhancing labour productivity through investments in education, skills development, technology adoption, and infrastructure can be instrumental in addressing unemployment challenges in Africa (World Bank, 2021). The data supports that it is reasonable to suggest that labour productivity is an important input into economic growth and as such serves as a measure of the socio-economic impact of various factors and policies such as education. By improving the inputs into labour productivity, such as education, societies can unlock economic growth, create employment opportunities, reduce poverty, and enhance the overall well-being of individuals and communities.

8.5. Labour Productivity and Technology

The symbiotic relationship between technology and labour productivity has been a focal point of economic studies for decades. Technological advancements have been instrumental in shaping modern industries, revolutionising the nature of work, and propelling economic growth. Conversely, the demands of a dynamic labour force have spurred innovation and driven the development of increasingly sophisticated technologies. This research explores the dynamics between technology and labour productivity, their mutual influence, impacts, and potential policy implications.

One of the most discernible effects of technological integration into the workforce is the marked increase in labour productivity. Automation, a hallmark of contemporary technology, has streamlined production processes, rendering them more efficient and precise. Repetitive, labour-intensive tasks, hitherto the province of human workers, have been entrusted to automated systems, liberating skilled labourers to focus on higher-order tasks that demand creativity and complex problem-solving abilities (Bessen, 2019). Consequently, this reallocation of tasks has engendered a surge in overall productivity.

Moreover, technology has given rise to a paradigm shift in communication and collaboration. Advanced communication platforms, coupled with project management software, have removed

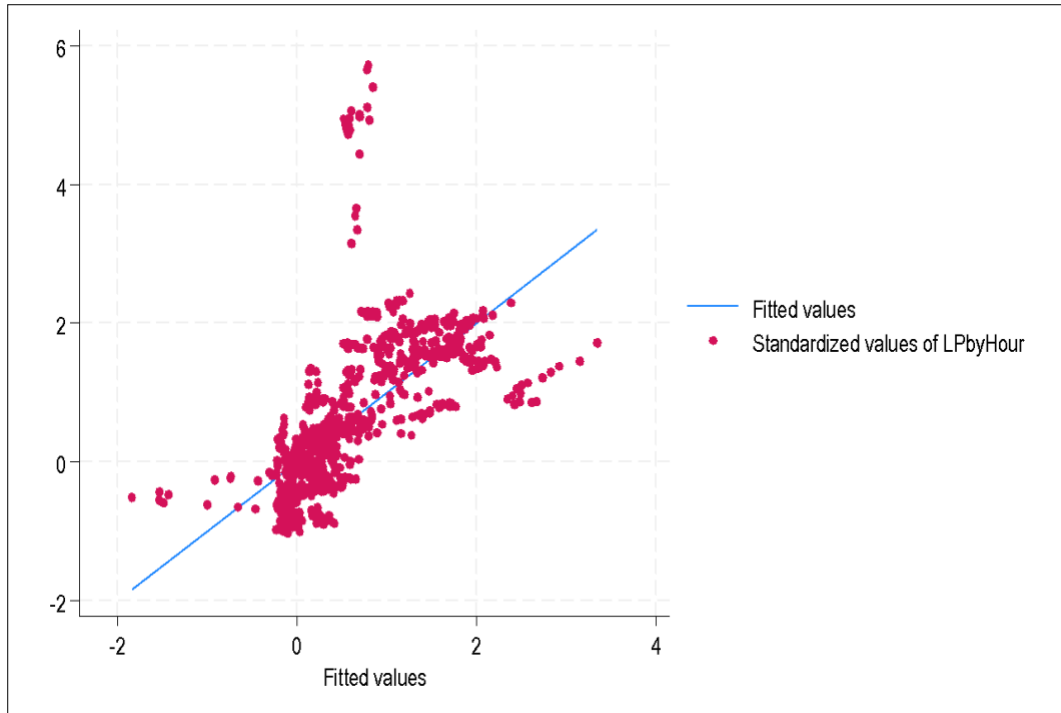
geographical barriers, enabling seamless interactions among dispersed teams. This unprecedented level of connectivity has not only expedited decision-making processes but has also fostered an environment of enhanced collective problem-solving and knowledge-sharing (Brynjolfsson, McAfee, 2014).

The ubiquity of information technology has provided the workforce with a reservoir of knowledge unparalleled in human history. Access to a wealth of information empowers workers with the ability to make informed decisions swiftly, amplifying their effectiveness in executing tasks and achieving organisational objectives (Brynjolfsson, McAfee, 2014). Furthermore, technology has facilitated a new era of customisation and personalisation. Through data analytics and machine learning algorithms, businesses can tailor products and services to meet individual customer preferences, fostering higher levels of customer satisfaction and brand loyalty (Davenport, Harris, 2007).

While the benefits of technological integration are evident, they are not without their challenges. One of the most pressing concerns is the potential displacement of jobs. Tasks that are ripe for automation, often involving routine and repetitive functions, may lead to workforce disruptions and necessitate reskilling efforts (Frey, Osborne, 2017). Additionally, the rapid pace of technological advancement underscores the imperative for continuous education and skills development. The emergence of novel technologies necessitates a nimble workforce capable of swiftly adapting to changing demands. The potential gap between the required skills and the existing capabilities poses a formidable challenge to realising the full potential of technological integration (Brynjolfsson, McAfee, 2014).

Root MSE	0.8275	F(3,921)	229.37	No. of Obs
R-squared	0.4276	Prob>F	0.0000	925
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Patent Applications by Residents	-0.458	0.046	-9.8	0.000
R&D Expenditure	0.606	0.025	24.11	0.000
Patent Receipts	0.357	0.596	6.00	0.000
Constant	0.425	0.027	15.29	0.000

Table 8.5.1 World Data: OLS Regression SST Investments and Labour Productivity (Standardised)



Graph 8.5.1 Scatter plot of actual versus predicted values Labour Productivity (Regression Table 9.5.2)

Root MSE	0.9361	F(3,52)	17.27	No. of Obs
R-squared	0.4990	Prob>F	0.0000	56
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Patent Applications by Resident	-0.198	0.186	-1.06	0.293
R&D Expenditure	0.768	0.228	3.36	0.001
Patent Receipts	0.344	0.254	1.35	0.182
Constant	0.231	0.138	1.67	0.100

Table 8.5.2 SSA Countries: OLS SST investment and Labour Productivity

Root MSE	0.7819	Wald chi2(1)	92.54	No. of Obs
R-squared	0.5958	Prob>F	0.0000	44
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
R&D Expenditure	3.519	0.365	9.62	0.000
Constant	0.486	0.256	1.90	0.058

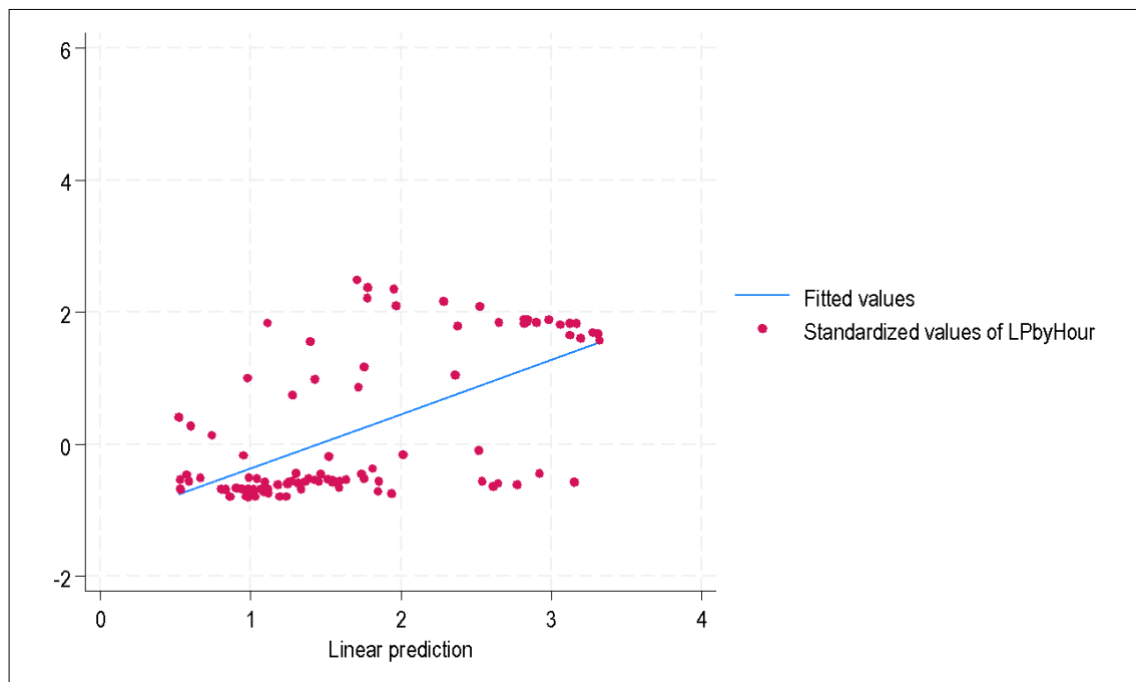
Table 8.5.3 SSA Countries: IV Regression GMM SST investment and Labour Productivity

Hypothesis Test:

H0: Technology development is not a determinant of Labour productivity.

H1: Technology development is a determinant of Labour productivity.

H0 is rejected at the 5% level, and technology development is a determinant of Labour productivity. The residual scatter plot in Graph 3.12 below, shows that a considerable number of countries in SSA have labour productivity figures that align closely with the model's predictions, as depicted by the clustering of data points around the fitted regression line. This suggests a satisfactory predictive accuracy of the model regarding labour productivity. However, the existence of outliers and the discernible pattern within the residuals raises the possibility of omitted variables that influence labour productivity beyond the scope of the model, which utilises R&D investment and patent receipts as proxy indicators for technological investment.



Graph 8.5.2 Scatter Plot of actual versus predicted values Labour Productivity (Regression Table 9.5.3)

Despite these limitations, the analysis generally supports the existence of a positive relationship between technological investments and labour productivity. The variability within the context of SSA data, where the expected positive impact of R&D expenditure on labour productivity is not consistently observed, can be explained by several factors. SSA countries may grapple with optimising resource allocation for R&D due to constraints in funding, infrastructure, and competing economic priorities, which could weaken the impact of R&D on productivity (Easterly, 2001). The capability of SSA countries to execute and integrate new innovations from R&D may be undermined by shortcomings in technical expertise, institutional robustness, and regulatory

frameworks, limiting the conversion of R&D activities into productivity improvements (Eifert et al., 2010). The insufficiency of critical infrastructure, including reliable power and internet services, can hinder the assimilation of technological advancements, thus neutralising the potential productivity benefits of R&D investments (World Bank, 2018). The advantageous effects of R&D investments on productivity can be compromised by macroeconomic instability characterised by high inflation and exchange rate fluctuations, which deter long-term R&D investments (Agenor et al., 2000). The limited access to quality education and training may result in a scarcity of skilled labour, thereby diminishing the returns on technological advancements in terms of productivity (Aghion et al., 2005). Governance weaknesses, corruption, and political instability can obstruct the effective employment of R&D investments for economic growth, potentially leading to less than optimal outcomes (Kaufmann et al., 2010). In light of these considerations, while the overall data suggests a positive correlation between technology investment and labour productivity, the complexities specific to SSA highlight the necessity for a comprehensive assessment of an array of socio-economic factors. Such an approach is essential to more accurately capture the intricate relationship between R&D investments and labour productivity across different economies.

In addressing the interplay between technology and labour productivity, policymakers ideally adopt a multifaceted approach. Balancing the imperatives of innovation with the protection of workers' rights is paramount to successful interventions, as well as implementing policies that incentivise investment into education and training programmes that will equip the workforce with the requisite skills to harness new technologies effectively (Bessen, 2019). Furthermore, safeguards against income inequality and job displacement must be instituted to ensure the equitable distribution of the benefits of technological progress (Frey, Osborne, 2017). The interrelationship between technology and labour productivity is a dynamic and evolving phenomenon, with implications for the future of work and economic growth. While technology augments productivity, it necessitates strategic responses to address the challenges and to maximise the benefits. Through judicious policy-making and a commitment to lifelong learning, societies can harness the potential of technology to foster sustainable economic development and improve the well-being of their workforce.

8.6. Labour Productivity and Employment

Differences in labour productivity across Africa is attributed to variations in economic structure, investment levels, access to technology, and quality of infrastructure. Labour productivity levels also differ significantly across sectors within SSA economies. Industries such as mining,

manufacturing, and services, particularly finance and telecommunications, tend to exhibit higher labour productivity compared to agriculture and informal sectors. This is mainly due to differences in technology adoption, capital intensity, and skills requirements. Limited access to technology and low levels of innovation are often cited as factors contributing to lower labour productivity in SSA economies. The adoption and effective utilisation of advanced technologies, such as digital technologies, can have a positive impact on labour productivity by improving efficiency, reducing costs, and enhancing market access. Inadequate infrastructure, including transport, energy, and telecommunications, can hinder labour productivity growth in these economies. Insufficient infrastructure leads to higher transaction costs, lower connectivity, and limited access to markets, which can impede productivity gains. As discussed, education and skills play a critical role in improving labour productivity. Enhancing the quality and importantly the relevance of education and training systems is essential for developing a skilled workforce capable of driving productivity growth.

The relationship between labour productivity and the employment types was shown to be non-linear in the linear regressions analysis, as such the analysis conducted was a log-log regression. The general form of the equation for the log-log regression model is:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \cdot \ln(X_{it}) + \epsilon_{it} \quad \text{Equation 8.6.1}$$

$\ln(Y_{it})$ is the natural logarithm of the dependent variable

β_0 is the intercept of the regression after the logarithmic transformation

β_1 is the coefficient of the independent variable after the logarithmic transformation, representing the elasticity of the dependent variable with respect to the independent variable

$\ln(X_{it})$ is the natural logarithm of the independent variable

ϵ_{it} is the error term.

Root MSE	0.3407	F(3,5264)	308.06	No. of Obs
R-squared	0.5256	Prob>F	0.0000	1943.87
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Employment Agriculture	-0,856	0.028	-30.36	0.000
Employment Industry	0.252	0.027	9.12	0.000
Employment Services	1.884	0.055	33.95	0.000
Constant	3.607	0.262	13.75	0.160

Table 8.6.1 World Labour Productivity, employment in services, industry and employment in agriculture

Root MSE	0.5677	F(3,626)	320.48	No. of Obs
R-squared	0.6057	Prob>F	0.0000	630
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Employment Agriculture	-0.702	0.131	-5.32	0.000
Employment Industry	-0.508	0.083	-6.07	0.000
Employment Services	1.671	0.127	13.08	0.000
Constant	5.950	0.836	7.11	0.000

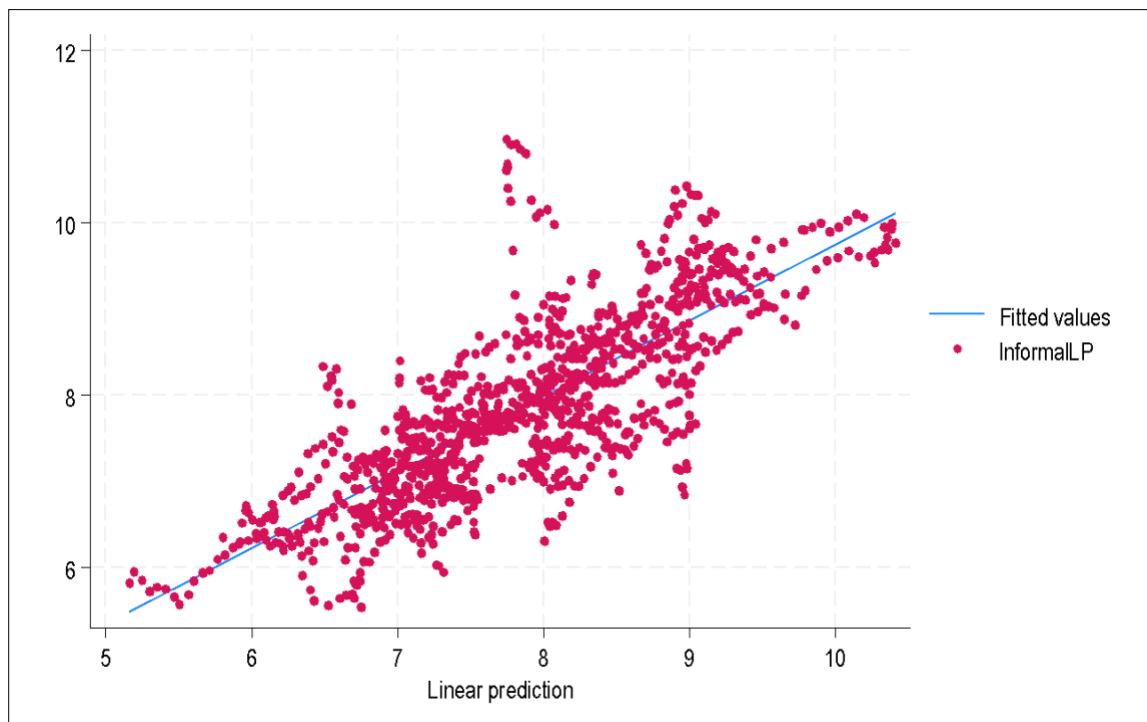
Table 8.6.2 Fixed Effects Regression SSA Labour Productivity and Employment Sectors

Hypothesis test

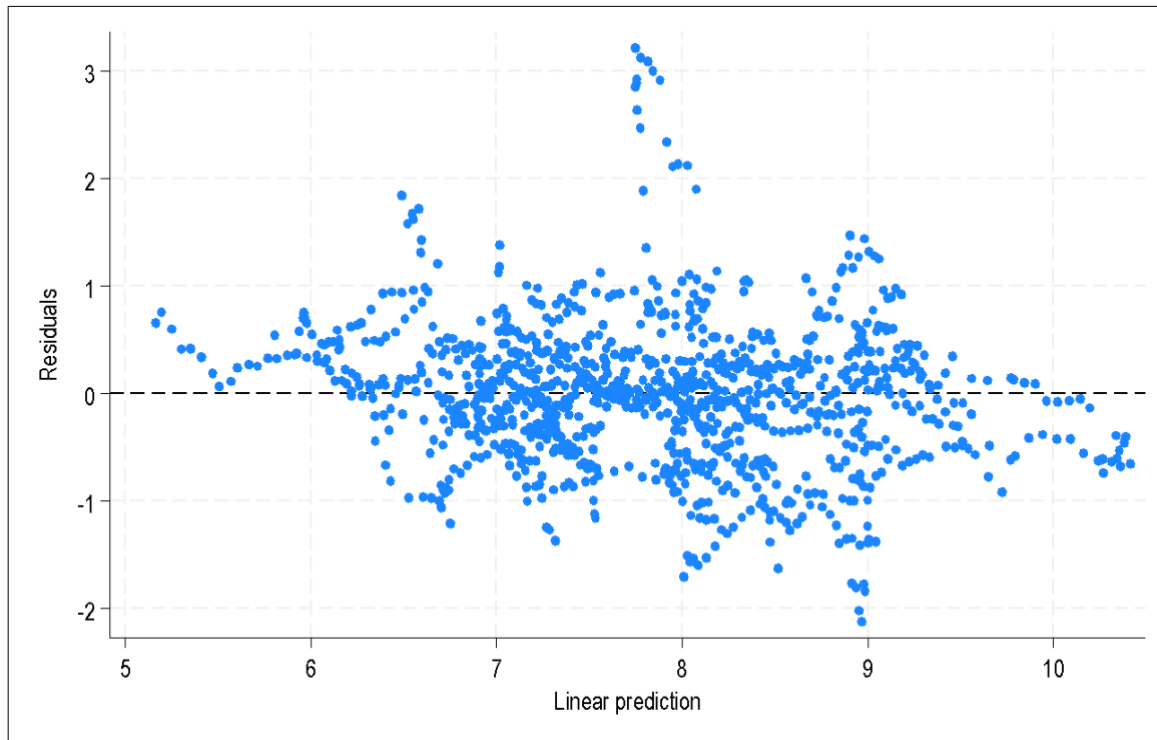
H0: Employment market structure is not a determinant of Labour productivity.

H1: Employment market structure is a determinant of Labour productivity.

H0 is rejected at the 5% level, and the Employment market structure is a determinant of Labour productivity. There are clear patterns in the residuals in Graph 9.6.2 below, particularly the looping or curved patterns and this suggests non-linear relationships or interaction effects that might not be captured by the model. The looping patterns can indicate that a higher-order term might be beneficial in explaining the variance in the response variable.



Graph 8.6.1 Scatter plot of actual versus predicted values Labour Productivity (Regression Table 9.6.2)



Graph 8.6.2 Residual Plot Labour Productivity (Regression Table 9.6.2)

In using higher order terms in the regression, the model showed definite improvement and it is clear that external or latent factors not included in the current model could also be contributing to the patterns observed. For the purposes of this research, the impact of types of employment on labour productivity is sufficiently demonstrated and further data transformations will not be explored. It is important to note that the above observations are based on general trends in labour productivity within SSA economies. The data is subject to non-systematic error and significant outliers, non-systematic error can introduce variability into the data that is not consistent across observations. This inconsistency can make it difficult to discern true patterns and result in less precise estimates of labour productivity. It is worth noting that the random error can also increase the chance of Type I (false positive) and Type II (false negative) errors. The other challenge is that there is collinearity due to the correlation between the different employment types. The data in fact shows that labour productivity is positively impacted by employment in industry but negatively impacted by employment in services and agriculture. That said however, investment into capital, technological progress, and human capital development have been shown to be positive determinants of labour productivity (OECD, 2015), both the public and private sectors can increase labour productivity through direct investment and incentives for increases in technology, human capital and physical capital. In reviewing employment in the industrial sector, within SSA

economies, this has grown only at an equivalent rate to that of growth of the labour force (Fox et al., 2017), which represents good employment growth, but not transforming growth.

The employment shift out of agriculture has predominantly gone to services. The transition from agriculture to industry is a non-trivial and gradual process that varies from one country to another. While some SSA countries have made progress in industrialisation, others continue to experience a shift toward the service sector due to the factors mentioned above. Policymakers often face the challenge of promoting balanced economic development and industrialisation while recognising the immediate opportunities presented by the service sector and the informal economy. SSA countries often have economies that are heavily reliant on agriculture. Since the transition from agriculture to industry typically occurs as countries develop and industrialisation takes place, many SSA countries have not yet reached the stage of industrialisation seen in more advanced economies (Soludo, 1998). Limited industrialisation in many SSA countries poses various challenges, including infrastructure deficiencies, lack of access to finance, and regulatory barriers. This limited industrialisation restricts the availability of jobs in the industrial sector. The service sector in SSA, including retail, healthcare, education, and hospitality, often presents more immediate opportunities for employment compared to the industrial sector. Rapid urbanisation and a growing middle class create demand for services, which can absorb labour from agriculture. While agriculture may employ a significant portion of the population in SSA economies, it often yields low productivity due to factors such as outdated farming practices, limited access to modern technology, and land fragmentation. As a result, labour can shift away from agriculture without necessarily leading to increased industrialisation. Many individuals transitioning from agriculture enter the informal economy, which includes small-scale businesses, street vending, and other non-formal employment. This informal sector can absorb labour and contribute to the growth of services. Educational and skills mismatch occurs when labour force skills may not align with the needs of the industrial sector, which often requires more specialised technical skills (Bangasser, 2000). As a result, individuals may find it easier to enter the service sector, which may have lower skill requirements. In addition, a significant portion of the labour force in SSA engages in entrepreneurship and self-employment, which can be service-oriented, and starting a small business or offering services can be a way for individuals to create employment opportunities. As mentioned earlier, resource-dependent economies in SSA heavily rely on natural resources for economic growth and as such the service sector may grow faster than the industrial sector. Government policies and development strategies may emphasise the growth of the service sector as a means of economic diversification and job creation. This shift generates some employment transformation, but not as much as might have been hoped given the growth rates. The modest performance of the industry in absorbing employment is, however, consistent with the view that

the influx of capital to finance industrial activities remains weak among sub-Saharan African economies. The highest-productivity sector needs the most capital and technology to expand (Fox et al., 2017). In other research, Majid (2010) presented the good or fair employment indicator which is basically the extent to which good employment, as opposed to any employment, is generated in the process of economic growth in a developing economy. Good employment refers to a minimum acceptable level of returns to workers from their employment. The indicator showed that there has been an increase over time in the absolute numbers of employed persons, with acceptable incomes, as developing economies have grown. However, such increases, when seen in terms of a percentage of total employment, do not systematically vary with per capita economic growth in the developing countries. In other words, Majid (2010) notes that utilising the typical measures can achieve misleading results and as such there is the need to rework and reconstruct the collected data to construct economy-wide proxies that are consistent with a more appropriate characterisation of the structure of typical developing economies.

The literature review identified the view to transform economic structures away from areas of low productivity of labour such as subsistence agriculture, towards industrial activity, with a higher productivity of labour. The basic assumption of the Lewis model (Lewis, 1954) is that there exists surplus labour in the subsistence sectors whose marginal productivity is zero, or positive but less than the institutional wage. Lewis proposed that the driver of capital accumulation was a movement of labour, the factor of production abundant in developing countries, from the 'traditional' sector of lower productivity and lower wage, to the 'industrial' sector of higher productivity. Due to the existence of surplus labour in the traditional sector, wages are set just above subsistence across the whole economy. When the surplus labour disappears an integrated labour market and economy emerge, and wages will then start to rise.

Economic dualism, under a broad definition, refers to the coexistence of two or more economic systems (Philips, 1965) within a country and describes, according to Cazes and Verick (2013), the economic structure of developing countries – namely the structure and distribution of their economic geography between rural and urban areas, and the weaker integration of labour markets in comparison to more developed countries. Another distinction is the relative abundance of labour supply and the scarcity of capital in many developing SSA countries. The combination of these factors results in inadequate investment and a lack of capital accumulation, with greater labour supply pressures leading to a shortage of productive employment (ILO, 2017).

9. The Labour Productivity Gap

The labour productivity gap refers to the difference or disparity in labour productivity levels between different countries, industries, or sectors. It is a measure that highlights variations in the efficiency and output per unit of labour input across different entities or regions.

The labour productivity gap can manifest in several ways. The international labour productivity gap refers to the differences in labour productivity levels between countries with higher labour productivity and higher levels of economic output per worker, as compared to countries with lower labour productivity. The international labour productivity gap can be attributed to various factors, including differences in technology, capital investment, human capital, infrastructure, and institutional factors.

Research has highlighted significant labour productivity gaps between North African countries (e.g., Tunisia, Morocco, Egypt) and Sub-Saharan African countries. North African countries tend to have higher labour productivity levels, partly due to their closer ties to European markets and more advanced infrastructure. Labour productivity gaps can be substantial between urban and rural areas within African countries. Urban areas often benefit from better infrastructure, access to education, and job opportunities, leading to higher labour productivity compared to rural regions. Landlocked African countries often face challenges related to transportation and trade, which can result in labour productivity gaps when compared to coastal countries with easier access to international markets.

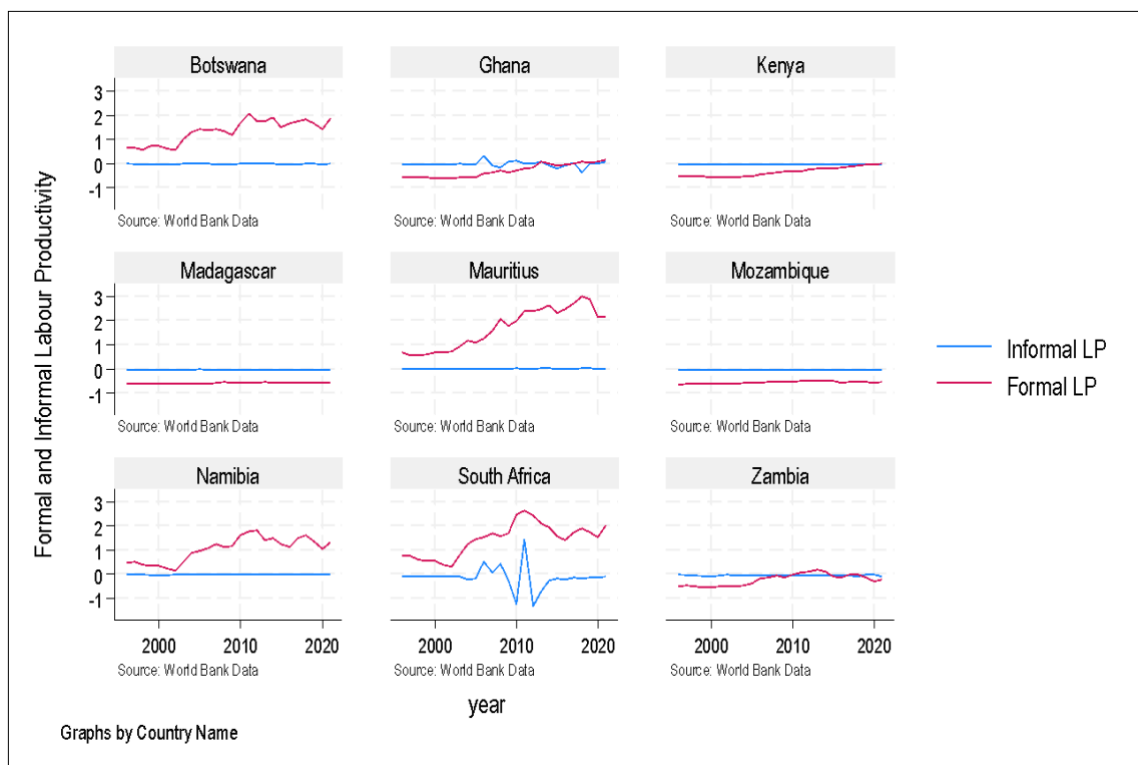
The sectoral labour productivity gap refers to different sectors within an economy that can exhibit varying levels of labour productivity. Some sectors may be more technologically advanced, capital-intensive, or benefit from economies of scale, leading to higher labour productivity compared to other sectors. The sectoral labour productivity gap can arise due to differences in technology adoption, resource allocation, and efficiency levels across industries. Labour productivity gaps also exist between the formal and informal sectors within SSA economies. The informal sector, which often lacks access to capital and technology, tends to have lower labour productivity compared to the formal sector.

The firm-level labour productivity gap refers to firms within the same sector, the individual firms can exhibit disparities in labour productivity. Some firms may be more productive due to factors such as managerial effectiveness, technological capabilities, employee skills, and operational efficiency, while others may lag behind. The firm-level labour productivity gap can reflect differences in management practices, investment decisions, innovation capabilities, and workforce

skills. Labour productivity gaps can be observed between skilled and unskilled labour within African countries. Skilled workers, with access to education and training, tend to have higher productivity levels compared to unskilled workers.

Identifying and understanding the labour productivity gap is crucial for policymakers as it provides insights into areas where improvements can be made to enhance productivity levels. Addressing the labour productivity gap may involve implementing policies that promote technology adoption, investment in human capital, infrastructure development, fostering innovation, improving managerial practices, and creating a conducive business environment. Closing the labour productivity gap can lead to higher economic growth, increased competitiveness, and improved living standards.

An additional labour productivity gap that is essential to this research is the difference between formal and informal labour productivity. The proposed indicator by this study measures the difference between formal and informal labour productivity relative to formal labour productivity. Since in many developing SSA countries, the informal sector constitutes a large portion of the economy, understanding the formal-informal labour productivity gap can highlight the potential for economic growth if informal activities were formalised (La Porta, & Shleifer, 2014). This indicator can inform policy by identifying the magnitude of productivity differences, and these differences could be addressed through education, training, or investment in infrastructure to increase efficiency in the informal sector (ILO, 2013). It provides insight into where to allocate resources more effectively. If the formal-informal labour productivity gap is large, it might suggest that the formal sector is absorbing too much of the investment relative to its size or that the informal sector is under-supported (Perry et al., 2007). The measure could also be useful for tracking progress over time as economies transition from informal to formal, which is a common path of development. A decreasing gap might indicate successful integration policies (Gollin, 2002). The proposed formal-informal labour productivity gap reflects labour market dynamics, showing how labour is moving between sectors and whether there is an efficient allocation of labour across the economy (Fields, 2005). The productivity difference is often linked to income inequality. A high gap can indicate significant disparities in income, which might be a focal point for social policy (Agenor & Montiel, 2008). During economic downturns, informal sectors can act as a buffer. Understanding productivity levels can inform on resilience and sustainability of livelihoods in the face of shocks (Maloney, 2004).



Graph 9.1 Africa SKA Partner Countries: Formal and Informal Labour Productivity

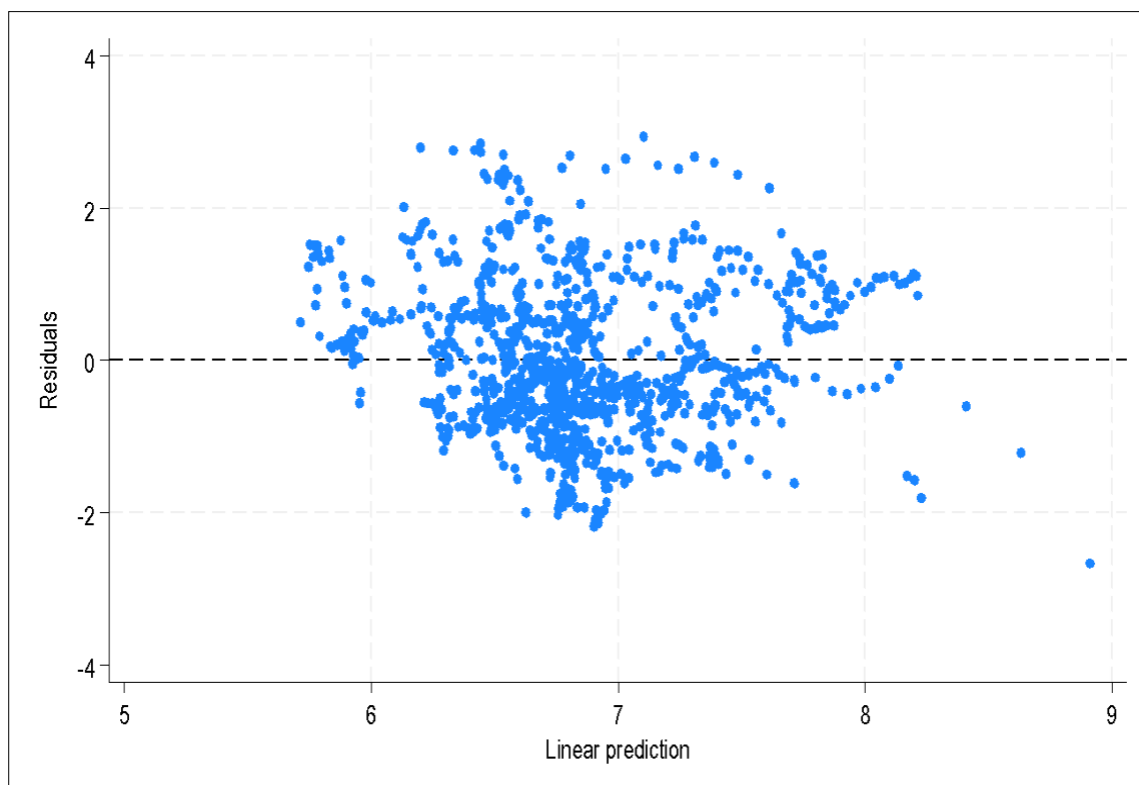
9.1. The Effects of the Informal Sector

Informal economic sectors in SSA economies refer to the economic activities that operate outside the formal regulatory framework, often characterised by limited government oversight, lack of formal registration, and informal employment arrangements. These sectors typically include small-scale businesses, self-employment, and various informal unregulated economic activities. The informal sector also encompasses economic activities that are unprotected by the government, and lack legal recognition, and social protection. This sector, as a substantial component of many SSA economies, accounts for a significant share of employment and economic activity (Bouis, 2020). It encompasses a wide range of activities, including street vending, small-scale agriculture, artisanal production, domestic work, and informal trade and is prevalent in a wide range of industries, including agriculture, trade, services, construction, and manufacturing. These sectors are characterised by low barriers to entry, flexibility, and the ability to operate with minimal capital and infrastructure since entrepreneurs in the informal sector often face challenges related to formal access to finance, business support services, and market linkages.

The informal sector is often an important source of employment, particularly in urban areas with high levels of unemployment and underemployment, as it offers opportunities for individuals who may lack formal education or face barriers to entering the formal labour market. The informal

sector is thus associated with informal employment arrangements, including self-employment and casual labour. Many workers in the informal sector lack formal contracts and often face lower wages, limited job security, and challenging working conditions. Nevertheless the informal sector provides income-generating opportunities for individuals and households, offering a means of subsistence for those who may not have access to formal wage employment and thus contributes to poverty reduction.

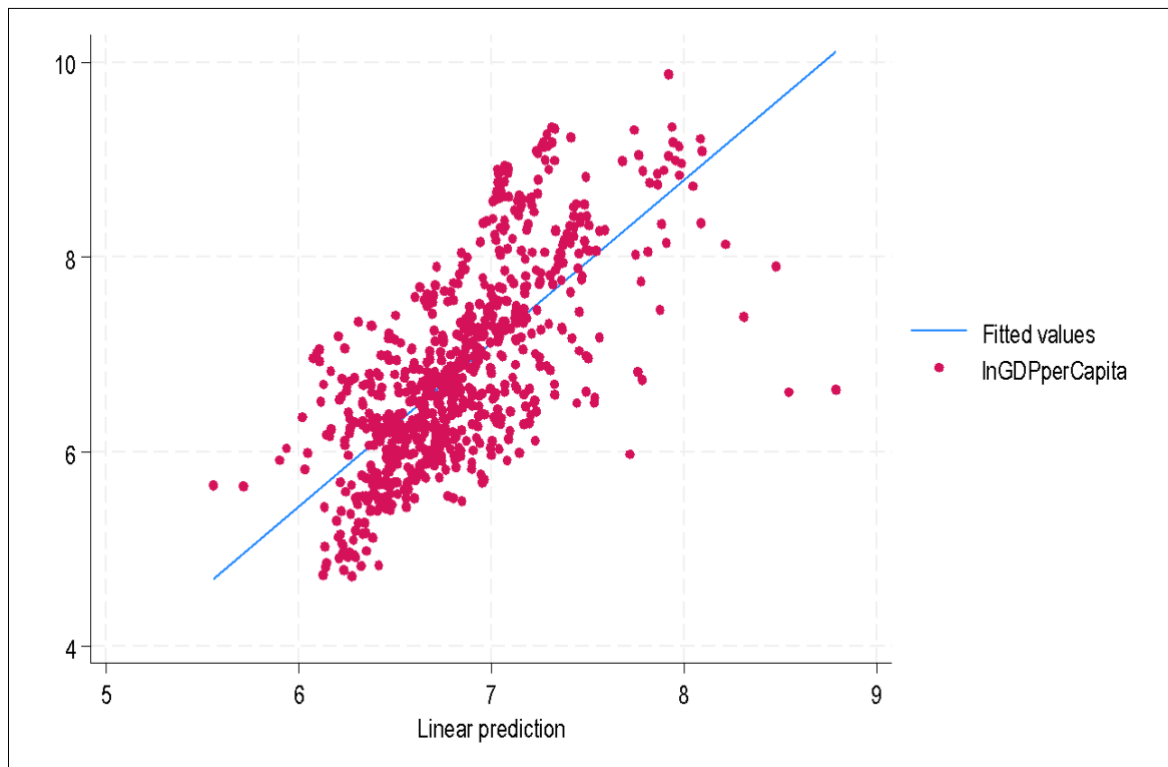
Informal trade, including cross-border trade, is a prominent feature of the informal sector in Africa. Informal traders engage in the exchange of goods and services outside formal channels, often driven by factors such as proximity to borders, market dynamics, and trade restrictions. Informal cross-border trade can also contribute to regional integration and economic linkages. Informal economic activities often rely on personal relationships, social networks, and trust-based arrangements, this can include family-based businesses, community cooperatives, and informal credit systems. Informal networks play a crucial role in accessing resources, information, and market opportunities.



Graph 9.1.1 SSA Countries: Residual Plot Informal Output versus GDP per Capita

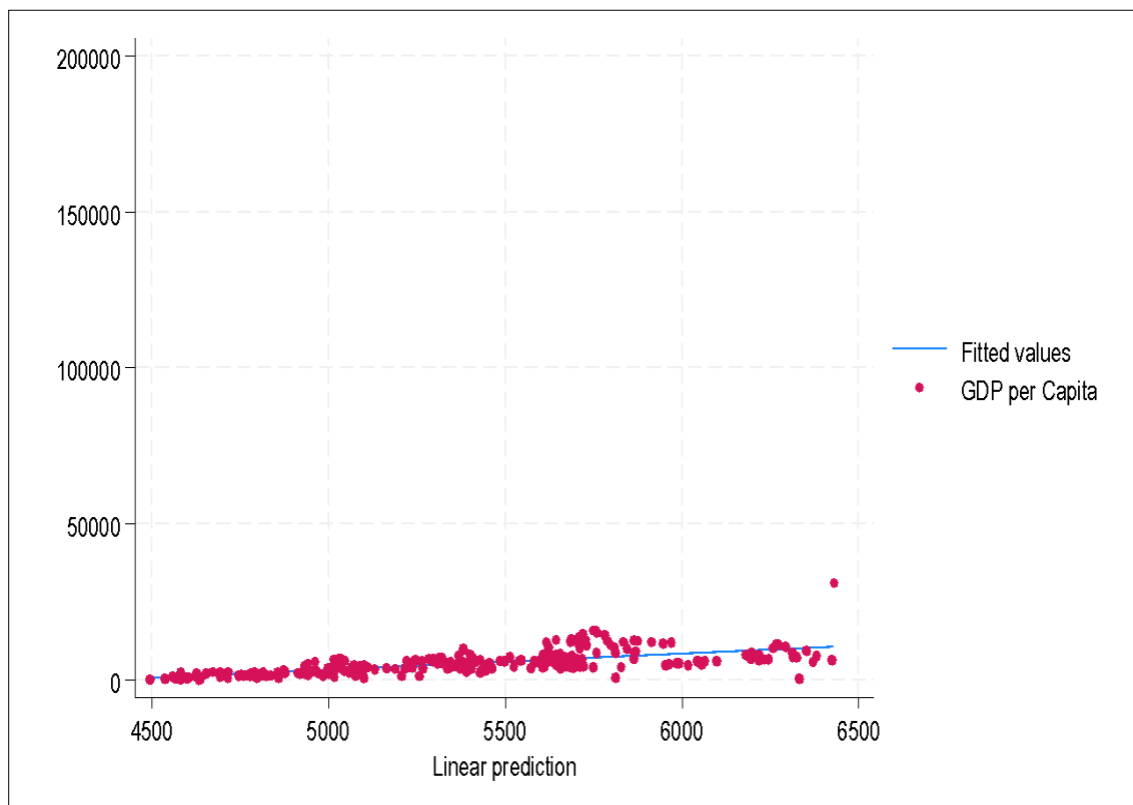
This economic sector operates outside the formal regulatory framework, and this can be attributed to challenges in accessing formal markets, burdensome regulations, and limited enforcement capacity by the government. Governments and policymakers in Africa are increasingly recognising the importance of the informal sector and working towards creating an enabling environment that

supports the formalisation, productivity, and inclusiveness of informal economic activities (Allard, 2017).



Graph 9.1.2 SSA Countries: Regression Informal LP and GDP per Capita, actual versus predicted values

Graph 10.1.2 above, shows the relationship between GDP per capita on the y-axis and the size of the informal employment workforce on the x-axis, as a percentage of the total workforce. The fact that the confidence interval gets wider as GDP per capita increases suggests more variability in the informal workforce size at higher GDP per capita levels, or less certainty in the model's predictions at these levels. The steepness of the slope indicates the strength of the relationship. A steeper slope would imply a stronger relationship between GDP per capita and the informal employment workforce size. The slope here seems moderately steep, suggesting a reasonably strong negative correlation. The data points are more clustered at the lower end of GDP per capita, indicating that among countries or regions with lower GDP per capita, there's a more consistent association with a higher informal workforce size. As GDP per capita increases, the data points spread out, indicating more variability in the size of the informal workforce. There are a few points that stray from the main trend, especially at the lower end of GDP per capita. These could represent countries or regions where other factors may influence the size of the informal employment workforce, such as cultural factors, economic policies, or labour market conditions that are not captured by GDP per capita alone.



Graph 9.1.3 World Data: Scatterplot of GDP per capita and the size of the informal employment workforce

From a policy perspective, this plot may suggest that economic growth and increases in GDP per capita are associated with a shift from informal to formal employment. However, causation cannot be inferred from this plot alone.

The informal sector poses several challenges to economies, both at the individual and macroeconomic levels. Activities often escape formal taxation systems, leading to a loss of potential tax revenue for governments, which reduces the fiscal capacity of governments to provide public goods and services, invest in infrastructure, and address socio-economic needs. Workers in the informal sector generally lack access to social protection schemes, such as health insurance, unemployment benefits, and retirement pensions. This leaves them vulnerable to income shocks, poverty, and inadequate access to essential services. The absence of formal training and technological advancements hinders productivity growth and limits the ability to compete in domestic and international markets, and this can hinder overall economic development and competitiveness. Informal sector workers are more susceptible to exploitation and violations of labour rights, due to limited oversight and regulation of employment practices. The presence of a large informal sector can also create unfair competition for formal businesses, since informal businesses, operating with lower overhead costs and regulatory requirements, can undercut formal businesses in terms of prices and wages and create an uneven playing field. The informal sector's

informal nature makes it difficult to accurately capture its size, contributions, and dynamics. This poses challenges for policymakers in formulating effective policies, targeting interventions, and monitoring economic trends accurately. Governments and policymakers can take measures such as promoting formalisation, improving access to finance, providing targeted support and training programmes, strengthening labour regulations, and implementing social protection schemes to enhance the productivity, competitiveness, and inclusiveness of the informal sector. Balancing the need for regulation and formalisation with the unique characteristics and dynamics of the informal sector is crucial to address these challenges effectively.

The structuralist "informalisation" approach refers to a concept that addresses the role and growth of the informal sector within an economy, particularly in the context of developing countries. This approach is often associated with the structuralist school of thought, which suggests that underdevelopment is due to the internal characteristics of a country's economy and its relationship to more developed economies (Meagher, 1995). The informalisation approach suggests several points; the economy is viewed as dualistic, comprising both formal and informal sectors. The formal sector typically includes large, organised industries or services, while the informal sector is made up of small, unorganised, and often unregistered economic activities. According to structuralists, the growth of the informal sector is not merely a result of personal choice but is driven by structural factors such as economic disparities, labour surplus and capital accumulation. The approach suggests that informalisation occurs as a response to constraints in the formal sector, including rigid labour laws, heavy taxation, and bureaucratic barriers that hinder the establishment and growth of small and micro enterprises. Structuralists argue that the informal sector plays a critical role in economic development, it acts as a buffer during economic downturns, provides employment, and supports the formal economy through various linkages. The informal sector should not be dismissed or stigmatised, but instead, it should be integrated into economic policy and development strategies, with measures that recognise its contributions and address its challenges. Structuralists often advocate for state intervention in managing the relationship between the formal and informal sectors, through policies that might encourage the transition of informal businesses to the formal sector or through social protection programmes. Addressing the challenges posed by the informal sector requires a comprehensive and context-specific approach and is beyond the scope of this research but it is an essential element to understanding labour productivity within SSA economies. The informal sector has implications for the overall impact of labour productivity, but due to its unique characteristics and measurement challenges, it is challenging to analyse quantitatively. Interpretation of the relationships between various variables and inference of potential causal directions based on the use of the instrumental variables (IV) and

generalised method of moments (GMM) estimation technique, yields the results in Graph 10.1.4 below.

Root MSE	0.1541	F(2,25)	203.44	No. of Obs
R-squared	0.6161	Prob>F	0.0000	60
Variable	Coefficient	Std Error	t	P>|t|
Labour Productivity	1			
Informal Workforce	-0.1072	0.0005	-20.16	0.000
Informal Output	-0.0102	0.0271	-3.95	0.001
Constant	12.7999	0.9110	14.05	0.000

Table 9.1.1 SSA Countries: Fixed Effects Regression Labour Productivity and the Informal Sector

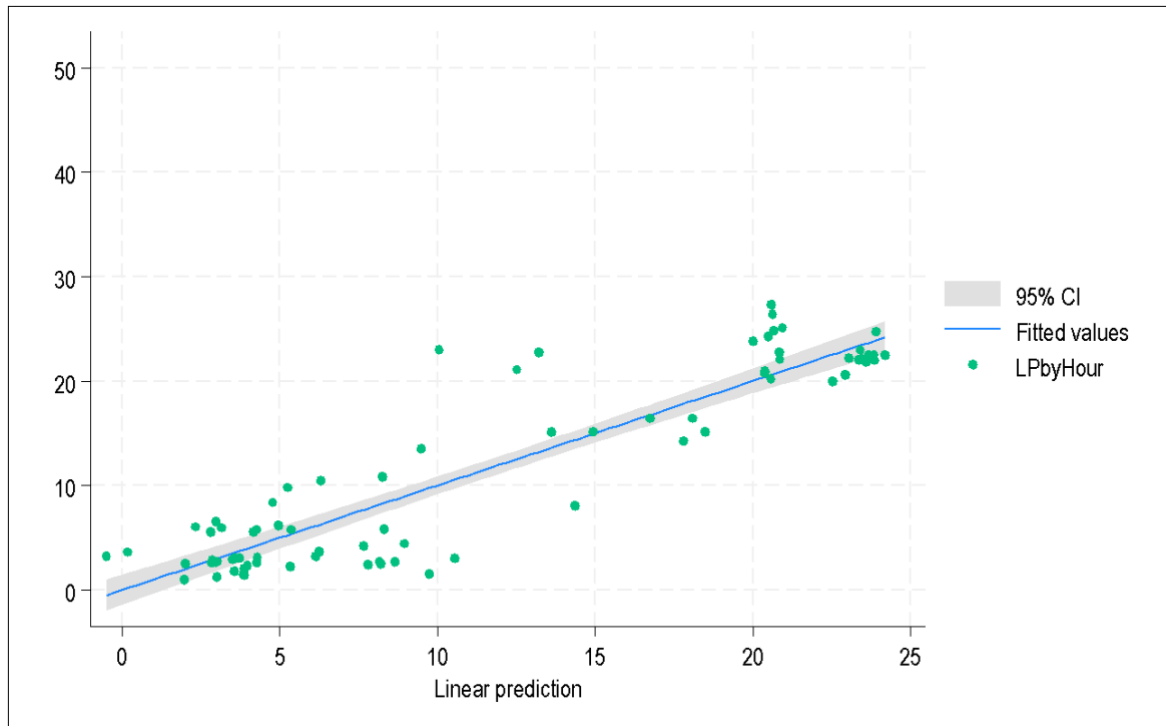
Hypothesis Test:

H0: Informal sector size is not a determinant of Labour productivity.

H1: Informal sector size structure is a determinant of Labour productivity.

H0 is rejected at the 5% level, and the informal sector size is a determinant of labour productivity. The positive slope of the regression line indicates that as the combined effect of informal output and informal labour increases, the labour productivity per hour also tends to increase. This implies a positive association between the predictors and labour productivity. Scatter around the fitted line shows variability in labour productivity that is not explained by the model. This is expected due to other factors affecting labour productivity that are not included as independent variables in the model.

As noted, obtaining accurate data on informal sector activities is challenging, as many informal businesses and workers operate outside formal registration systems, and as a result, data on the informal sector employment, hours worked, and output is incomplete or unavailable. This makes it difficult to accurately calculate labour productivity for the entire economy or specific sectors. When estimating aggregate labour productivity, the inclusion of informal sector workers with lower productivity levels can impact overall productivity calculations. The size and composition of the informal sector can vary across sectors within an economy, this means that sectors with a larger share of informal activities may exhibit lower labour productivity levels compared to sectors dominated by formal businesses (Amin et al., 2019). Failing to account for the sectoral composition of the informal sector when calculating aggregate labour productivity can lead to distorted results (Alvarez, 2019).



Graph 9.1.4 Actual versus Predicted Plot of Labour Productivity with the

Root MSE	0.1157	F(3,21)	11.04	No. of Obs
R-squared	0.5741	Prob>F	0.0001	54
Variable	Coefficient	Std Error	t	P>|t|
GDP per Capita	1			
Labour Productivity	1.532	0.3032	5.05	0.000
Informal Workforce	-0.007	0.0016	4.26	0.000
Informal Output	-0.024	0.1589	-1.51	0.145
Constant	5.900	0.8309	7.10	0.000

Table 9.1.2 SSA Countries: Fixed Effects Regression GDP per Capita, LP and the Informal Sector

Hypothesis Test:

H0: Informal sector size is not a determinant of GDP per Capita.

H1: Informal sector size structure is a determinant of GDP per Capita.

H0 is rejected at the 5% level, and the informal sector size is a determinant of GDP per Capita. For an increase in labour productivity, GDP per capita is expected to increase. The model has a high R-squared, indicating that labour productivity explains a substantial portion of the variation in GDP per capita, as shown earlier. The coefficients are statistically significant at the 5% level

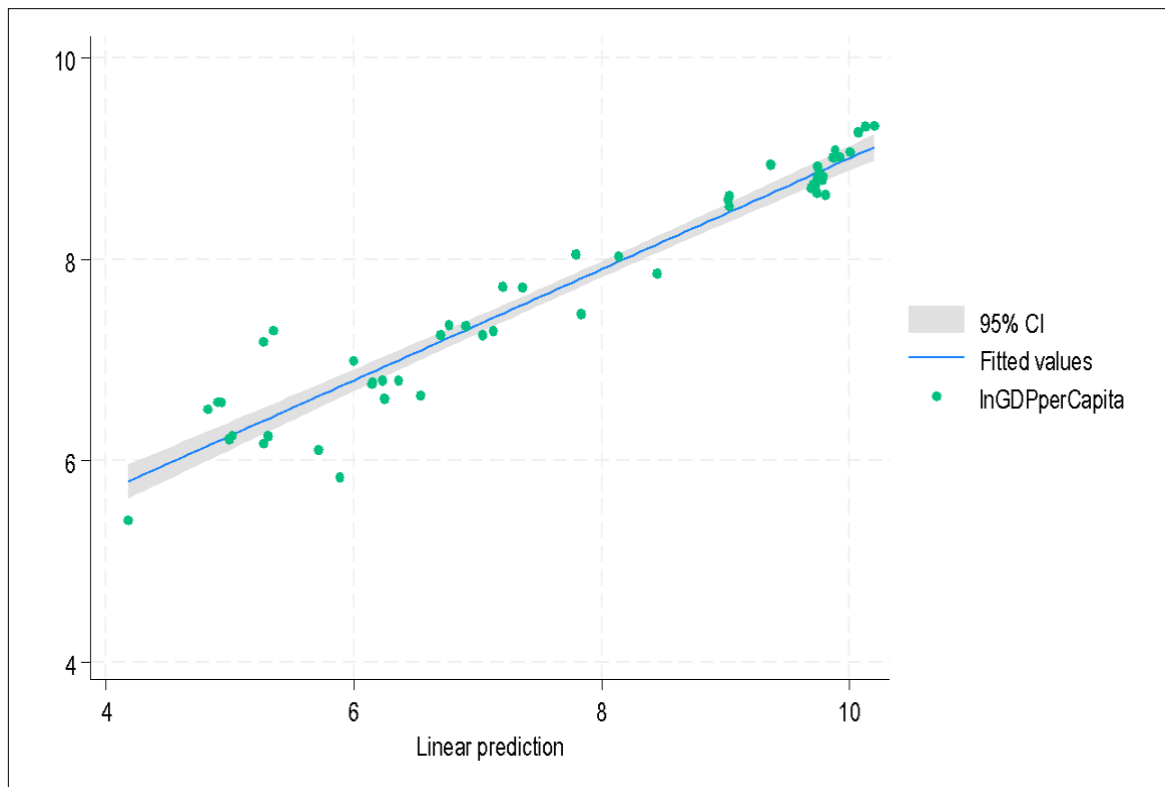
except for informal output, which is not statistically significant. The informal sector size has a small negative impact on GDP per Capita.

An increase in informal labour is also associated with a decrease in labour productivity. An increase in the share of informal output in GDP is associated with a decrease in labour productivity. Similar to the relationship with informal labour, it is presumed that a negative relationship exists between GDP per capita and informal output as a percentage of GDP in reality. This did not show in the regression and as such the data was re-examined using Structural Equation Modelling (SEM), which allows for the examination of interrelated dependence relationships simultaneously. This method is useful when the hypothesis involves multiple dependent variables and the relationships are not just linear but may have mediating or moderating effects. SEM explicitly accounts for measurement errors in the estimation process, which can lead to more accurate results, especially in cases where measurement errors or missing data are a concern.

There is insufficient statistical evidence to suggest that as countries become wealthier (increase in GDP per capita), the size of the informal output tends to decrease, although this is likely since the informal output is correlated to the informal labour force, and there is evidence that as countries become wealthier (increase in GDP per capita), the size of the informal workforce tends to decrease. This could be due to formalisation processes that typically accompany economic development. Increased labour productivity is associated with higher GDP per capita, which could suggest that as workers become more productive, the economy grows. However, it seems that where the informal economy is larger, it may be associated with lower labour productivity. This could reflect less efficient production methods in the informal sector or a diversion of resources from more productive formal sectors.

This research therefore assumes that causality between these two indicators cannot be established in one direction as there is a feedback loop between GDP per capita and the informal labour force, and this reflects that both variables influence each other over time. GDP per capita may serve as an initial trigger is a sensible assumption in economic theory, higher GDP per capita often correlates with greater formal employment opportunities, better education, and more robust healthcare, which can reduce the necessity for informal labour. On the other hand, in countries with lower GDP per capita, fewer job opportunities may drive more people into the informal sector. As the informal sector grows, it may affect GDP per capita by either underreporting economic activity, since informal work is often not captured in official statistics or by providing a buffer during economic downturns, thus mitigating the fall in GDP per capita that would occur if these informal workers were entirely unemployed.

Over time, the informal sector will influence the formal economy and vice versa. For instance, a large informal sector could suppress wages in the formal sector, potentially impacting GDP per capita. Conversely, improvements in GDP per capita could lead to better regulation and absorption of informal workers into the formal sector.



Graph 9.1.5 Residual Plot of GDP per Capita, Labour Productivity, Informal Labour

Given the challenges in measuring and accounting for the informal sector's impact on economic growth, it requires significant study and exploration, a further analysis of this relationship is beyond the scope of this research.

9.2. Technology and the Informal Economy

The informal economy, characterised by unregulated and often cash-based transactions, coexists with formal economic systems. It is necessary to explore the reciprocal effects of technology development on the informal economy and vice versa, shedding light on the interactions. This relationship between technology development and the informal economy constitutes an important aspect of contemporary economic study.

The advent of technology is causal to transformative shifts within the informal economy, eliciting a spectrum of effects. Firstly, technology has enabled the formalisation and inclusion of segments

of the informal economy into the formal economy. Digital platforms, mobile banking, and electronic payment systems have facilitated the integration of informal economic activities into formal financial systems (De Soto, 2000). This process of formalisation not only grants informal workers access to formal markets, but also engenders an environment conducive to economic growth and stability. Furthermore, technology has led to heightened levels of productivity and efficiency within the informal sector. The proliferation of mobile applications and digital communication platforms has revolutionised the operational landscape for informal enterprises. These tools provide entrepreneurs with avenues for coordination, marketing, and customer engagement, thereby augmenting business performance and competitiveness (Fiorini et al., 2019). Technology has also provided avenues for market access and globalisation for informal businesses. Online platforms transcend geographical boundaries, linking informal entrepreneurs with a global customer base. This newfound global reach not only expands revenue streams, but also fosters economic diversification and resilience within the informal sector (Aterido, et al., 2011).

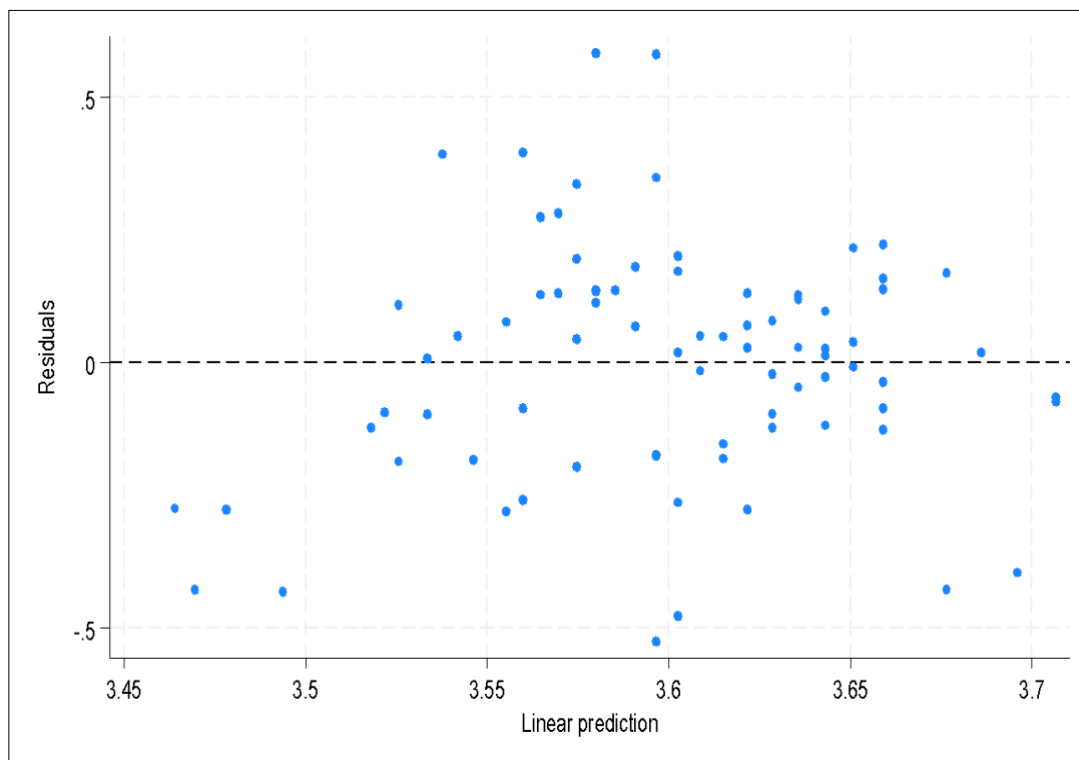
Moreover, technology contributes to enhanced transparency and trust within the informal economy. Digital transactions, coupled with online reviews and ratings, act as mechanisms to establish and fortify trust between informal businesses and their customers. This heightened level of transparency cultivates reputational capital, nurturing enduring customer relationships and bolstering market presence (Aterido et al., 2011).

Conversely, the informal economy has a notable influence on the trajectory of technological development. The informal sector, characterised by its resourcefulness and adaptability, serves as a fertile area for innovation since its participants, often faced with resource constraints, are adept at devising creative and cost-effective solutions to address specific needs. These localised innovations can, in turn, serve as fertile ground for the refinement and dissemination of formal technological advancements (Portes, et al., 1989). In addition, the informal economy constitutes a significant market segment for technological products and services. Feedback loops from this sector, driven by unique consumer demands and constraints, serve as invaluable inputs for the iterative refinement of technologies. The iterative nature of this feedback mechanism fosters the development of technologies that are more inclusive and accessible to a broader swath of society (Portes et al., 1989).

In some instances, the limitations of the informal sector propel the phenomenon of technological leapfrogging. Resource-constrained environments incentivise the adoption of more advanced and cost-effective technologies. For instance, mobile technology has circumvented the need for traditional infrastructure in several regions, enabling informal workers to access global markets with newfound agility and efficiency (Mansell & Wehn, 1998).

Root MSE	0.0208	F(1,39)	21.96	No. of Obs
R-squared	0.3165	Prob>F	0.0000	80
Variable	Coefficien	Std Error	t	P>|t|
Informal Output	1			
Technology Adoption Index (TAI)	-0.1749	0.0373	-4.69	0.000
Constant	3.3859	0.0457	74.08	0.000

Table 9.2.1 SSA Countries: Fixed Effects Regression Informal LP and TAI



Graph 9.2.1 Residual Plot Table 3.17 Regression, Informal LP and TAI

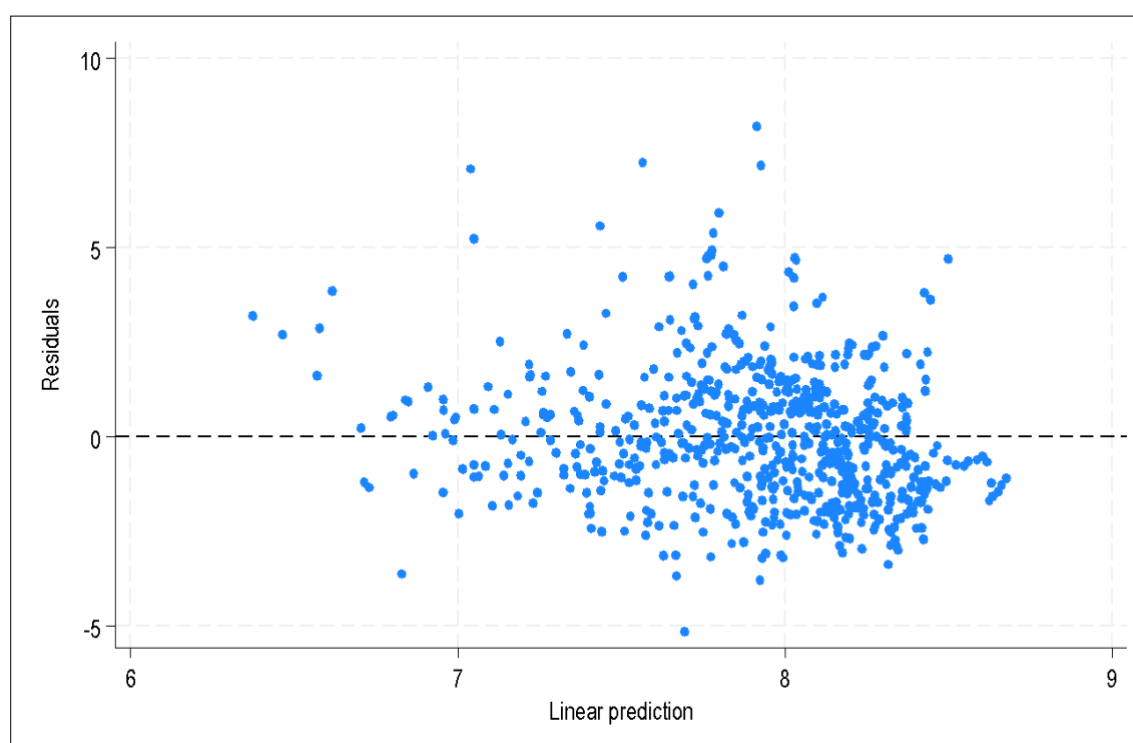
The regression output is summarised in Table 10.2.1 and the residual plot in Graph 10.2.1, showing the relationship between the Informal Output as a percentage of GDP and the Technology Adoption Index, examined using an instrumental variables approach with Fixed Effects Regression.

The coefficient for Technology Adoption Index is negative and significant which suggests that as the Technology Adoption Index increases by one unit, the Informal Output as a percentage of GDP decreases. The R-squared value is fairly low, indicating that the Technology Adoption Index

only explains about 31% of the variance in the informal output as a percentage of GDP within each country. This result is also subject to the small sample size since the Technology Adoption Index is only available for limited years. There is a potentially causal relationship where increases in technology adoption are associated with a decrease in the share of informal output in an economy's GDP, implying that technology adoption contributes to the formalisation of economic activity.

Root MSE	0.9112	F(1,43)	11.04	No. of Obs
R-squared	0.1134	Prob>F	0.0000	689
Variable	Coefficient	Std Error	t	P>|t|
Informal Labour Productivity	1			
Mobile Subscriptions	1.532	0.3095	4.95	0.000
Constant	5.743	0.4390	13.08	0.000

Table 9.2.2 SSA Fixed Effects Regression Informal Labour Productivity and Mobile Subscriptions



Graph 9.2.2 Residual Plot of Informal Labour Productivity and Mobile Subscriptions

An examination of mobile subscription data suggests that mobile connectivity could enhance formal labour productivity by improving communication, facilitating access to information, and enabling the adoption of mobile-based business applications that streamline operations and reduce costs (Qiang et al., 2009). It can also enable better market access and financial services, which are

crucial for productivity in the formal sector. The positive impact of mobile subscriptions on informal productivity shown in Table 10.2.2, indicates that mobile technology adoption is beneficial for the informal sector. This is a unique example and it should be acknowledged that in other technology areas, informal sector adoption may not yield positive results. Resources such as time and money might be diverted towards obtaining and using technology, which could detract from other productivity-enhancing investments (Donner & Escobari, 2010). Technology might not be as suitable for the types of activities carried out in the informal sector, or there may be a lag in learning how to integrate the technology effectively (Aker & Mbiti, 2010). There could be a digital divide where individuals in the informal sector do not have the same access to technology, or the same level of digital literacy, thereby limiting its positive impacts (Chinn & Fairlie, 2007). The results could also suggest an economic shift where the informal sector is declining as the formal sector becomes more productive, potentially leading to a reallocation of labour as workers move towards more productive, technologically-advanced formal employment (Murphy & Schleifer, 2003). There might also be a substitution effect at play where increased productivity in the formal sector leads to a reduction in the relative size or productivity of the informal sector, as more efficient formal businesses outcompete informal ones (Maloney, 2004).

The relationship between technology, above showing an example of mobile subscriptions as a proxy for technology, and informal output in Africa is complex. Various studies have explored the impact of mobile technology on economic activities, particularly in the context of developing regions in Africa. Mobile subscriptions can significantly increase access to information, which is crucial for informal sector participants. For instance, a study by Aker and Mbiti (2010) highlighted how mobile phones improve the functioning of markets by providing individuals with better access to information, thus reducing transaction costs and improving market efficiency. This is particularly beneficial for the informal sector, where formal market mechanisms may be lacking or less developed. The rise of mobile money services, like M-Pesa in Kenya, has been instrumental in fostering financial inclusion among the unbanked population, which predominantly operates within the informal sector. Suri and Jack (2016) provided evidence of the long-term economic benefits of mobile money services, showing increased household consumption and reduction of poverty in Kenya. Mobile subscriptions have empowered entrepreneurs in the informal sector by facilitating communication with customers and suppliers, coordinating business activities, and even accessing online marketplaces. This has been discussed in numerous case studies and papers focusing on the role of ICT in entrepreneurship (Donner and Escobari, 2010). There is evidence suggesting that increased mobile phone penetration contributes to job creation, particularly in the informal sector. While mobile subscriptions can offer numerous benefits, challenges such as digital literacy, infrastructure, and affordability can limit the extent to which the informal sector can

leverage mobile technology for economic gain. The relationship between mobile subscriptions and informal output also varies across different SSA countries and regions, depending on the level of mobile penetration, regulatory environment, and the nature of the informal economy.

In summary, while mobile subscriptions are generally seen as a positive driver of economic activity in Africa's informal sector by facilitating communication, financial inclusion, and access to information, the exact nature of this relationship can be context-dependent.

The reciprocal relationship between technology development and the informal economy constitutes a dynamic relationship. Technology acts as a catalyst for the formalisation, productivity enhancement, and globalisation of the informal economy. Simultaneously, the innovative spirit and market demand emanating from the informal sector exert discernible influences on the trajectory of technological progress. Recognising this interplay is an important consideration for policymakers and stakeholders seeking to harness the potential of both sectors for inclusive economic growth and societal advancement. A balancing of regulatory frameworks with opportunities for innovation and inclusion can foster a more harmonious and mutually beneficial interaction between technology development and the informal economy.

9.3. Foreign Direct Investment, Labour Productivity and the Informal Sector

Foreign Direct Investment (FDI) is considered a vital source of capital, technology transfer, and economic development for African countries (UNCTAD, 2020). However, the coexistence of a significant informal sector poses challenges and opportunities for FDI inflows. The informal sector in SSA encompasses a wide range of economic activities, from small-scale agriculture and informal trading to artisanal mining and unregistered enterprises. It often operates outside the purview of formal regulations and tax systems (ILO, 2018). The informal sector constitutes a significant portion of the African labour force and contributes to income generation and poverty reduction (Chen, 2019). FDI is recognised as a catalyst for economic growth, technological transfer, and employment creation (UNCTAD, 2020). FDI can introduce new technologies and skills to an economy. Informal sector workers and enterprises can benefit indirectly by acquiring new knowledge and skills through interactions with formal sector employees and supply chains (Markusen, 2004).

Since the SSA informal sector provides a vast labour pool, this offers potential investors access to a diversified workforce. FDI inflows can benefit from the adaptability and entrepreneurial spirit of workers in the informal sector, which can enhance productivity (Loayza & Sugawara, 2009). The informal sector also serves as a market entry point for foreign investors and often acts as a

distribution network, allowing FDI firms to reach consumers in remote areas (Amador & Cristea, 2017) facilitating FDI market penetration. FDI firms may collaborate with informal sector actors for innovation and technology transfer, for example, partnerships with small-scale agricultural producers can lead to the adoption of advanced farming practices (OECD, 2019). However, the informal sector operates with minimal legal protections, exposing FDI investors to risks such as property rights violations and contract disputes (De Soto, 1989). This can deter FDI inflows. Informal sector activities often evade taxation, leading to revenue loss for governments and as FDI investors seek a stable tax environment, high levels of informality can create uncertainty (Fuest et al., 2015).

Schneider (2016) notes that African governments should pursue policies that encourage the formalisation of informal sector activities. This includes simplifying registration procedures and offering incentives to transition into the formal economy. This was suggested earlier by Asiedu (2006), in that African nations should focus on improving the overall investment climate. This includes strengthening legal frameworks, protecting property rights, and reducing corruption. Policymakers can promote collaboration between FDI firms and SMEs in the informal sector and this support can include training, access to finance, and technology transfer programmes (UNCTAD, 2020). While the informal sector can provide advantages such as a flexible labour force and market opportunities, it also poses challenges.

One of the primary ways FDI influences the informal sector is through job creation. FDI can generate employment opportunities both directly, within the formal sector, and indirectly, by stimulating demand for goods and services supplied by informal enterprises (UNCTAD, 2005). FDI firms often source goods and services from local suppliers, including those in the informal sector. This can lead to increased demand for informal sector products, providing a boost to these enterprises (Dicken, 2015).

Increased FDI can lead to increased competition for resources and market share, thus the informal sector enterprises may struggle to compete with the larger, more efficient, and well-funded foreign-owned firms (Alfaro & Rodriguez-Clare, 2004). In some cases, the entry of FDI firms may displace informal sector activities, especially when land or resources are reallocated for large-scale projects (UNCTAD, 2005). Policymakers can foster linkages between FDI firms and the informal sector. This can be achieved through targeted programmes that encourage local procurement and technology transfer (UNCTAD, 2020). Investments in education and skills development can help informal sector workers adapt to changing market conditions and take advantage of FDI-induced opportunities (ILO, 2019). Implementing effective competition policies can mitigate the adverse effects of FDI-induced competition, ensuring a level playing field for all enterprises (Alfaro & Rodriguez-Clare, 2004). In summary, the relationship between FDI and the informal sector in SSA

and it is context-specific. While FDI can bring numerous benefits such as job creation, technology transfer, and market expansion, it can also pose challenges like increased competition and informal sector displacement.

The eclectic paradigm is a widely recognised framework for understanding FDI. The eclectic paradigm, also known as the Ownership, Location, and Internalisation (OLI) framework, is a well-established theory in international business that seeks to explain the motivations and determinants of FDI by multinational enterprises (MNEs) (Dunning, 1988). While the eclectic paradigm primarily focuses on the decisions of MNEs regarding their foreign investments, it has implications for labour productivity within these enterprises. Ownership advantages refer to the unique assets, capabilities, and advantages that a firm possesses. Within the eclectic paradigm, ownership advantages are central to a firm's decision to engage in foreign direct investment. These advantages may include technological expertise, brand recognition, management skills, and access to financial resources (Dunning, 1988). Location advantages encompass the benefits associated with a specific geographic location for a firm's operations. These advantages can include access to markets, natural resources, skilled labour, infrastructure, and regulatory factors (Dunning, 1988). Internalisation advantages refer to the benefits gained by a firm when it internalises certain functions or activities instead of relying on external markets or partners. Internalisation can enhance a firm's control over its assets and may lead to efficiency gains (Casson, 1987).

Ownership advantages often include advanced technologies, managerial expertise, and proprietary knowledge. These advantages can directly impact labour productivity within MNEs. For example, firms with ownership advantages may introduce more efficient production processes, training programmes, and quality control measures, ultimately leading to higher labour productivity (Caves, 1996). Ownership advantages in the context of MNEs' engagement with the informal sector may include access to advanced technologies, management expertise, and proprietary knowledge. MNEs can leverage these advantages to enhance the productivity and competitiveness of informal sector enterprises. For example, introducing efficient production processes or managerial practices can positively impact the informal sector's performance (Safarian, 2003).

The choice of location, influenced by location advantages, can significantly affect labour productivity. Access to skilled labour, efficient infrastructure, and proximity to key markets can enhance productivity levels. Conversely, unfavourable location factors, such as inadequate infrastructure or political instability, can hinder labour productivity (Buckley & Casson, 2009). The application of location advantages to the informal sector involves recognising that informal economic activities often cluster in specific geographic areas. MNEs can choose to engage with these clusters to gain proximity to suppliers, customers, or labour. This can lead to collaborations, partnerships, or sourcing arrangements that benefit both MNEs and the informal sector (Porter,

1998). Internalisation advantages often revolve around efficiency gains achieved through vertical integration and control over the production process. By internalising specific functions, MNEs can streamline operations, reduce transaction costs, and optimise resource allocation, thereby boosting labour productivity (Buckley & Casson, 2009). Internalisation advantages within the informal sector context can manifest in the form of vertical integration. MNEs may choose to internalise certain functions within informal sector supply chains to achieve efficiency and quality control. For instance, an MNE operating in agribusiness may internalise the processing of raw materials, improving product quality and reducing transaction costs (Peng, 2016).

Understanding the eclectic paradigm's application to the informal sector has significant implications for economic development in SSA. MNEs, through their engagement with the informal sector, can foster productivity improvements, knowledge transfer, and capacity building within this sector. This, in turn, can contribute to broader economic growth, poverty reduction, and inclusive development (Chen, 2016). MNEs continue to make decisions about FDI based on ownership, location, and internalisation advantages. As technology advances and supply chains become more complex, the paradigm provides a valuable framework for understanding how these firms can enhance labour productivity by leveraging their unique advantages across borders.

9.4. Informal Sector Labour Productivity

Labour productivity is a concept typically applied to the formal sector of the economy, where activities are regulated, tracked, and reported in a systematic manner. Assessing informal sector labour productivity is complex due to its heterogeneity and informality. Labour productivity in the informal sector varies significantly across different subsectors. For instance, agricultural activities may exhibit different productivity levels compared to service-oriented enterprises. Understanding these variations is essential for effective policymaking (Maloney, 2004). Informal labour markets often lack the efficiency and transparency of formal labour markets and factors such as information asymmetry and limited job-matching mechanisms negatively impact productivity (Fields, 2005). The absence of formal record-keeping mechanisms is a pervasive impediment to measuring productivity in the informal sector. Unlike their counterparts in the formal economy, informal enterprises often operate without structured accounting practices and this absence of data undermines efforts to quantify output, hindering accurate productivity assessments. Due to the diverse array of economic activities in the informal sector, ranging from street vending to small-scale manufacturing, each of these activities possesses unique characteristics and outputs, rendering the establishment of a standardised measure of productivity a formidable task. The

variability in goods and services produced, along with the disparate modes of operation, further complicates productivity assessment. Informal workers frequently contend with irregular and unpredictable working hours and unlike the fixed schedules prevalent in the formal sector, hours worked in the informal economy can fluctuate based on a myriad of factors, including market demand, personal circumstances, and economic conditions. This variability undermines attempts to establish consistent metrics for productivity.

In order to begin quantifying informal sector labour productivity, determinants can be grouped into three main areas; human capital, informal institutions, access to resources and technology adoption. Investments into education, skills development, and health significantly influence labour productivity in the informal sector. Higher levels of education and skills are associated with increased productivity (Maloney, 2004). Access to resources, including capital, and inputs, are critical for productivity enhancement and limited access to these resources can constrain productivity growth (ILO, 2018). Informal institutions such as social networks and community-based organisations can impact productivity through information sharing, access to markets, and risk-sharing mechanisms (Portes & Haller, 2005). The implications of increased informal sector labour productivity is the contribution to poverty reduction by increasing the income-generating capacity of vulnerable populations (Fields, 2005). Labour-intensive informal sector activities can also absorb surplus labour, reducing unemployment and underemployment rates (Loayza & Sugawara, 2009). Importantly, productivity gains in the informal sector can have spillover effects on the formal economy, contributing to overall economic growth (Maloney, 2004).

Policy implications must thus include prioritising investments into education, vocational training, and healthcare to enhance the human capital of informal sector workers (Fields, 2005), facilitating access to microfinance and credit services can enable informal sector enterprises to invest in productivity-enhancing resources (ILO, 2018) and formalisation policies that are designed to reduce regulatory burdens and provide incentives for informal sector enterprises to transition into the formal economy (Loayza & Sugawara, 2009).

Labour productivity in the informal sector is a concept influenced by various determinants. Understanding its dynamics and promoting productivity-enhancing policies is essential for economic development in many developing economies. It is clear though that investing in human capital, improving resource access, and adopting appropriate formalisation strategies, can harness the potential of the informal sector to drive inclusive growth and poverty reduction.

9.5. Leveraging SST for Socio-Economic Development in Sub-Saharan Africa

The advent of SST stands as a pivotal turning point for advancing socio-economic development in Sub-Saharan Africa. This region, characterised by diverse cultures and economies, faces unique challenges that could be significantly alleviated through strategic investments into space-related technology. By harnessing the capabilities such as satellite communication, Earth observation, and navigation technologies, SSA economies can leapfrog developmental hurdles, enhance their infrastructural capabilities, and ultimately, stimulate sustainable growth. This section explores the relationship between space science investments and socio-economic development, elucidating how this high-technology sector can serve as a catalyst for transformative change across the continent. Central to this is the concept of labour productivity as a barometer for economic vitality. Labour productivity is not merely a statistical measure, but as shown, it is a reflection of a nation's educational attainment, technological sophistication, and overall economic health. In SSA, where the potential for economic expansion and human development is immense, an increase in labour productivity could signal a decisive step towards poverty reduction, improved standards of living, and enhanced global competitiveness.

The next subsection provides the examination of labour productivity as an indicator of socio-economic impact from SST, within SSA economies. It will explore the empirical results of how investments into research and development, as a proxy for SST, correlate with labour productivity metrics, drawing on recent data and analytics. The analysis will seek to quantify the tangible benefits and highlight the transformative potential of science and technology when aligned with the goal of uplifting the socio-economic landscape of Sub-Saharan Africa.

Part 4

Model Development

10. Model Development - Quantitative Analysis

10.1. Labour Productivity as a proxy for socio-economic impact

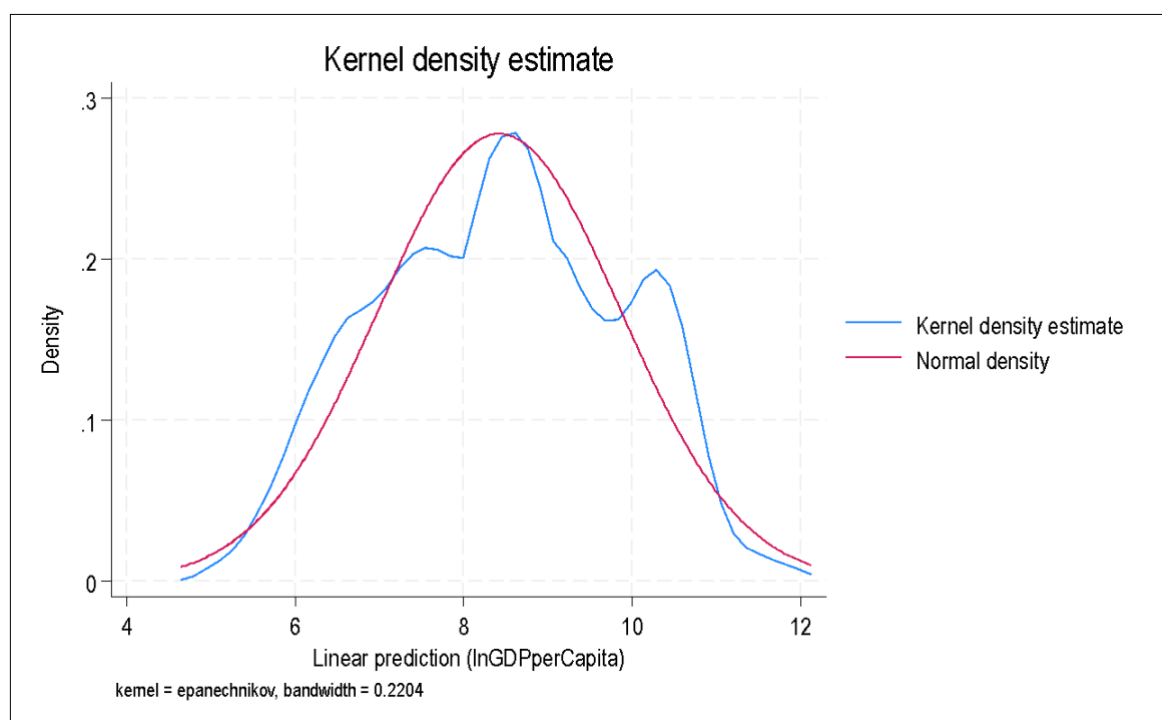
It is proposed that the effects of SST investments, ranging from innovations in product development to advancements in infrastructure, can be reflected in shifts observed in labour productivity. This is predicated on the notion that such investments not only enhance the cognitive capital of the workforce through improved educational outcomes but also stimulate economic vitality by fostering high-skill job creation and technology diffusion across sectors. SST investments act as a catalyst for educational advancements by inspiring STEM (Science, Technology, Engineering, and Mathematics) education and creating a skilled workforce (Marginson et al., 2013). In terms of poverty alleviation, SST investments can introduce innovations that drive economic inclusion and improve living standards (Sen, 1999). Moreover, the diffusion of technology from the space sector to the broader economy can spur productivity across sectors (Mankins, 1995). The employment market also benefits from the diversification and creation of high-technology jobs (Autor, 2015), while access to finance can be broadened through improved financial technologies and data management systems (King & Levine, 1993). Labour productivity possesses a demonstrable correlation with GDP per capita, establishing it as a reliable indicator for gauging economic and social progress. Therefore, labour productivity is a compelling proxy for the economic and social dividends accruing from SST investments. Embedding labour productivity within the mathematical modelling offers a robust mechanism to capture the socio-economic impact of SST investment. This approach aligns with the literature that posits labour productivity as a key determinant of GDP per capita, which is a widely used indicator of economic prosperity (Romer, 1986). By leveraging the below econometric technique one can attempt to quantify the extent to which SST investments permeate and enhance labour productivity, and subsequently, GDP per capita.

Structural equation model		Number of obs = 5,920				
Estimation method: ml						
Log likelihood = 83237.831						
	Coefficient	Std. Error	z	P>z	[95% confidence interval]	
Ln(GDP per Capita)						
Ln(Informal Output)	-0.397	0.026	-15.240	0.000	-0.448	-0.346
Ln(Labour Productivity)	1.210	0.010	125.830	0.000	1.191	1.229
China	0.384	0.095	4.060	0.000	0.199	0.569
South Africa	-0.401	0.094	-4.280	0.000	-0.585	-0.217
USA	0.000	1.26e ⁵	0.000	1.000	-2.47e ⁵	2.47e ⁵
Japan	0.360	0.094	3.840	0.000	0.176	0.543
Germany	0.163	0.092	1.780	0.075	-0.017	0.343
UK	0.000	1.26e ⁵	0.000	1.000	-2.47e ⁵	2.47e ⁵
India	-0.426	0.092	-4.620	0.000	-0.607	-0.245
France	0.042	0.095	0.440	0.659	-0.144	0.228
Italy	0.086	0.092	0.940	0.349	-0.094	0.266
Israel	0.239	0.091	2.610	0.009	0.060	0.418
Netherlands	0.061	0.095	0.650	0.519	-0.125	0.248
Singapore	0.058	0.096	0.600	0.546	-0.130	0.245
_cons	6.777	0.105	64.260	0.000	6.571	6.984
Var (e.lnGDPperCapita)	0.139	0.004			0.131	0.148

Table 10.1.1 Structural Equation Model: GDP per Capita, Informal Output and Labour Productivity

The SEM output relates to the relationship between formal labour productivity, informal sector output as a percentage of GDP, and GDP per capita, with country-specific dummies included in the model. This is a strong positive association indicating that in the context of this SEM, formal labour productivity is a significant predictor of GDP per capita. As the informal sector's share of GDP increases, the negative coefficient indicates that GDP per capita decreases. This could reflect inefficiencies or low productivity in the informal sector compared to the formal sector, which is common in many developing countries. The country-specific dummy variables have been included in the model to control for country-specific effects that are not captured by the other variables. The model strongly supports that increasing formal labour productivity has a substantial positive

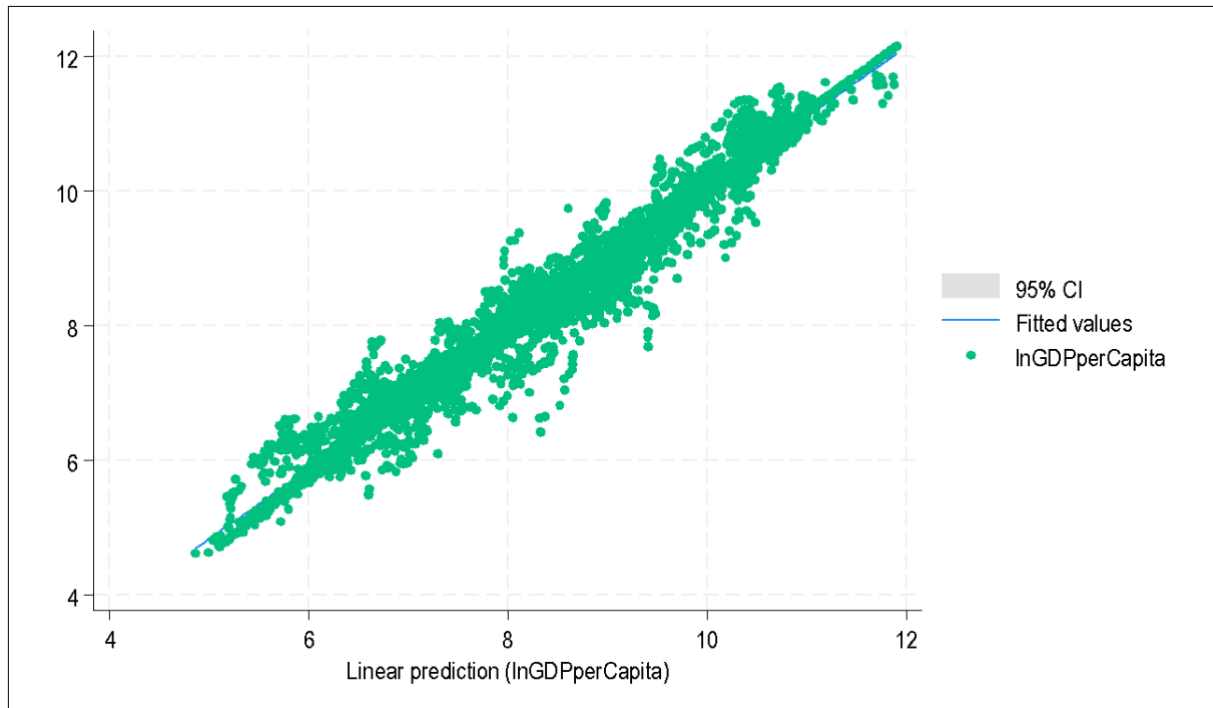
effect on GDP per capita, while a larger informal sector (relative to GDP) is associated with lower GDP per capita. SEM assumptions often include normality of the variables involved.



Graph 10.1.1 Kernel Density Estimate (KDE): normality plot

The Kernel Density Estimation (KDE) plot in Graph 11.1.1 allows one to assess how closely the data follows a normal distribution. The plot provides insights into country-specific differences in GDP per Capita. Since the KDE shows multiple peaks, it can indicate heterogeneity in the economic indicators among the countries in the sample, which is expected.

The country dummies indicate that there are significant country-specific differences in GDP per capita that are not explained solely by labour productivity or the size of the informal sector, this is of course expected as the prediction of GDP requires additional inputs. It is noted that the result for this relationship was significant for the developing countries but not so for developed countries. GDP per capita can be influenced by labour productivity across countries due to a range of structural, economic, and policy-related factors. In terms of the structure of the economy, within developing countries, the formal sector includes industries that are typically more productive and generate higher value-added per worker. Therefore, increases in formal labour productivity directly contribute to higher GDP per capita. In contrast, the informal sector in these countries may largely consist of low-productivity jobs that do not contribute significantly to the GDP.



Graph 10.1.2 SEM Results: Actual versus Predicted values of ln GDP per Capita

High levels of informal labour productivity might even indicate that too much labour is trapped in low-value-added activities, which could lead to a drag on the overall economic performance. In advanced economies however, a smaller proportion of the workforce is in the informal sector. Their formal economies are highly integrated and efficient, with social safety nets and labour policies that minimise the size and impact of informal activities.

Economic policies and governance in developing nations may also have different regulatory environments, labour laws, and degrees of enforcement that affect the productivity dynamics between the formal and informal sectors. Strong governance and regulatory frameworks in the developed economies ensure that even the informal activities are relatively productive and do not negatively impact GDP per capita. Furthermore, advanced economies often have more effective mechanisms for transitioning informal sector workers into the formal sector, thereby harnessing their productivity for official GDP. In developed nations, the labour markets are more dynamic and efficient, with high labour mobility that allows for better allocation of workers to productive sectors. Investments into education and training are usually higher in formal sectors and advanced economies, leading to higher productivity. The informal sectors in emerging markets may not benefit from such investments, limiting their positive impact on GDP per capita. Formal sectors in developed countries and the technology-intensive sectors in emerging economies are likely to see continuous improvements in labour productivity due to capital investments and technology absorption, contributing positively to GDP per capita. The informal sector in contrast may not

have the same level of access to capital and technology, which can inhibit productivity growth. In contrast, advanced economies are highly integrated with global markets, and their formal sectors are geared towards high productivity to remain competitive. This integration ensures that productivity gains translate effectively into GDP per capita growth. The informal sector in these countries are small and often oriented towards local services, which may not impact GDP per capita as significantly.

Formal labour productivity typically measures output in the formal sector, which includes activities that are officially registered and accounted for in national statistics, it can reflect the impact of science and technology on market-based economic activities. Formal labour productivity data is also readily available and comparable across countries and regions, making it a convenient proxy for cross-country or cross-sector comparisons. As previously noted, formal labour productivity does not capture the contributions of the informal sector, which is prevalent in many developing economies. Investments into science and technology may have indirect effects on the informal sector but these are difficult to track and formal labour productivity does not account for the distribution of benefits from science and technology investments. Socio-economic impact extends beyond economic growth and includes factors such as, but not limited to health, education, quality of life, and environmental sustainability, and SST investments can lead to technology spillovers, which benefit various sectors, including the informal economy and non-market activities. It is a limitation that these spillovers may not be reflected in formal labour productivity and as such it is necessary to incorporate a measure of informal impact. A further challenge is that the full socio-economic impact of SST investments may take time to materialise and may extend beyond the scope of formal labour productivity measurements.

The size and output of the informal labour sector can be indicative of labour conditions within an economy. A large informal sector might suggest challenges in terms of formal employment opportunities, worker protections, and overall labour market conditions. Informal labour productivity, measured as output per worker or output in the informal sector, can indirectly reflect the quality of labour conditions. Higher productivity may suggest that workers are more efficient and effective, possibly due to better working conditions or higher skills. The informal sector often includes vulnerable workers who lack social protections, access to healthcare, and other benefits. The size of the informal sector can reflect the extent of such vulnerabilities. The income earned in the informal sector is a key determinant of the well-being of workers and their families. Higher income in the informal sector can lead to better living conditions, healthcare access, and educational opportunities. Research on informal labour often focuses on the rights of workers, including issues related to discrimination, exploitation, and social exclusion and thus the size and conditions of the informal labour sector may reflect the level of social inclusion and labour rights.

Informality is often associated with underdeveloped economies where a large informal sector coexists with a smaller formal sector, or economic dualism as noted in the Lewis Structural Change Model.

It is thus deduced that using the size and output of the informal labour sector to estimate informal labour productivity, weighted with formal labour productivity, as a proxy for the quality of the conditions of the labour force is a reasonable hypothesis. The case for this hypothesis, in addition to the statistical testing, is supported by existing research on labour conditions, informality, and economic indicators. The literature review has shown that labour productivity encapsulates the effects of education, poverty levels, technological advancements, employment market dynamics and access to financial resources.

In the case of South Africa, as the host country to the MeerKAT and SKA case studies, this research posits that labour productivity as the dependent variable, is influenced by a spectrum of economic factors. The nation's labour productivity growth rate lags behind its emerging economy counterparts (OECD, 2018), a phenomenon attributable to an array of structural impediments including a pervasive skills deficit, elevated operational costs, and limited market competition.

Further delineating the context of South Africa's labour force, it is notable that in 2019, a substantial 28.5% of the labour force was unemployed, yet actively seeking employment (ILOSTAT, 2022). Moreover, 20% of the workforce was absorbed by the informal sector (STATSSA, 2021), and over a third resided in rural locales, often beset by access constraints including transportation—a mere 29% of the populace had dependable transport services at their disposal. The dichotomy in electrification between urban and rural areas is striking, with the urban sector being 3.5 times more likely to have access to electricity (Sarkodie & Adams, 2020). Furthermore, while a majority have access to basic sanitation facilities, a marginal yet significant portion of children remain outside the educational system (World Bank, 2019). These factors illuminate the broader environment shaping the labour force, within which a distressing 55.5% of the population subsists below the national upper poverty threshold (World Bank, 2020).

Standard economic descriptors might ignore the specific characteristics of the labour-housing environment, in so far as there is not an actionable translation from the applicable determinants to the real challenges characterised by the environment. If one is able to examine each aspect of labour productivity, but not measurably impact the environment containing the labour force, growth will be stunted.

10.2. SST Impact-Causality Cycle

This research proposes a cycle of causality, it is a comprehensive interconnected cycle, represented by a causal chain of relationships linking SST investment to various socio-economic indicators. The cyclic framework is designed as the tool on which to establish and test the mathematical relationships and on which to demonstrate the relevant statistical relationships. It highlights the multifaceted nature of development and the importance of considering a range of factors in policy planning and investment strategies. There may exist similar frameworks in economics and development studies that analyse the relationships between different variables in a more general sense, for example, the Solow Growth Model, the Human Development Index (HDI), and various input-output models that examine economic growth, human development, and industry interdependencies, but they do not typically focus on SST investment as a starting point. The proposed causal chain stands out for its explicit inclusion of SST investment as the initial driver, which is not a standard feature in most existing development models. This unique aspect of the framework makes it a distinctive approach to understanding the potential impacts of SST investments on socio-economic indicators as well as how to use the causal links in reverse to maximise the socio-economic impacts of the investment. The SEM diagrams in Appendix C model the impacts of SST investment as it related to economic variables.

The SST Impact-Causality Cycle described in Figure 11.2.1, represents a model derived from data that identifies the causal links and reverse order of impact, for maximising socio-economic outcomes from SST investment. This framework comprises a chain of interrelated components, with feedback loops between each, contributing to the cumulative socio-economic impact. It is best visualised as two identical disks that impact one another at each point but are turning in opposite directions.

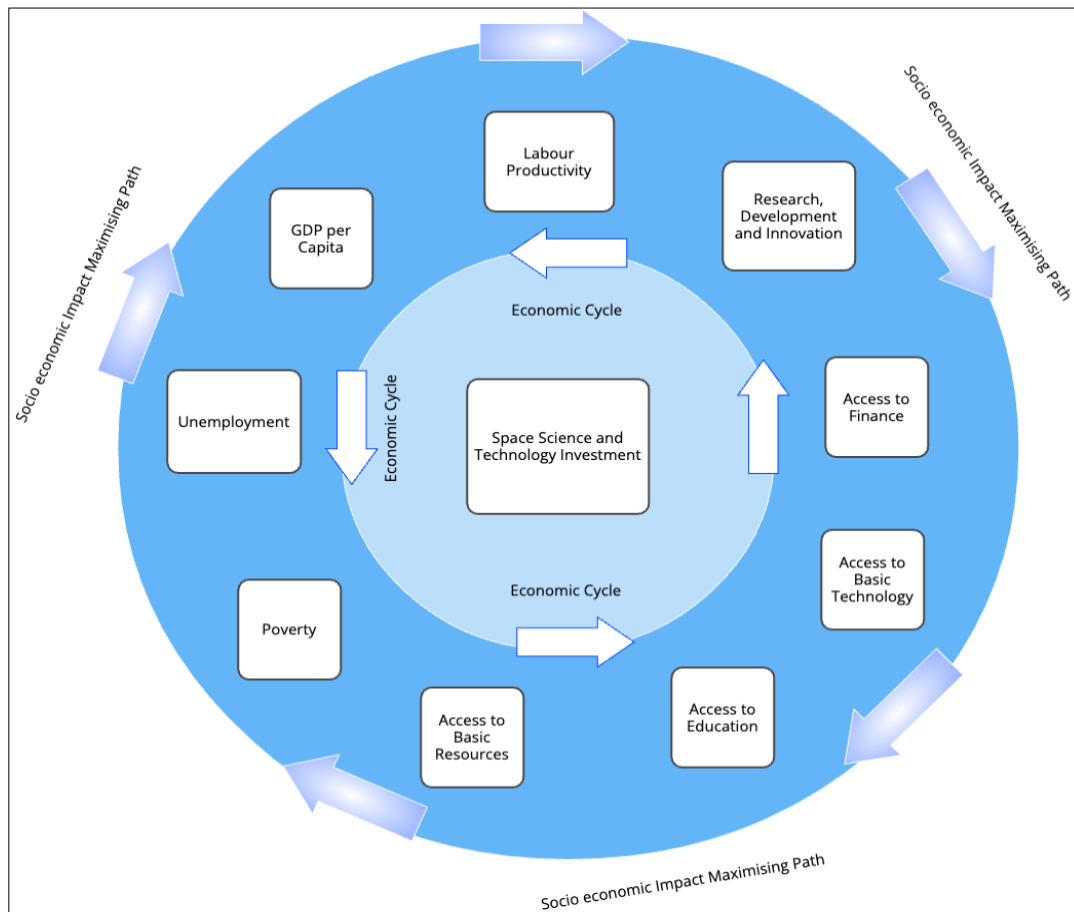


Figure 10.2.1 The SST Impact-Causality Cycle

The list in Table 11.2.1 below highlights the components of the framework, and each item in the list exists in a feedback loop with the items that occur in the items before.

SST Investment	This serves as the foundational element, symbolising the initiation point for the framework. Investments into SST, including satellite technology, data products and related innovations, propel the subsequent series of transformations.
Poverty Reduction	The framework asserts that SST investments exert a direct or indirect influence on poverty alleviation. This impact materialises through various channels, such as technology transfer, job creation due to and within the space sector, or the emergence of ancillary industries connected to space technology. For instance, the utilisation of satellite data for precision agriculture can enhance crop yields and generate economic opportunities, contributing to poverty reduction (Wawire et al., 2021).
Access to Basic Resources	Poverty reduction sets in motion a causal link to improved access to basic resources, particularly in areas such as sanitation and healthcare infrastructure. Elevated poverty levels often result in inadequate infrastructure, including sanitation facilities. Improved sanitation infrastructure subsequently mitigates health challenges, particularly those affecting children, thereby laying the foundation for holistic well-being (World Bank, 2020).

Access to Basic Technology	A reduction in basic health challenges and enhanced access to resources can catalyse increased access to fundamental technologies. For instance, improved economic conditions and increased investment in energy infrastructure may yield greater access to electricity. This, in turn, engenders expectations of heightened internet accessibility, underlining the dependency of digital connectivity on reliable power sources (African Union Commission, 2017).
Access to Education	Enhanced internet access facilitates educational opportunities, leading to elevated secondary school enrolment rates. This underscores the pivotal role of technology in expanding educational access and quality. For example, e-learning platforms can empower students in remote areas with access to quality education (UNESCO, 2020).
Access to Finance	Increased secondary school enrolment rates may contribute to a more skilled and educated workforce, potentially enhancing credit availability for the private sector. Financial institutions may become more inclined to extend credit to individuals and businesses with improved educational backgrounds (Akerlof & Shiller, 2015).
Research and Development (R&D) Investment	A flourishing private sector, bolstered by enhanced access to credit, can foster increased investments in Research and Development (R&D). This underscores the pivotal role of innovation in driving economic development. R&D investments enable the development of new technologies, products, and services, thereby bolstering economic competitiveness (Mowery & Rosenberg, 1998).
Labour Productivity	Higher R&D investments engender increased labour productivity. Technological advancements and innovation lead to greater efficiency and effectiveness in production processes. For example, the application of advanced manufacturing technologies can significantly enhance productivity in various industries (Brynjolfsson & McAfee, 2014).
GDP per Capita	Elevated labour productivity translates into higher Gross Domestic Product (GDP) per capita, emblematic of economic growth and improved living standards. Increased output per worker signifies enhanced economic prosperity for individuals and communities (Solow, 1956).
Unemployment Reduction	As the economy expands, unemployment rates are poised to decrease. The growth in economic activity generates new job opportunities, subsequently reducing unemployment. For instance, investments in technology-intensive sectors can create high-skill employment opportunities (Autor et al., 2003).
Poverty Reduction	The cycle attains completion with the reduction in unemployment and overall economic advancement culminating in decreased poverty levels. Sustainable economic growth, coupled with equitable access to opportunities and resources, contributes to lasting poverty alleviation (Duflo, 2012).

Table 10.2.1 The SST Impact-Causality Cycle Elements

The SST Impact-Causality Cycle encapsulates a dynamic set of cause-and-effect relationships, highlighting the transformative potential of SST investments on a spectrum of socio-economic dimensions. The intersection of SST with socio-economic development presents a potent catalyst

for progress, particularly in regions facing unique challenges such as is the case in SSA. With the potential for innovation and transformation, SST offers many opportunities to address socio-economic issues in the region. This framework seeks to delineate a causal cycle, beginning with strategic investments in SST, and culminating in a series of interconnected socio-economic indicators. In acknowledging the multi-faceted nature of development, this complexity also invites the potential for shortcomings, including data limitations, contextual disparities, and the need for strategic focus. By adopting a reverse lens, this framework offers a proactive approach, allowing policymakers and stakeholders to pinpoint critical junctures for intervention and optimisation.

10.3. Development of the Labour Productivity SST Equation

10.3.1. Methodology

Based on the considerations proposed in the SST Impact-Causality Cycle, this research seeks to design a regression equation as a method for understanding the socio-economic impact of investment in SST on labour productivity.

Dependent Variable (DV):

Labour Productivity: This indicator is chosen as the dependent variable for exploring the socio-economic impacts of investment, as higher productivity often translates to better economic outcomes.

Independent Variables::

Education Ratio: The variable is designed to capture the level of advanced educational enrolment relative to more foundational education enrolment. The assumption is that higher-level educational enrolment reflects continued education, a more educated workforce, and a reflection of the environment enabling education.

Education Ratio = (pre-primary enrol + primary enrol) / (secondary enrol + tertiary enrol)

Equation 10.3.1.1

Employment Ratio: This is a construct aimed at capturing the structural composition of the workforce in terms of skilled versus unskilled labour.

Employment Ratio = employment in agriculture / employment in services

Equation 10.3.1.2

Access to Finance Ratio: The ratio attempts to capture both the availability of credit and the cost of borrowing. This is a relevant factor since access to capital is essential for technological advancements and economic growth.

Access to Finance Ratio = Domestic Credit to the Private Sector / Interest Lending Rate

Equation 10.3.1.3

Technology Efficiency Ratio: This ratio represents the return on investment of technology and innovation, where the proxies are R&D expenditure for the investment, and patent receipts as the returns or the innovation outputs. This is a way to look at how efficiently a country or sector turns research into potentially profitable outcomes.

Technology Efficiency Ratio = Patent receipts / R&D Expenditure

Equation 10.3.1.4

10.3.2. Education Ratio

The proposed ratio is representative of the education pipeline, which is the sum of pre-primary and primary school enrolments divided by the sum of secondary and tertiary enrolments, and offers a perspective into the educational environment, particularly when applied to the context of SSA. This variable essentially compares the enrolment numbers in the early stages of education (pre-primary and primary) with those in the later stages (secondary and tertiary).

A higher value indicates that there are significantly more students in the earlier stages of education compared to the later stages. This could suggest high drop-off rates as students transition from primary to secondary education and then to tertiary education, possibly due to economic constraints, insufficient infrastructure such as a lack of secondary or tertiary institutions, societal factors, or other barriers to continued education. Values close to 1 and just below suggest a more balanced distribution or even a larger enrolment in the higher stages of education. This would be indicative of successful transition rates and could point to a well-functioning education system with adequate capacity and accessibility at the higher education levels. Dominance of early-stage enrolment can also indicate demographic trends like high birth rates leading to a "youth bulge" in the population. In countries with younger population structures, primary and pre-primary

enrolments will naturally be higher. Higher enrolments in secondary and tertiary levels may reflect a stabilising or ageing population, or successful outcomes of policy interventions aimed at keeping students in school longer. The relative numbers can shed light on the effectiveness of education policies and investments at different levels. For instance, significant investments in primary education might not yield the desired long-term educational outcomes if students don't continue into secondary and tertiary education. The transition from primary to secondary education is critical and is often where major drop-offs occur. Higher numbers in the early education stages and lower numbers in secondary and tertiary stages can also point to socio-economic barriers, such as the need for older children to work to support family incomes, the cost of education, or cultural factors affecting educational participation, especially dominant among the female population in developing economies. Brock and Cammish (1997) examined the various factors influencing female participation in education across and highlight the impact of geographical, sociocultural, economic, and health factors, noting a significant cultural bias favouring males and the economic obstacles faced by females. The study also noted the limited political will to implement initiatives aimed at increasing female educational participation.

As an illustrative example, see Table 11.3.2.1 below, South African data has been selected here from the SSA panel dataset as a snapshot. Since the MeerKAT and SKA case study in Chapter 13 is focused on South Africa, it is worth viewing the South African data that makes up the Education Ratio, in particular, to understand the movement of the value over the ten years from 2010 to 2019. For example, there is potentially a visible 'youth bulge impact' over the period as discussed above but there is a significant ratio of older dependents to the workforce.

South Africa	Education Ratio	Pre-primary enrolment	Primary school enrolment	Secondary enrolment	Tertiary enrolment	Percentage of the labour force Unemployed	Ratio of older dependents to working population	Percentage of population aged 0 - 14 years
2010	1,10	18,50	104,73	93,74	18,36	24,68	5,01	28,74
2011	1,05	18,67	103,42	96,18	19,61	24,64	4,97	28,52
2012	1,03	18,82	103,23	98,83	19,14	24,73	4,95	28,43
2013		18,34	102,67		19,93	24,56	4,94	28,42
2014	0,95	18,84	102,70	107,80	19,81	24,89	4,95	28,39
2015	0,94	18,70	105,57	109,44	22,26	25,15	5,00	28,28
2016	0,95	18,19	103,18	107,18	20,92	26,54	5,07	28,37
2017	0,94	18,45	100,86	104,70	22,37	27,04	5,12	28,59
2018	0,93	17,63	98,54	100,51	23,80	26,91	5,17	28,68
2019	0,92	17,84	98,37	102,56	23,87	28,47	5,22	28,75

Table 10.3.2.1 Comparison of Education data for South Africa, years 2010 - 2019

Economic factors can particularly influence tertiary education numbers, as university-level education might be either unaffordable or seen as unnecessary for employment in certain economies. Families and students might opt out of higher education if the perceived quality or relevance of the education system is low. This variable can thus also help in assessing whether the quality of education at different levels meets the expectations and needs of the population.

When applying rationale to the SSA context, it is essential to acknowledge that SSA is incredibly diverse, with variations in educational systems, economic conditions, cultural norms, and governmental policies and this diversity means that national and regional differences can significantly affect how this variable can be interpreted. For example, countries experiencing conflict, or economic hardship, or those with less government investment in education might show a large positive value, indicating more enrolment in primary than in secondary and tertiary levels. The fixed-effects regression model results in Table 11.3.2.2 below provide insight into the ‘within-country’ dynamics affecting labour productivity per hour, highlighting the negative impact of both the education ratio and unemployment as a percentage of the labour force, on labour productivity. However, the low ‘within’ R-squared value of 9 % suggests that additional factors not captured by the model are influencing labour productivity within these entities. This is expected as the relationship of education on labour productivity is isolated here, and the other impacts have been deliberately ignored. 36.4% of the variation between countries is captured by the regression suggesting a stronger association between the variables and labour productivity at the between-country level compared to within the countries. The significant country-specific effects underscore the importance of controlling for the unobserved heterogeneity in the panel data analysis.

Labour Productivity	Coefficien t	Std. Dev	t	P>t	95% Confidence Interval	
Education Ratio	-0.0398	0.0146	-2.72	0,007	-0.0686	-0.0109
Unemployment as a percentage of the Labour Force	-0.0231	0.0081	-2.85	0,005	-0.0391	-0.0071
Constant	0.19887	0.0699	2.84	0,005	0.0609	0.3368
R-squared	0.0903		No. of Obs.	222		
Adj. R-squared	0.0820		F(2,188)	9,33		
Root MSE	0.1245		Prob>F	0,0001		

Table 10.3.2.2 Labour Productivity Regression with Education Ratio and Unemployment

The regression coefficient of the Education ratio is -0.04 for the variable in relation to labour productivity in SSA countries. The negative sign indicates an inverse relationship, therefore as the number of enrollees in pre-primary and primary exceeds the number of enrollees in secondary and tertiary education, labour productivity tends to decrease. The negative coefficient suggests that when there are disproportionately more students in the early stages of education compared to the later stages, labour productivity is negatively impacted. This could be interpreted as a signal that higher levels of education are contributory to improving labour productivity. If students are not continuing beyond primary education, they may lack the skills and knowledge that higher education imparts, which are often essential for higher labour productivity.

This relationship can also indicate a mismatch between the skills taught in early education stages and those required later in the labour market. Furthermore, if the quality of primary and pre-primary education is lacking, even high enrolment numbers in these stages might not translate into productive skills. Economies where a larger portion of the population has only primary or pre-primary education might be more focused on labour-intensive, low-productivity sectors. In contrast, economies with higher secondary and tertiary education enrolment are often more diversified and include higher-value, knowledge-based industries. From a policy standpoint, this finding could indicate the need to focus not just on getting children into school but also on keeping them in school through secondary and tertiary levels. It emphasises the importance of quality education at all levels and the alignment of educational curricula with market needs.

The regression analysis does not imply causation but only association, so it is prudent to note that other variables and external factors not included in the model influence both education enrolment and labour productivity. Individual countries may show different trends due to varying economic structures, educational systems, time lagged impacts and cultural contexts.

The negative correlation suggests that in SSA, an educational focus skewed heavily towards early schooling with less continuation into secondary and tertiary education might be linked to lower labour productivity. It is worth noting that an increase in unemployment in the results in Table 4.3 shows a reduction in labour productivity which is intuitive but it is not always the case in SSA country analysis. In many SSA countries, the formal employment sector is often small relative to the overall economy, with a large informal sector. High unemployment rates could mean more people are moving into informal or self-employment sectors, potentially driving up productivity in those sectors. High unemployment might also coincide with structural shifts in the economy, for instance, a transition from predominantly agricultural to more industrial or service-oriented jobs, which are typically more productive.

10.3.3. Employment Ratio

This proposed ratio reflects the structural aspect of employment in the economy, contrasting the agricultural sector with the services sector. This ratio may indicate the stage of economic development of a country. Economies with a higher ratio are often in earlier stages of development, characterised by a larger agricultural sector relative to services. Conversely, more developed economies typically have a larger service sector. The agricultural sector typically has lower labour productivity compared to the services sector and as such a higher employment ratio might thus be associated with lower overall labour productivity, which can be an important control variable in the model. The ratio serves as a structural indicator of an economy's composition as the shift from agriculture to services and industry is a well-documented path of economic development, often associated with increases in labour productivity due to higher productivity in services and industrial sectors compared to agriculture (Kuznets, 1966). There are inherent differences in productivity levels between the agricultural and service sectors. Agriculture typically has lower labour productivity due to factors such as dependence on natural conditions, lower levels of technology infusion, and less capital intensity. In contrast, the services sector often benefits more directly from technological advancements, including those stemming from SST investments, leading to greater productivity improvements (Rostow, 1960). The employment ratio can help identify how the structure of the labour market influences the diffusion and adoption of technologies derived from SST. For example, the service sector may more readily absorb and utilise SST advancements, thus impacting productivity differently than in agriculture (Mowery & Rosenberg, 1988). The employment ratio can also capture the transitional dynamics of an economy, in other words, as SST investments potentially drive economic development, a decrease in the ratio could be both a cause and effect of the SST investment impact on productivity, reflecting labour reallocation from agriculture to more productive service sectors (Todaro and Smith, 2015). Below in Table 11.3.3.1 is a selection of the SSA panel dataset from South Africa over the period 2010 to 2019, this allows for a view of the movements of the employment ratio variables over the period. Since the employment percentage in agriculture is increasing while employment in services is increasing at a much smaller rate, it could be the case that the increase in the agricultural sector is due to movement into the informal sector and likely the subsistence agriculture.

South Africa	Employment Ratio	Employment in services	Employment in agriculture	Ratio of older dependents to working population	Unemployment percentage of the labour force
2010	-0,9916413	70,75	4,85	5,01	24,68
2011	-0,9933871	71,24	4,60	4,97	24,64
2012	-0,9921743	71,73	4,83	4,95	24,73
2013	-0,9911636	71,51	4,98	4,94	24,56
2014	-0,9933578	71,94	4,65	4,95	24,89
2015	-0,9868415	70,57	5,61	5,00	25,15
2016	-0,9873481	71,10	5,57	5,07	26,54
2017	-0,9892647	71,38	5,28	5,12	27,04
2018	-0,9901479	71,71	5,16	5,17	26,91
2019	-0,9897261	72,41	5,28	5,22	28,47

Table 10.3.3.1 Comparison of Employment data for South Africa, years 2010 - 2019

The benefits of SST are not uniform across sectors and agriculture may benefit from SST in terms of improved crop yields due to better weather forecasting and satellite imagery, while services may benefit from improvements in communication and information technologies (Martin and Scott, 1996). The ratio can help to measure these differential impacts. It is proposed that the employment ratio can be relevant for policymakers in understanding the relationship between employment structures and labour productivity in the context of SST investment, and can help tailor policies to maximise the socio-economic benefits, especially in terms of labour market interventions and educational programs (Freeman and Soete, 1997).

Labour Productivity	Coefficient	Std. Dev	t	P>t	95% Confidence Interval	
Employment Ratio	-0.0359	0.0153	-2.34	0,020	-0.0661	-0.0057
Dependency ratio of older people	-0.0004	0.0001	-2.65	0,008	-0.0007	-0.0001
Constant	0.3275	0.1030	3.18	0,002	0.1251	0.5298
R-squared	0.0202		No. of Obs.	630		
Adj. R-squared	0.0820		F(2,586)	6.05		
Root MSE	0.1975		Prob>F	0,0025		

Table 10.3.3.2 Labour Productivity Regression with Employment Ratio

The regression output in Table 11.3.3.2 above shows that the education ratio is a predictor of labour productivity. The negative coefficient for the employment ratio suggests that, within the data sample analysed, an increase in the employment ratio is associated with a decrease in labour productivity. This could be for a number of potential reasons highlighted above and summarises the structural differences within the employment sector.

10.3.4. Access to Finance Ratio

A well-functioning financial system is known to allocate resources to the most productive uses, thereby enhancing overall economic output and productivity (Beck et al., 2000). Below in Table 11.3.4.1 is a selection of the SSA panel dataset from South Africa over the period 2010 to 2019, this allows for a view of the movements of the access to finance ratio over the period.

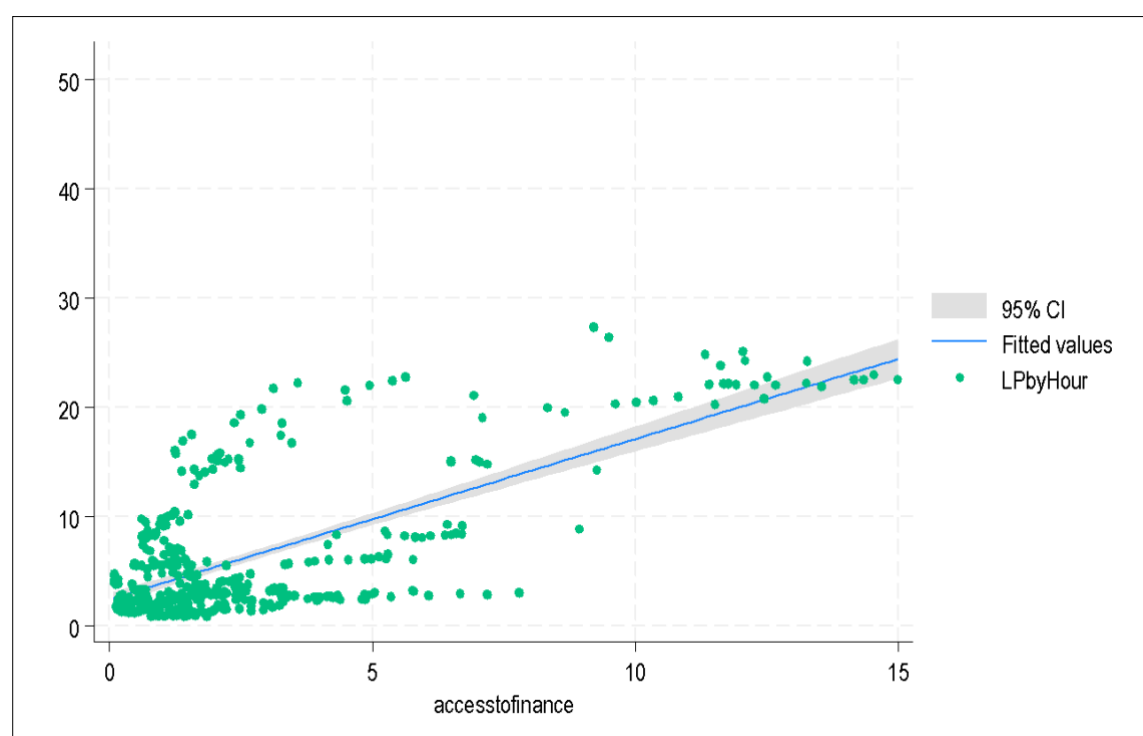
South Africa	Access to Finance Ratio	Inflation	Domestic Credit to the Private Sector	Lending Interest Rate	Government Spending as per Budget
2010	3,982936	4,09	124,55	9,83	101,42
2011	4,202658	5	119,24	9	98,95
2012	4,614369	5,72	125,5	8,75	99,97
2013	4,857282	5,78	127,4	8,5	99,24
2014	4,543839	6,13	129,17	9,12	99,24
2015	4,312085	4,54	127,5	9,42	99,24
2016	3,701179	6,57	124,63	10,46	
2017	3,831661	5,18	127,24	10,38	
2018	3,644387	4,52	118,64	10,08	
2019	3,610373	4,12	118,22	10,12	

Table 10.3.4.1 Comparison of Financial data for South Africa, years 2010 – 2019

Labour Productivity	Coef.	Std. Error	t-value	p-value	[95% Confidence Interval]		Sig
Access to Finance	1.466	.061	23.99	0.000	1.346	1.586	***
Constant	2.427	.228	10.66	0.000	1.981	2.873	***
Mean dependent var	6.294		SD dependent var	6.301			
R-squared	0.490		Number of obs	426			
Chi-square	575.678		Prob > chi2	0.000			
*** $p < .01$, ** $p < .05$, * $p < .1$							

Table 10.3.4.2 Labour Productivity Regression with Access to Finance Ratio

Table 11.3.4.2 displays the results of the regression model assessing the impact of access to finance on labour productivity, the coefficient for access to finance is highly significant and positive, suggesting a robust relationship between access to finance and labour productivity per hour. This implies that as access to finance improves, measured as the ratio of domestic credit to the private sector over the lending rate, labour productivity increases substantially. The statistical significance of this finding underscores the importance of financial access as a key input for enhancing labour productivity.



Graph 10.3.4.1 SSA Countries: Actual versus Predicted values for Labour Productivity

The scatter plot in Graph 4.3 suggests that at lower levels of access to finance, interventions could have varying effects on labour productivity, but as access improves, the productivity gains become more predictable. This analysis aligns with economic theory that posits access to finance as a catalyst for economic growth and productivity. By providing the private sector with the necessary capital for investment and expansion, financial access plays a crucial role in facilitating innovation, improving efficiency, and promoting entrepreneurship (Levine, 2005).

The findings contribute to the substantial body of literature that emphasises financial development as a cornerstone of economic advancement. The results advocate for policies that improve access to finance as a means to boost labour productivity, which is a key determinant of economic growth and competitiveness, and key to the successful implementations of SST programmes.

10.3.5. Technology Efficiency Ratio

The technology efficiency ratio can be understood as the return on investment of innovation and technology expenditure and the ratio is examined to assess the impact of SST investments on socio-economic benefits, particularly labour productivity. It is a measure of the output of innovation activities (patents receipts lagged by 3 years) relative to the inputs (R&D expenditure), which can be seen as an indicator of innovation efficiency or productivity. It reflects how effectively R&D investments are translated into tangible outcomes, in this case, patented technologies (Hall et al., 2005). The use of a 3-year lag for patent receipts accounts for a time-to-patent process, which includes the time required for R&D activities to result in patentable inventions, and the time needed for these inventions to go through the patent application and granting process. This lag structure aligns with empirical observations of innovation processes and patenting lags (Pakes and Griliches, 1980). In the field of SST, R&D projects are often complex and long-term, making the lag between R&D spending and resulting patents particularly relevant. This delay is due to the time required for space technology development, testing, and certification (European Space Agency, 2004). Patents are often linked to productive economic activities and are considered a proxy for economically valuable innovations. By measuring the financial returns from patents (receipts) relative to R&D expenditure, the technology efficiency ratio can serve as a proxy for the economic impact of innovation activities, which is directly relevant to labour productivity (OECD, 2009). For policymakers, understanding the efficiency of R&D expenditures in generating patents can help in the assessment and design of innovation policies, especially in SST where investments are significant and the potential for socio-economic benefits is high (European Commission, 2010).

The results in Table 11.3.5.1 below show that as technology efficiency improves, labour productivity is likely to increase, contributing to broader economic development and growth. The results also imply that improving technology efficiency should be a key focus area for policymakers in SSA to enhance labour productivity. Investments into technology and related infrastructure could yield significant productivity gains.

Labour Productivity	Coef.	Std. Error	t-value	p-value	[95% Confidence Interval]		Sig
Technology Efficiency Ratio	0.0135	.0019	6.81	0.000	0.0095	0.0175	***
Constant	5.0998	1.3036	3.91	0.000	2.4756	7.7239	***
Root MSE	7.1286						
R-squared	0.5019		Number of obs		48		
F(1,46)	46.36		Prob > F		0.000		
*** $p < .01$, ** $p < .05$, * $p < .1$							

Table 10.3.5.1 SSA Data: Regression Labour Productivity and Technology Efficiency Ratio

Below in Table 11.3.5.2 is a selection of the SSA panel dataset from South Africa over the period 2010 to 2019, this allows for a view of the movements of the technology efficiency ratio over the period.

South Africa	Technology Efficiency Ratio	R&D Expenditure	Researcher in R&D	Journal Papers	Patent Applications by Residents	Patent Receipts	Patent Payments
2010	2,05480	0,66	365,5	7575,5	821	113 985 145	1 941 103 069
2011	1,87088	0,67	386,8	8266,46	656	139 891 552	2 118 146 097
2012	1,75054	0,67	404,72	8930,94	608	135 297 384	2 017 325 060
2013	1,76986	0,66	434,85	9547,56	638	135 485 212	1 936 693 353
2014	1,14347	0,71	432,16	10192,54	802	136 803 953	1 732 081 250
2015	0,95791	0,73	472,31	10914,22	889	126 114 071	1 641 134 757
2016	0,99696	0,75	492,04	11924,93	704	139 258 221	1 831 242 821
2017	1,39830	0,76	517,72	12851,91	728	157 684 449	1 883 350 101
2018	1,88388	0,69		13422,23	657	182 504 287	1 540 106 740
2019	1,58312	0,62		14999,24	567	150 760 779	1 356 151 183

Table 11.3.5.2 Comparison of Research and Innovation data for South Africa, years 2010 – 2019

10.3.6. Data Set

The SSA Data Set is comprised of data for indicators for 48 SSA countries from the years 1996 to 2021. Below is a data sample of the SSA countries to illustrate the economic overview of the SSA region and the variations that exist. This sample was selected by participation in the SKA Africa Programme.

Indicator	Botswana	Ghana	Kenya	Madagascar	Mauritius	Mozambique	Namibia	South Africa	Zambia
Employment in Agriculture	20%	30%	54%	64%	6%	70%	22%	5%	50%
Labour Productivity	22,76	6,67	4,44	1,87	26,4	2,03	14,79	22,14	4,57
New Business Density	12,19	0,87	1,37	0,11	7,05	0,29	0,78	10,66	1,01
Reliance on Natural Resources	5	4	1	3	1	3	5	4	5
Regulatory Environment	4	3	2	1	5	1	4	3	1
Youth Population	33%	37%	38%	39%	44%	16%	36%	29%	43%
Access to Finance	3	5	3	2	3	3	1	2	1
Urbanisation	72%	59%	29%	40%	38%	41%	54%	68%	46%
SSA Trade imports	67%	8%	8%	5%	26%	10%	63%	10%	42%
FDI	0,56%	5,68%	1,33%	3,36%	3,36%	22,70%	-1,41%	1,32%	0,83%
Informal Sector: Output	28%	38%	27%	37%	20%	28%	25%	24%	0%
Informal Sector: Labour Force	71%	78%	86%	95%	49%	95%	44%	55%	86%
Digital Divide	3	3	5	1	5	1	3	5	3
Research and Development	54%	38%	69%	1%	37%	31%	34%	62%	28%
Innovation	4	3	5	1	5	2	2	5	2
Technology Adoption	0,47	0,45	0,45	0,25	0,62	0,25	0,38	0,64	0,34
Primary Enrolment / Secondary Enrolment	1,35	1,40	1,83	3,88	1,02	3,04	1,74	0,96	1,67
Employment in Services	62%	49%	39%	27%	70%	21%	61%	72%	40%
GDP per Capita	6349	2254	1872	478	8633	4157	5656	985	1137
Unemployment	25%	5%	6%	2%	7%	21%	29%	13%	6%
Sanitation	80%	23%	33%	12%	96%	36%	35%	78%	31%

Table 10.3.6.1 Summary country list from SSA, comprised of the SKA Africa countries, 2018

10.3.7. Hypothesis Testing

This research has shown that labour productivity can serve as a useful predictor of the socio-economic impact of investment into SST, and labour productivity can provide insights into the potential effects of this type of investment. Investment, particularly in capital and technology, can enhance productivity levels and contribute to economic growth. When labour productivity increases, it suggests that workers are producing more output per unit of input, indicating higher efficiency and potential economic expansion. Higher labour productivity resulting from investment can lead to increased output, improved competitiveness, and overall economic development. Investment that improves labour productivity can stimulate job creation in various sectors of the economy and when businesses invest into capital equipment, technology, and skills development, they can increase production capacity and expand operations, leading to greater employment opportunities, reduced unemployment rates, and improved living standards.

As discussed, when productivity improves, workers can produce more output within the same timeframe, potentially leading to higher wages and income growth, thus improvements in GDP per capita. In terms of the national accounts, increased income can positively impact household consumption, savings and investment, improve competitiveness and would contribute to poverty reduction. This is highlighted in the socio economic impacts in the case study in Chapter 6.

It is important to note that the impact of investment into SST on labour productivity and the associated socio-economic outcomes may vary depending on the specific context, sector, and policies in place. Additionally, other factors such as institutional quality, access to finance, infrastructure, and human capital development also play significant roles in shaping the socio-economic impact of investment.

While there is not a specific mathematical model that directly relates labour productivity to socio-economic impact resulting from SST investment in developing countries, it is a starting point to use established economic growth models as a framework to analyse this relationship. These models often include labour productivity as a key determinant of economic growth and can be adapted to explore the impact of SST investment. The Solow Growth Model, which incorporates labour productivity as a crucial factor in economic growth, can be adapted to include variables related to SST investment. Below is a simplified representation of integrating labour productivity, SST investment, and socio-economic impact within a Solow-like framework.

The Production Function:

In the Solow Model, output (Y) is a function of labour (L) and capital (K), represented as:

$$Y=A \cdot f(K,L)$$

Where:

A represents total factor productivity (which can be influenced by technological progress and science investment).

K is the capital stock.

L is the labour force.

Investment in Science and Technology:

Introduction of an additional term to represent the effect of science and technology investment (I_{ST}) on total factor productivity (A):

$$A = A_0 + I_{ST}$$

Where:

A_0 represents the initial level of total factor productivity.

I_{ST} represents the investment in science and technology.

Labour Productivity:

Labour productivity (LP) can be represented as output per worker:

$$LP = Y/L$$

Socio-Economic Impact:

Socio-economic impact (SEI) can be related to labour productivity (LP) and science and technology investment (I_{ST}):

$$SEI = LP \cdot I_{ST} \quad \text{Equation 10.3.7.1}$$

Equation 11.3.7.1 suggests that socio-economic impact is a function of both labour productivity and investment in SST. To support this argument, the parameters of the model will be estimated using empirical data from the SSA countries and how SST investment affect total factor productivity (A), labour productivity (LP), and ultimately, socio-economic impact (SEI) will be examined. While this is a simplified representation, it provides the framework to explore the relationships among labour productivity, SST investment, and socio-economic impact. This research has tested the following hypotheses:

Hypothesis One

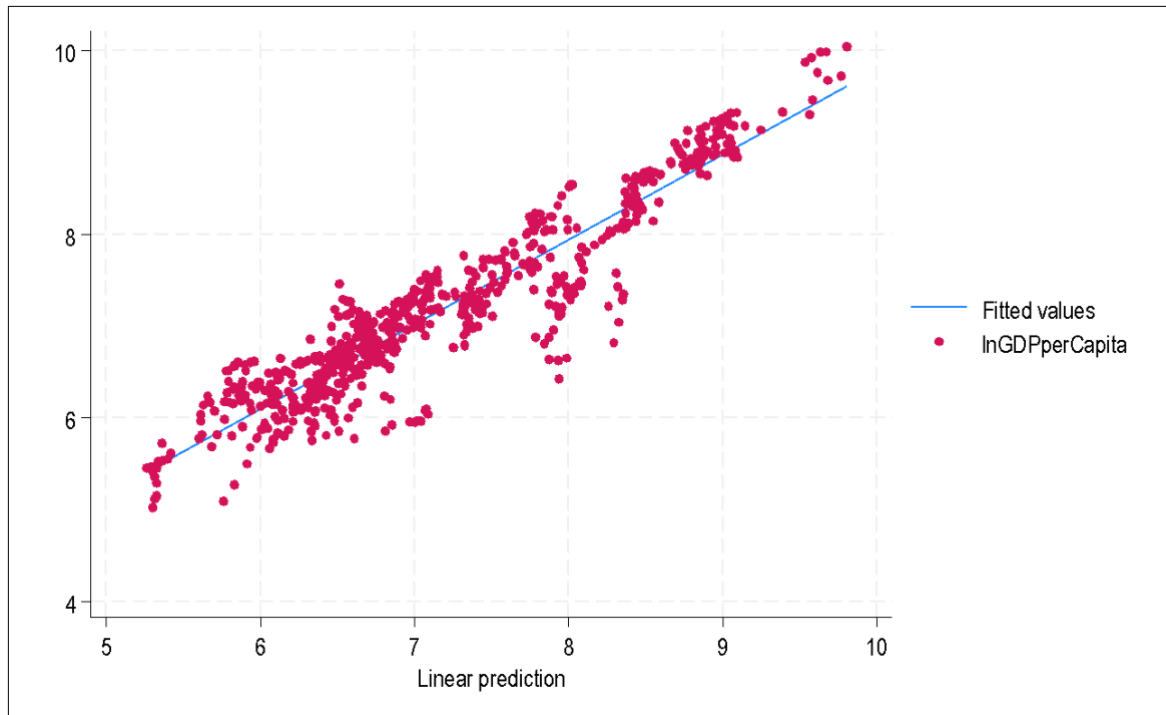
H0: Labour productivity is not a significant determinant of the socio-economic impact of SST investment in developing countries.

H1: Labour productivity is a significant determinant of the socio-economic impact of SST investment in developing countries.

It has been shown that labour productivity can be used as a proxy for socio-economic impact and in section 3.3.1 it was concluded that labour productivity is a significant determinant of GDP per Capita. Improvements in GDP per capita, is associated with positive socio-economic outcomes, such as poverty reduction, improved health, and education outcomes (OECD, 2018). RND Expenditure and Patent Receipts have a statistically significant impact on labour productivity and a non-significant, or in the case of patent receipts a small impact, directly on GDP per Capita. Thus the statistical test selected for this hypothesis test is Instrumental Variable regression using the General Method of Moments, with RND Expenditure as a percentage of GDP and patent receipts as the instrumental variables. The resultant Hansen's J chi-squared statistic is 0.084574 with a p-value of 0.7712 , thus the test assesses the validity of the instruments used in the model and the instruments are appropriately exogenous.

GDP per Capita (Log-Log)	Coef.	Std. Error	t-value	p-value	[95% Interval]	Confidence	Sig
Labour Productivity	1.1111	0.2952	37.65	0.000	1.10533	1.1689	***
Constant	5.4182	0.0754	71.89	0.000	5.2705	5.5659	***
Endogenous	Labour Productivity		SD dependent var		36686.012		
exogenous	RND Exp, Patent receipts		Number of obs		73		
Wald chi2(1)	1417.20		Prob > Chi2		0.0000		
R-Squared	0.95503		Root MSE		0.26773		
*** $p < .01$, ** $p < .05$, * $p < .1$							

Table 10.3.7.1 IV Regression Labour Productivity Regression with Instruments: RND Expenditure and Patent receipts



Graph 10.3.7.1 Residuals versus Actual Values: RND Expenditure as a percentage of GDP

The results from Table 11.3.7.1 show that H_0 is rejected at the 5% level. The analysis indicates that there is a significant relationship between labour productivity and the socio-economic impact of SST investment in developing countries, with a p-value less than 0.05. Consequently, we reject the null hypothesis that labour productivity is not a significant determinant of the socio-economic impact. These findings suggest that policies aimed at improving labour productivity may be effective in enhancing the socio-economic benefits of SST investments in developing countries.

Hypothesis Two

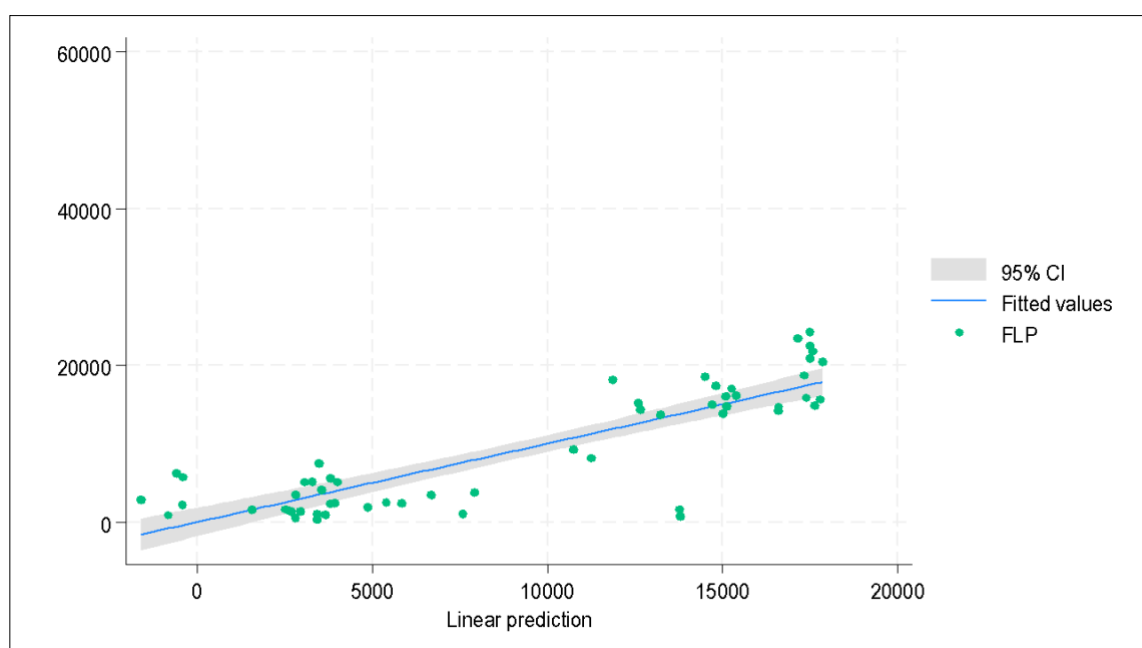
H_0 : Labour Productivity is not related to the informal sector output in an economy

H_1 : Labour Productivity is related to the informal sector output in an economy

Formal Labour Productivity	Coef.	Std. Error	t-value	p-value	[95% Confidence Interval]	Sig
Informal Output	-440.605	132.398	-3.33	0.001	-700.101 -181.11	***
Informal Employment	-131.122	45.931	-2.85	0.004	-221.144 -41.1	***
Constant	31642.009	2131.034	14.85	0.000	27465.259 35818.758	***
Mean dependent var		9124.719	SD dependent var		7600.997	
R-squared		0.734	Number of obs		57	
Chi-square		176.740	Prob > chi2		0.000	
*** $p < .01$, ** $p < .05$, * $p < .1$						

Table 10.3.7.2 SSA Data Labour Productivity Regression with Informal Output and Informal Workforce

The results in Table 11.3.7.2 show that the highly significant p-values ($p < 0.01$) for both informal output and informal employment indicate strong evidence against the null hypothesis H_0 . Thus, we reject H_0 in favour of the alternative hypothesis H_1 , concluding that labour productivity is indeed related to informal sector output in the economy. The R-squared value of 0.734 shows a good fit for the model, suggesting that the independent variables explain a substantial portion of the variance in formal labour productivity. The regression analysis provides evidence that informal sector activities significantly impact formal labour productivity, highlighting the importance of addressing informal sector challenges to improve economic outcomes.



Graph 10.3.7.2 Regression Residual plot: Formal Labour Productivity

Hypothesis Three

H0: The Labour Productivity difference does not impact GDP per capita

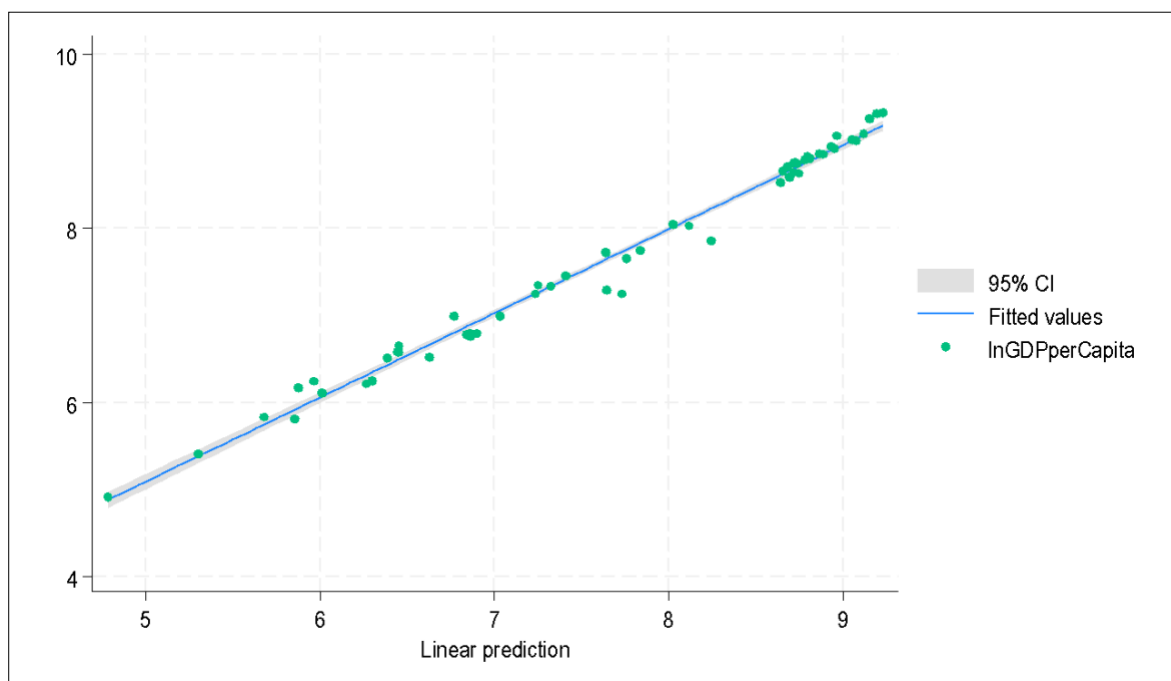
H1: The Labour Productivity difference does impact GDP per Capita

Where the Labour Productivity difference is defined as Formal Labour Productivity - Informal Labour Productivity.

Ln(GDP per Capita)	Coef.	Std. Error	t-value	p-value	[95% Confidence Interval]		Sig
Ln(Labour Productivity Difference)	.985	.015	65.11	0.000	.955	1.016	***
Constant	-.771	.131	-5.88	0.000	-1.034	-.508	***
Mean dependent var		7.692		SD dependent var		1.174	
R-squared		0.987		Number of obs		57	
F-test		4238.899		Prob > F		0.000	
Akaike crit. (AIC)		-65.376		Bayesian crit. (BIC)		-61.290	
*** $p < .01$, ** $p < .05$, * $p < .1$							

Table 10.3.7.3 SSA Regression of GDP per Capita and the Labour Productivity Difference

The regression results shown in Table 11.7.3.3 show that we reject the null hypothesis H_0 at the 1% significance ($p < 0.01$) and the narrow confidence interval indicates a robust and reliable relationship between the labour productivity difference and GDP per capita. This finding implies that reducing the gap between formal and informal labour productivity could positively influence GDP per capita. Policies aimed at narrowing the labour productivity gap between the formal and informal sectors could have substantial positive effects on GDP per capita. Fostering productivity in the informal sector to bring it closer to the formal sector's levels can boost overall economic performance. This relationship underscores the importance of addressing productivity disparities between sectors to enhance overall economic growth.



Graph 10.3.7.3 GDP per Capita and the Labour Productivity Difference

10.3.8. Propensity to value time in terms of money (PVTM)

This indicator as proposed in the literature review, seeks to combine the concept of the time value of money with productivity differentials between the formal and informal sectors to create a new metric: the Propensity to Value Time in terms of Money (PVTM). The concept of the time value of money is a foundational principle in financial theory, capturing the intrinsic value of money available in the present over future sums, a principle that has been presented in the work of Fisher (1930). This principle underscores the formulation of interest rates, a central theme in Samuelson's (1937) discussion on the quantification of utility and economic decision-making. As such, interest rates are pivotal in dictating the dynamics of savings and investments, which Fisher (1930) identifies as crucial engines for economic growth.

This study introduced PVTM, an indicator formulated from the inverse of the lending interest rate, adjusted by the relative productivity in formal versus informal sectors, where the role of the informal sector in economic development remains indeterminate as demonstrated by La Porta and Shleifer (2014). By assessing the lending rate of a country one has a picture of a part of its institutional and economic position. World Bank (n.d.) notes that the development relevance of this indicator is in that both banking and financial systems enhance growth, the main factor in poverty reduction. At low levels of economic development commercial banks tend to dominate

the financial system, while at higher levels domestic stock markets tend to become more active and efficient. The argument could be made that the level of the interest lending rate provides an indication of the propensity to value time in terms of money – that is, a lower interest rate would indicate a higher propensity to value time in terms of money, however when taking the inverse of the interest rates, a larger differential is observed for the purposes of practical analysis.

The PVTM is posited to provide a quantifiable measure of the economic utility of time, facilitating an understanding of financial attitudes and temporal preferences within different economic structures. Cultural attitudes towards work and entrepreneurship can significantly impact both formal and informal labour productivity. In many societies, there is a strong tradition of self-employment and small-scale entrepreneurship, which is often captured within the informal sector. In such contexts, cultural norms may favour flexibility, familial or community-based business practices, and cash-based transactions that fall outside of formal channels (De Soto, 2000). The historical context of a country's development often shapes its labour market. In some African nations, for instance, colonial legacies have influenced the formalisation of certain industries, while others have remained predominantly informal due to cultural continuity and resistance to changes imposed from outside (Meagher, 2013). The ease of business entry, regulatory quality, and the enforcement of property rights are also culturally influenced. Where bureaucratic obstacles to formal business are high, cultural adaptability may lead to a vibrant informal sector (La Porta & Shleifer, 2014). Cultural factors influence the education system's focus, potentially affecting labour productivity. In some regions, there may be a greater emphasis on vocational training relative to academic or technical education, which could impact the skill sets available in the labour market (Appleton, Balihuta, 1996). Cultural practices often include informal apprenticeships and knowledge transfer, which contribute significantly to informal labour productivity. This form of human capital development, while not captured in formal metrics, is crucial in many African economies (King, 1996). The way cultural groups view labour relations and collective bargaining can impact productivity. In some cultures, there is a strong emphasis on consensus and communal decision-making, which can affect both the organisation of labour and productivity outcomes (Hyden, 1983).

To briefly revisit the rationale behind this indicator and its potential implications, the inverse of the lending interest rate is used to reflect the time value of money. Conventionally, a high interest rate indicates a high money-time preference, meaning economic agents prefer current consumption over future consumption. Inversely, a low interest rate suggests a lower time preference, or a greater willingness to defer consumption for future benefits. The difference between formal and informal labour productivity, normalised by formal labour productivity, is a way to capture the relative efficiency of the formal sector versus the informal sector. If formal

labour productivity is significantly higher, this ratio will approach zero, whereas if informal productivity approaches or surpasses formal productivity, the ratio increases. By multiplying the inverse interest rate with the productivity differential, this research proposes an index that correlates a country's valuation of time in monetary terms with its labour efficiency. The underlying assumption is that an environment with a high time valuation and higher relative formal sector productivity is more conducive to economic activities, including large-scale programmes in SST. A high PVTM value might suggest that the environment undervalues future returns since it's attached to a higher interest rate, and possibly that the informal sector is behind the formal sector in productivity, which could mean less structural differentiation in the economy. For SST programmes, which typically require long-term investments with deferred returns, this could imply a challenging environment. As such, rigorous planning, risk management, and sustainability measures would be critical. As mentioned, cultural and time perspectives are important and have to be factored in, as culture and tradition can significantly influence economic behavior and the interpretation of interest rates and productivity. Differing attitudes towards time and money across societies impact how investment in long-term projects is perceived and managed.

The PVTM indicator attempts to link economic theory with practical measures of productivity and cultural attitudes towards time and money. It's a multifaceted approach that tries to capture complex socio-economic dynamics. There have been challenges with this approach as the assumption that the interest rate inversely represents the time value of money in a linear fashion may not hold in all economic contexts, especially in volatile economies or where interest rates are manipulated by central banks. The normalisation of the productivity differential by formal sector productivity alone might not account for the size and economic significance of the informal sector, which can vary widely between countries. The indicator still requires substantial empirical testing to validate its effectiveness in predicting or explaining economic behaviour, especially in the context of large-scale, long-term investment projects like those in SST.

Incorporating the PVTM in predictive models for labour productivity presents a methodological challenge if PVTM itself is partly derived from measures of labour productivity. If the calculation of PVTM includes labour productivity, using it as a predictor for labour productivity would introduce circularity, which means one would be predicting a variable with a derivative of itself. This is a form of endogeneity and can bias the estimates. Given that PVTM is intended to reflect a societal or economic environment's time-value orientation, it would be more appropriate to use it as a balancing factor or a moderating variable rather than a direct predictor. PVTM could be considered a moderating variable that affects the strength or direction of the relationship between other independent variables and labour productivity. For instance, the impact of investment into SST on labour productivity might be stronger in environments with a high PVTM.

One could use PVTM as a weighting factor in the analyses. For instance, when aggregating data from different sectors or regions, one could weight observations by their PVTM to account for the differing time-value orientations across these sectors or regions. PVTM can be included as a control variable in models predicting labour productivity from other variables not including labour productivity itself. By controlling for PVTM, one can account for the variation in labour productivity that is due to differences in the time-value orientation of different environments.

To further investigate this concept, a factor analysis was performed to identify if there is a hidden cultural factor that influences labour productivity. This research selected the use of indicators for tourism and informal output as proxies for cultural aspects, which help explain variations in labour productivity. This approach simplifies the complexity of multiple variables into a single, interpretable factor. In running a factor analysis on the SSA data using the dependent variable as labour productivity and the independent variables the education, employment, technology efficiency and access to finance ratios, one factor was retained based on eigenvalues and the proportion of variance explained. In other words, the factor analysis shows that a single factor explains a significant portion of the variance in the variables. This factor likely represents a combination of cultural aspects, as seen through the strong relationships with tourism indicators and informal output in the regression results shown in Tables 11.3.8.1 and 11.3.8.2.

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	4.27844	4.12805	0.9653	0.9653
Factor2	0.15039	0.10139	0.0339	0.9992
Factor3	0.04901	0.05677	0.0111	1.0103
Factor4	-0.00776	0.02991	-0.0018	1.0085
Factor5	-0.03767	.	-0.0085	1.0000
LR test: independent vs. saturated: $\chi^2(10) = 168.96$ Prob> $\chi^2 = 0.0000$				

Table 10.3.8.1 Factor Analysis

Variable	Factor1	Uniqueness
Labour Productivity	0.9658	0.0673
Education Ratio	-0.9610	0.0765
Employment Ratio	-0.9436	0.1095
Technology Efficiency Ratio	0.7533	0.4325
Access to Finance Ratio	0.9820	0.0357

Table 10.3.8.2 Factor Loadings

The first factor has a significantly high eigenvalue (4.27844) compared to the others, indicating that it explains a substantial portion of the variance in the data. The subsequent factors have small

or negative eigenvalues, suggesting they do not contribute positively to explaining the variance. The likelihood ratio test for independence versus the saturated model has a high chi-square value with a p-value of 0.0000, indicating that the model significantly fits better than an independent model. The results suggest that while education, employment, and access to finance ratios are well captured by the identified factor and strongly related to labour productivity, there might still be other factors or variables impacting labour productivity that are not included in the model. Cultural aspects can indeed be a significant factor influencing labour productivity, and the omission might explain why some variance remains unexplained in the analysis.

The factor predominantly captures the variance in the labour productivity, Education Ratio, Employment Ratio, and Access to Finance Ratio, indicating these variables are closely related.

Although the Technology Efficiency Ratio loads on Factor 1, its higher uniqueness suggests there may be additional underlying factors influencing this variable not captured by Factor 1 alone. The significant LR test confirms that the model fits the data well, as shown in Table 11.3.8.2.

The use of tourism and informal output indicators as proxies for cultural aspects was deemed as a viable approach, as both reflect cultural attributes such as heritage, traditions, values, and local economic activities, which can influence labour productivity. Tourism is closely linked to cultural aspects because tourists are often attracted to destinations with rich cultural heritage, traditions, and values (Smith, 2009). Similarly, the informal sector often reflects local customs, traditional crafts, and community-based economic activities that are deeply rooted in culture (De Soto, 1989). Cultural events, historical sites, local traditions, and informal economic activities significantly impact tourism levels and informal output, making them indicative of a region's cultural vibrancy (Richards, 2018). Tourism contributes to the economy by generating income, creating jobs, and fostering economic development (World Tourism Organization, 2019). Regions with higher tourism often have better-developed infrastructure and services, which can indirectly impact labour productivity (UNWTO, 2018). Similarly, the informal sector plays a crucial role in many economies by providing employment, fostering entrepreneurship, and supporting livelihoods, especially in developing countries (De Soto, 1989). Limitations to this approach are that tourism and informal output may not capture all cultural aspects, especially those that are less visible or less commercialised (Smith, 2009). Both tourism and informal output are influenced by economic factors such as disposable income, travel costs, and regulatory environment, which may confound their use as pure cultural proxies (UNWTO, 2018). The impact of culture on tourism and informal output can also vary significantly between regions, making it important to contextualise findings (Richards, 2018). The regression results suggest that tourism and informal output indicators can significantly explain the variance in the factor, which represents underlying cultural factors impacting labour productivity. Given the high R-squared values, a substantial portion of the

variance in the factor score is accounted for by these indicators, supporting their viability as proxies for cultural aspects. The strong relationship between these indicators and the factor in the regression analysis supports this approach.

Factor 1	Coefficient	Std Error	t	P>|t|
Tourism	0.56	0.056	9.94	0.000
Constant	-12.01	1.21	-9.91	0.000
R-squared	0.8247			
Root MSE	0.4257		Observations	23
F(1,21)	98.82		Prob>F	0.000

Table 10.3.8.3 Regression Factor and Tourism

Factor 1	Coefficient	Std Error	t	P>|t|
Tourism	0.1005	0.0221	4.54	0.001
Constant	-1.648	0.563	-2.02	0.015
R-squared	0.673			
Root MSE	0.103		Observations	12
F(1,10)	10.64		Prob>F	0.011

Table 10.3.8.4 Regression Factor and Informal Output

In the realm of SST initiatives, where fiscal discipline and temporal efficiency are paramount, a substantial PVTM could signify a challenging environment for the administration of programmes. Given the complexity and scale of these projects, a high PVTM may forecast potential inefficiencies in budget and schedule adherence, necessitating the implementation of stringent management and risk mitigation strategies. The relevance of the proposition, in this context, is that a lower propensity to value time in terms of money has a significant impact on the success of SST programme investments, or in fact any project investments. A low propensity to value time in terms of money will negatively impact schedule and budget, two key failure points identified in an assessment of failed programmes.

The author concludes to move the full exploration of the PVTM to future studies as there is insufficient data available on the cultural and temporal aspects of SSA economies, and a meaningful and robust econometric study of this variable and its composition are beyond the scope of this work. Instead, the elements captured by the interest lending rate have been incorporated as a component of the Access to Finance Ratio, and the weighted factor of the informal and formal labour productivities have been incorporated into the SSA data analysis, discussed in Chapter 12.

11. Econometric Analysis

11.1. Introduction

The exploration of the proposed ratios influencing labour productivity initially employed a standard regression model. However, the complexity of the economic relationships soon made it evident that the associations were not strictly linear. To capture the proportional changes and elasticity between variables more accurately, the model transitioned to a log-log model, which renders the interpretation of coefficients as elasticities, providing a deeper understanding of the percentage changes in the dependent variable given a one percent change in the independent variables. Despite the improved fit, concerns about potential endogeneity led to an IV approach using the Generalised Method of Moments (GMM). This advanced technique allows for the correction of endogeneity bias, offering more reliable coefficient estimates. To further ensure the robustness of the findings, the xtabond estimator was used to conduct Arellano-Bond tests for autocorrelation. These tests are crucial for dynamic panel data models as they help to detect any correlation in the error terms across time, which, if present, could invalidate the model's results. Finally, recognising the possibility of inefficiency in the data, stochastic frontier analysis (SFA) was examined. The SFA model goes beyond the typical error structure of ordinary regressions by decomposing the error term into two parts: one capturing random noise and the other representing inefficiency. This allows for a more subtle understanding of how much of the variation in labour productivity is due to inefficiency versus random shocks, providing a comprehensive view of the labour productivity and highlighting areas for potential improvement. This stepwise progression through various econometric methods was the process of model selection and refinement in the economic analysis, ensuring that the conclusions drawn are both robust and useful.

The first set of results was conducted on world data, that is all countries in the World Bank Database over the period 1996 to 2020, as a baseline and then the tests are repeated on the SSA data.

Structural Equation Modelling (SEM) is the statistical analysis technique that is used for testing hypotheses about the relationships among observed and latent variables. It combines aspects of factor analysis and multiple regression. This allows for the examination of complex causal relationships and accounts for measurement error. SEM is used when the relationships between variables are hypothesised to be more complex than simple linear relationships, such as when variables influence each other reciprocally or through mediating variables. SEM also allows for the inclusion of latent variables, those variables that are not directly observed but are inferred from

other variables, which is useful in economics where constructs like intelligence, satisfaction, or socioeconomic status are often measured indirectly (Kline, 2015).

The SEM conducted on the SSA countries was estimated using maximum likelihood with missing values on the sample of 1,237 observations. The log likelihood of the model was -2893. The model investigated the impact of the proposed ratios on labour productivity per hour. The significant negative coefficients for the natural logs of the Education Ratio (-0.66), Employment Ratio (-0.71), Technology Efficiency Ratio (-0.19), and the Access to Finance Ratio (-0.29) suggest that increases in these ratios are associated with decreases in labour productivity per hour. All coefficients are significant at the 1% level. The constant term is also significant with a positive coefficient of 2.906. The model explains a significant portion of the variance in labour productivity, as indicated by the high R-squared value of 0.987. Additionally, the model includes covariances between the predictors, with significant relationships observed between Education Ratio and the Employment Ratio (0.26), the Education Ratio and the Access to Finance Ratio (-0.19), the Employment Ratio and the Technology Efficiency Ratio (-0.5), and the Employment Ratio and the Access to Finance Ratio (-0.45). These results show the complex interconnectedness between the education, employment, technological efficiency, and access to finance ratios in determining labour productivity in the SSA economies.

The SEM conducted on the global dataset comprised 6,258 observations and used maximum likelihood with missing values estimation. The model's log likelihood was -21702. The results indicate that the difference in labour productivity per hour is influenced by the proposed ratios. Specifically, the Education Ratio (-0.98), the Employment Ratio (-0.32), and the Technology Efficiency Ratio (-0.03) all have significant negative coefficients, suggesting that increases in these ratios are associated with decreases in labour productivity per hour. Conversely, the Access to Finance Ratio has a positive coefficient (0.14), indicating that better access to finance is associated with higher labour productivity per hour. All coefficients are significant at the 1% level. The constant term is also significant with a positive coefficient of 2.62. The model explains a substantial portion of the variance in labour productivity, with an R-squared value of 0.987. The covariance analysis reveals that significant relationships between the independent variables, such as the positive covariance between Education Ratio and the Employment Ratio (0.45), and the negative covariance between Education Ratio and Access to Finance Ratio (-0.26).

The findings highlight the importance of balanced improvements across these factors to enhance overall productivity and economic outcomes.

11.2. Econometric Analysis of the model: World Data

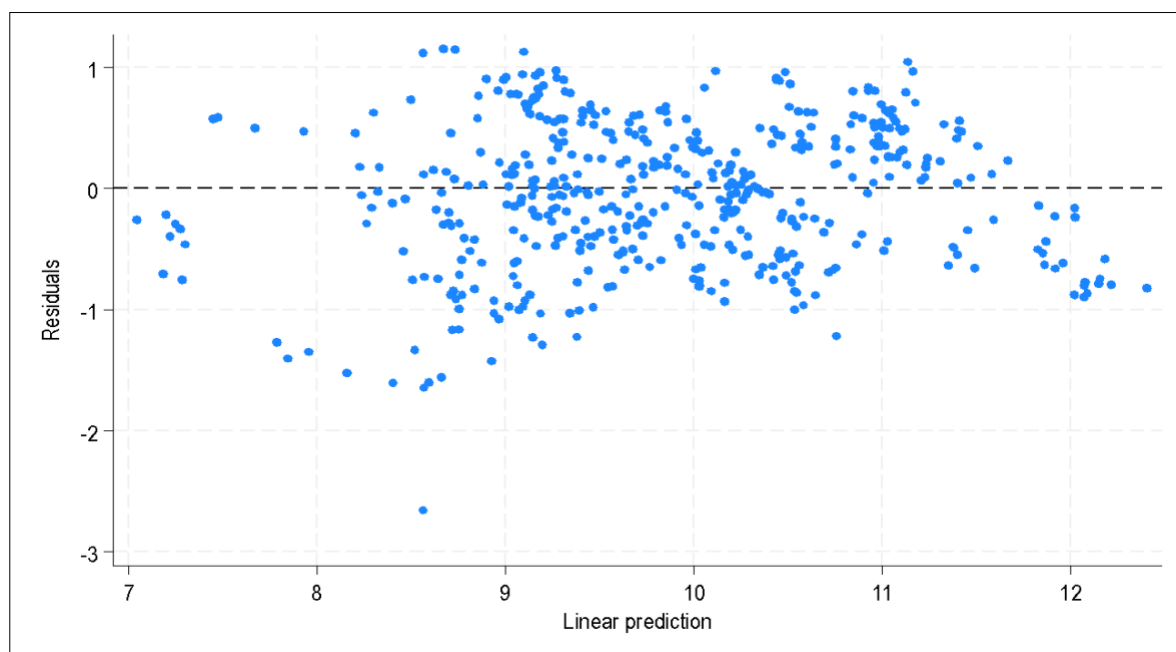
The results in Table 12.1.1 below were derived from using the instrumental variables Generalized Method of Moments (GMM) regression analysis on the global dataset. The negative and statistically significant coefficient of the Technology Efficiency Ratio suggests that an increase in the technology efficiency ratio is associated with a decrease in formal labour productivity. This could imply that higher patent receipts relative to R&D expenditure, indicating higher efficiency in technological innovation, might initially disrupt formal labour productivity due to adjustment costs or the reallocation of resources. The negative coefficient of the Education Ratio indicates that a higher education ratio, more foundational education relative to advanced education), is significantly associated with lower formal labour productivity. This suggests that economies with higher enrolments in pre-primary and primary education compared to secondary and tertiary education might have less skilled labour available for formal sectors, potentially reducing productivity. The significant negative impact of the employment ratio, employment in agriculture relative to employment in services, on formal labour productivity suggests that higher agricultural employment compared to service sector employment is associated with lower productivity in the formal sector.

Labour Productivity (log-log)	Coefficient	Std. Error	z-value	p-value	[95% Conf Interval]	Sig
Education Ratio	-0.5806	0.1243	-4.67	0.000	-0.8243 -0.3369	**
Employment Ratio	-0.3091	0.0270	-11.44	0.000	-0.3621 -0.2561	***
Technology Efficiency Ratio	-0.1061	0.0348	-3.04	0.002	-0.1744 -0.03775	***
Access to Finance Ratio	0.3675	0.0284	12.91	0.000	0.3117 0.4233	***
Constant	9.5190	0.2612	36.44	0.000	9.0069 10.0310	***
Root MSE 0.5255						
R-squared 0.7535		Number of obs 323				
Wald chi2(4) 1049.30		Prob > chi2 0.000				
*** $p < .01$, ** $p < .05$, * $p < .1$						

Table 11.2.1 World Data: Fixed effects regression results

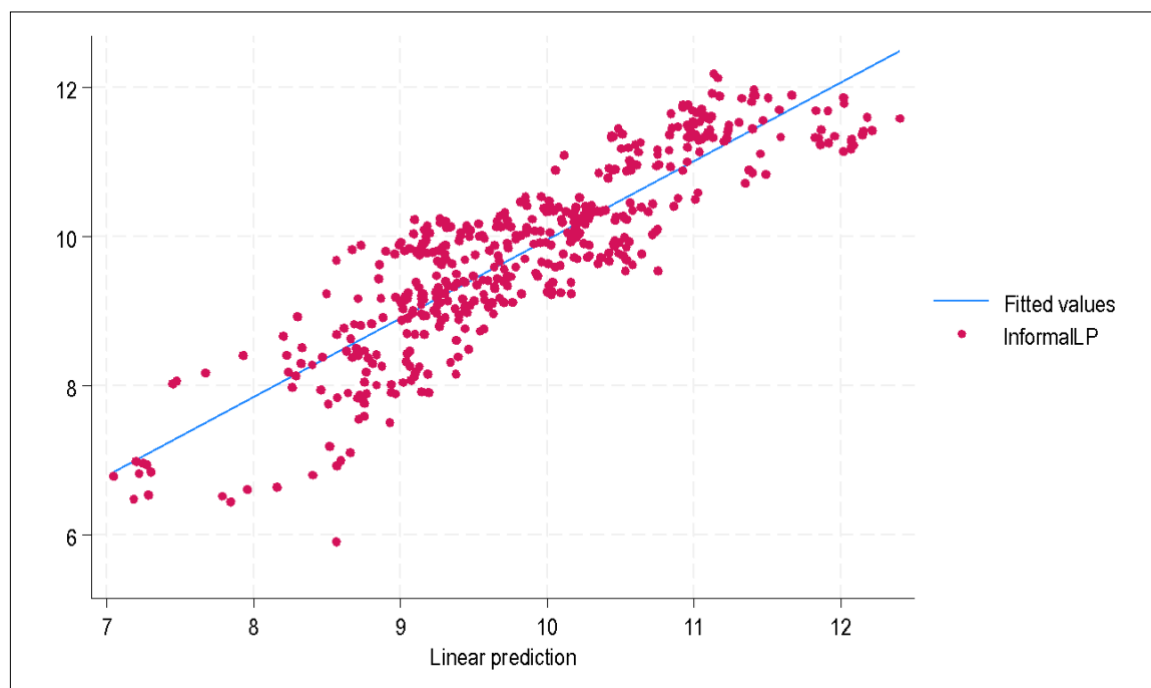
This might reflect the generally lower productivity levels in agricultural sectors. The positive and significant coefficient of Access to Finance indicates that better access to finance, higher domestic

credit to the private sector relative to the interest lending rate, significantly boosts formal labour productivity. This emphasises the importance of financial resources in enhancing productivity in the formal sector. The constant term is highly significant and positive, indicating that the baseline level of formal labour productivity is 9.51 when all explanatory variables are zero. High-tech exports was used as an IV for the Technology Efficiency Ratio due to endogeneity. High-tech exports are likely to be highly correlated with the Technology Efficiency Ratio. Countries or sectors that are efficient in converting R&D into innovative outputs are also likely to have higher levels of high-tech exports (OECD, 2011; World Bank, 2020). This relationship ensures that the instrument is relevant, meaning it has a strong correlation with the endogenous regressor. Countries with advanced technological capabilities and efficient innovation processes are often leaders in high-tech exports. These exports include products like electronics, pharmaceuticals, and other high-value goods that rely heavily on R&D and technological innovation (Keller, 2004). High-tech exports are plausibly exogenous to formal labour productivity, meaning they are not directly influenced by the productivity levels in the formal labour market. This is crucial for an instrument to be valid, ensuring that any effect on the dependent variable occurs through the endogenous regressor, here the Technology Efficiency Ratio, and not directly (Stock & Watson, 2015). High-tech exports depend more on international demand, global supply chains, and trade policies rather than domestic labour productivity in the formal sector. This separation helps in asserting the exogeneity of the instrument (OECD, 2011). Using high-tech exports as an instrument helps address the endogeneity problem where the Technology Efficiency Ratio might be correlated with unobserved factors affecting formal labour productivity.



Graph 11.2.1 World Data: IV GMM Regression Residuals Versus Prediction

For example, unmeasured managerial practices or industry-specific shocks could simultaneously influence both technological efficiency and labour productivity. By using an IV like high-tech exports, which is correlated with technological efficiency but not directly with labour productivity, we can obtain more reliable estimates of the causal effect (Angrist & Pischke, 2009). Endogeneity can cause bias in regression coefficients, leading to incorrect inferences. An appropriate IV mitigates this bias, providing a clearer picture of the causal relationship (Stock & Watson, 2015). This random distribution in the residual plot of the IV GMM regression, suggests that the model is well-specified and there are no obvious patterns in the residuals, which implies that the model's assumptions are likely valid. This consistency in the spread of residuals indicates homoscedasticity, meaning the variance of the residuals is constant across different levels of the predicted values. Homoscedasticity is a desirable property in regression models as it validates the assumption of equal variance. Outliers can indicate areas where the model does not fit the data well. These points should be investigated further but in this case are expected due to the nature of the global dataset. The absence of clear patterns supports the adequacy of the model used.



Graph 11.2.2 World Data: IV GMM Regression Residuals Versus Actuals Plot

11.3. Econometric Analysis of the model: SSA Data

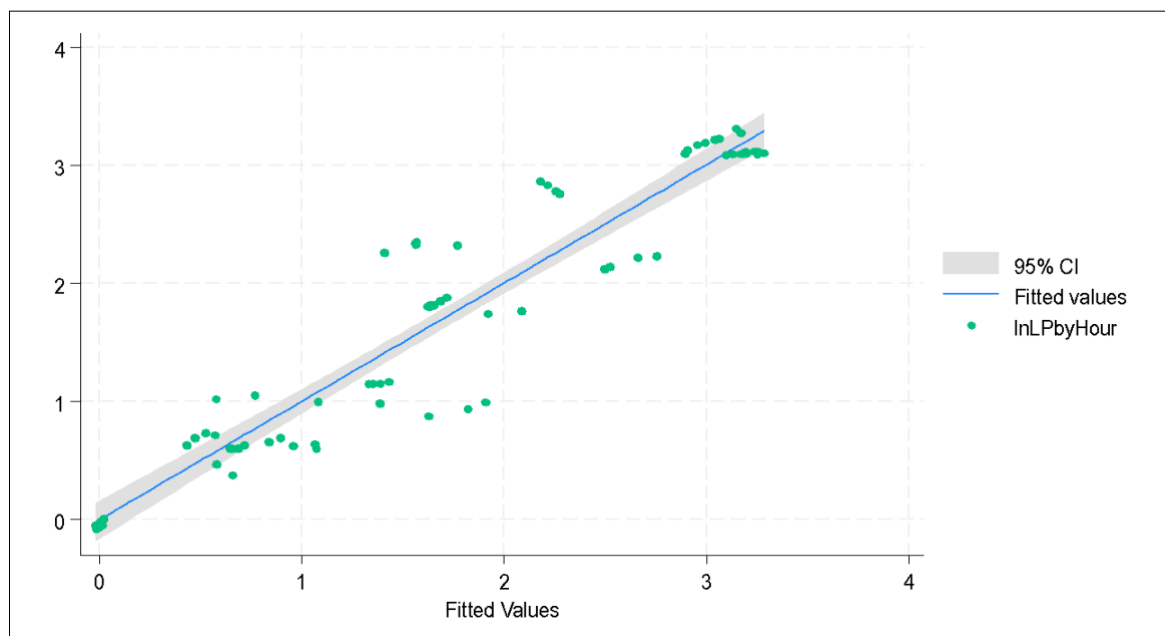
By comparing the results from the world data to those specific to SSA, one can gain insights into whether the proposed ratios; access to finance, employment, education, or technology efficiency ratios play a different role in this region. This comparison can shed light on specific policy interventions that might be effective for promoting economic development in SSA.

Labour Productivity (log-log)	Coefficient	Std. Error	t-value	p-value	[95% Conf Interval]	Sig
Education Ratio	0.276	0.128	2.15	0.035	0.02 0.532	**
Employment Ratio	-0.812	0.051	-16.00	0.000	-0.913 -0.71	***
Technology Efficiency Ratio	-0.006	0.003	-2.02	0.047	-0.012 0.00	**
Access to Finance Ratio	-0.15	0.067	-2.25	0.028	-.0283 -0.017	**
Constant	1.432	0.147	9.73	0.000	1.138 1.726	***
Mean dependent var		1.706		SD dependent var		1.123
R-squared		0.897		Number of obs		72
F-test		145.129		Prob > F		0.000
Akaike crit. (AIC)		66.721		Bayesian crit. (BIC)		78.105
*** $p < .01$, ** $p < .05$, * $p < .1$						

Table 11.3.1 Regression of Labour productivity and the predictive ratios

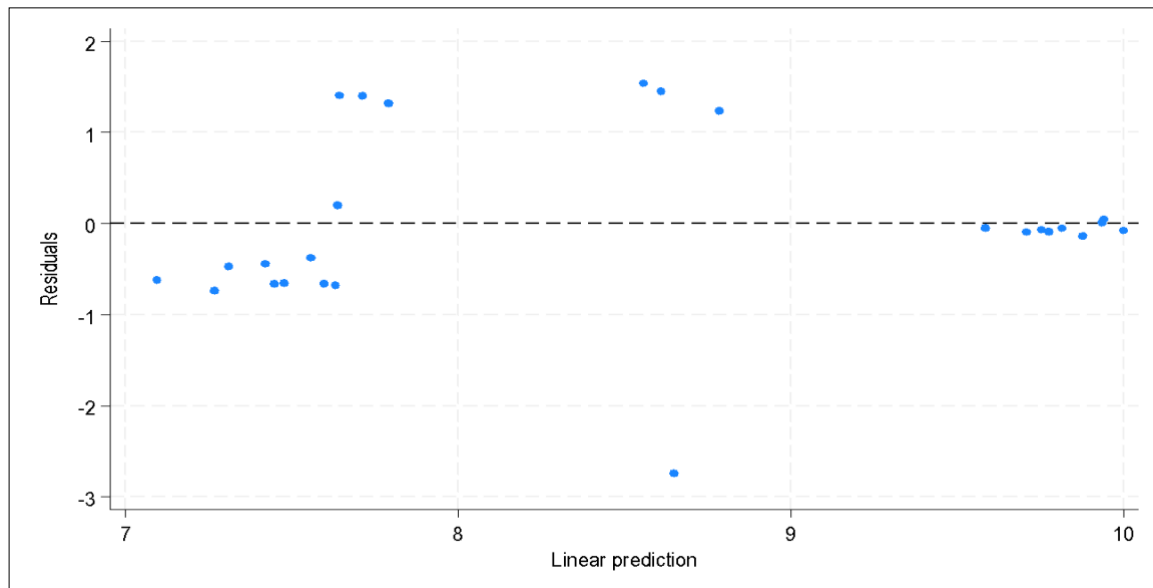
In this regression analysis focusing on SSA, the model evaluates the impact of access to finance, employment ratio, education ratio, and technology efficiency on labour productivity per hour, using a sample size of 72 observations. This sample size is too small for robust testing since the data available is limited. The high R-squared value of 0.89 suggests that about 89% of the variability in labour productivity can be explained by the model, which would be quite substantial, were the sample size larger. The results do show some differences from the global data, for example the coefficient for the access to finance ratio is negative (-0.15) and significant, indicating that within the context of SSA, increases in access to finance are associated with a decrease in labour productivity. This could be due to various factors such as misallocation of financial resources or inefficiencies in the financial sector. The employment ratio also has a significant negative

coefficient (-0.812), which is larger in magnitude than the coefficient for the access to finance ratio. This suggests that a higher employment ratio is even more strongly associated with decreased labour productivity. This might reflect underemployment or the employment of a large number of individuals in low-productivity and informal sectors. The education ratio shows a positive association with labour productivity (0.276), this result is not as statistically significant as expected. While education is typically seen as positive for productivity, in SSA, the quality or relevance of education to the labour market might not be aligned with obtaining productivity gains. The significance of the technology efficiency ratio is less significant when logged than in its raw form, thus it has not been logged for the regression. Additionally, based on the data scrutiny, the technology ratio should have a linear, rather than a multiplicative, relationship with labour productivity. The technology ratio is likely endogenous but a suitable instrument was not found as with the larger sample of global data. The coefficient for the technology efficiency ratio is modestly negative (-0.006) and significant, which contrasts with expectations as technological efficiency typically contributes positively to productivity. This could point to issues with technology adoption or adaptation in the region. The constant term is positive (1,432) and statistically significant. These findings point to a distinct set of challenges and dynamics in SSA that might not be as prevalent in the global context. The negative coefficients for variables traditionally seen as positive for growth suggest that more investigation into the quality and deployment of these factors is needed.



Graph 11.3.1 SSA Data: Residual Plot Informal Labour Productivity

Overall, these results offer a compelling argument for targeted policy interventions aimed at enhancing the quality and relevance of education, restructuring the labour market to optimise employment, improving the efficacy of technology implementation, and ensuring that financial systems are conducive to productive investment. Such measures are crucial to maximise labour productivity and, by extension, foster sustainable economic growth in SSA.



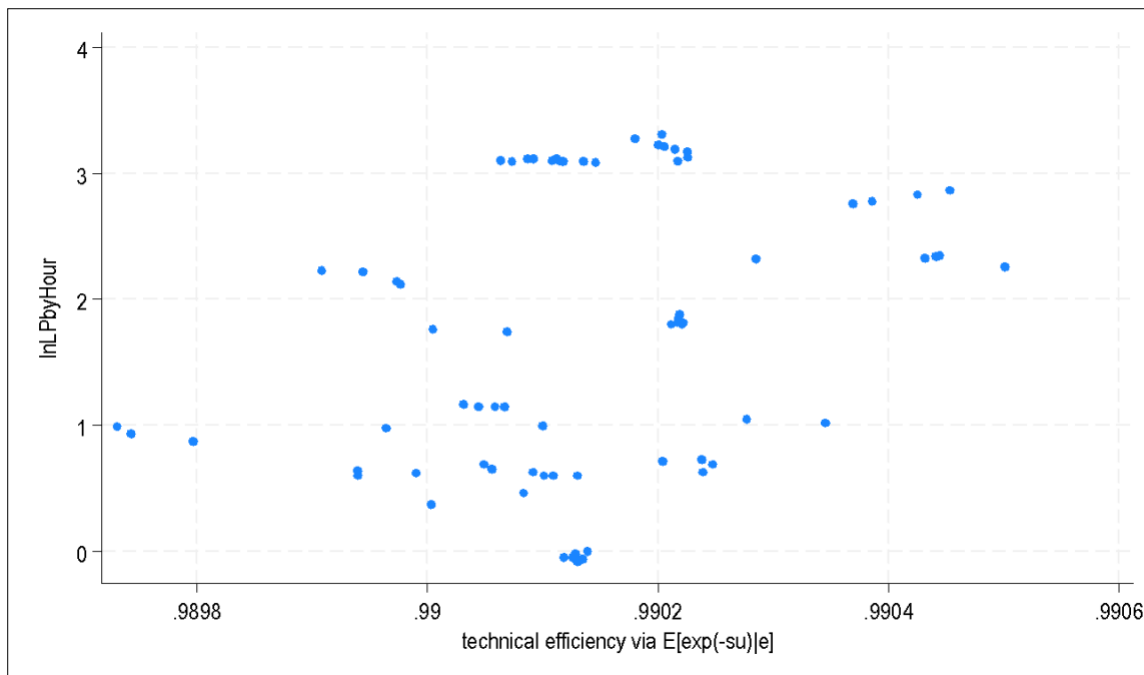
Graph 11.3.2 SSA Data: Predicted Values versus Actual Values Plot

Given the context of SSA and the assumption that countries are not operating efficiently, SFA is a useful method for the analysis. SFA is particularly appropriate when there is an assumption of inefficiency in the use of resources. In the case of SSA countries, where there are often significant constraints on resources and varying degrees of institutional and economic development, it's reasonable to assume that there might be inefficiencies in how countries convert inputs such as SST investments into the outputs labour productivity. The SFA for SSA, with its focus on labour productivity per hour, shows the picture of the economic factors shaping the region's output. The model's robust chi-square value affirms the strength of the relationships at play. Education emerges as a significant input for productivity, with its positive coefficient (0.276) underscoring the value of educational advancements in fostering economic efficiency, a finding that resonates with the widely acknowledged role of education in driving growth. In contrast, the employment ratio reveals a significant inverse relationship with productivity. The substantial negative coefficient (-0.812) suggests that an increase in the employment ratio is not inherently beneficial to productivity, alluding to a concentration of labour in low-productivity sectors or a misalignment between job creation and economic output.

Ln(Labour Productivity by Hour)	Coefficient	Std. Error	t-value	p-value	[95% Conf Interval]	Sig	
Ln(Education Ratio)	0.276	0.124	2.23	0.026	0.033	0.519	**
Ln(Employment Ratio)	-0.812	0.049	-16.59	0.000	-0.908	-0.716	***
Technology Efficiency Ratio	-0.006	0.003	-2.09	0.036	-0.012	0.000	**
Ln(Access to Finance Ratio)	-0.15	0.064	-2.34	0.019	-.0276	-0.024	**
Constant	1.442	0.476	3.03	0.002	0.509	2.374	***
Constant	-2.051	0.171	-11.96	0.000	-2.387	-1.714	***
Constant	-8.772	91.395	-0.10	0.924	-187.902	170.359	
Mean dependent var		1.706		SD dependent var		1.123	
Number of obs		72		Chi-square		623.841	
Prob > chi2		0.000		Akaike crit. (AIC)		70.721	
<i>*** p<.01, ** p<.05, * p<.1</i>							

Table 11.3.2 SFA For Labour Productivity Dependent On The Predictive Ratios

This presents a reminder that employment growth must be strategically aligned with industry needs to contribute positively to the economic cycle. The technology efficiency Ratio, with a slight negative value (-0.006), signals that technological advancements alone are insufficient to spur productivity. This hints at deeper issues such as inefficiencies in technology implementation or misalignments between technological investments and labour skills. Further complicating the output, the access to finance ratio also negatively correlates with productivity (-0.15), challenging the assumption that financial accessibility automatically catalyses output. This coefficient likely reflects the inefficiencies within financial institutions or a misdirection of financial resources away from productive sectors. With an AIC of 70.721, the model achieves a balance between fidelity to data and parsimony, striving for the simplest model without sacrificing explanatory power. The implications of this analysis for policy are multi-dimensional, emphasising that merely increasing employment and financial access is insufficient. Instead, a concerted focus on enhancing the quality of education and ensuring that technology and finance are effectively harnessed is required for realising the full potential of labour productivity in SSA. The results underscore the need for an integrated approach to economic reform, where systemic improvements in education and technology go hand in hand with strategic employment and financial sector reforms.



Graph 11.3.3 Labour Productivity And Technical Efficiency

The scatter plot, illustrating labour productivity against technical efficiency for Sub-Saharan Africa, shows neither a strictly positive or negative best fit line. Traditionally, higher technical efficiency is anticipated to correspond with increased productivity; however, the data suggests the possibility of an inverse relationship. This may be emblematic of the unique economic landscape of SSA, where several factors could contribute to this unexpected trend. Firstly, measurement issues are at play; the techniques used to quantify technical efficiency and productivity might not fully capture the realities of diverse SSA economies. The region's heavy reliance on informal sectors, which often escape conventional data capture methods, can lead to an underestimation of actual productivity (Diao, X., et al., 2017). Secondly, resource allocation inefficiency is a critical factor. Investments in technology and education may not be yielding the expected productivity returns due to misallocations or the absence of complementary assets like infrastructure or governance structures that are necessary for these investments to translate into productivity gains (Rodrik, D., 2016). Thirdly, the quality and relevance of technology being utilised within the labour force may be inadequate. In SSA, where resource constraints can limit access to state-of-the-art technology, the technology in use may not significantly enhance productivity or might be mismatched with the available skill sets (World Bank, 2019). Moreover, skill gaps within the workforce can lead to a situation where the labour force is unable to exploit technical efficiencies effectively. This

misalignment between the skills of the workforce and the demands of modern technology can result in higher technical efficiency not reflecting in labour productivity (UNESCO, 2017).

It is crucial to understand these dynamics within the broader context of SSA's development challenges. Policy interventions might need to focus on enhancing the quality of education, fostering skill development, improving technology access and infrastructure, and supporting the formalisation and integration of informal sectors into the broader economy (African Development Bank, 2018).

11.4. Adjusted Model

When the model from the previous section was used to estimate labour productivity, the estimates showed a variability from the actual values. This research attributes this variability in the predictive ability of the suggested model partly to insufficient data but also importantly to the exclusion of informal labour markets in the model. As such a new variable, weighted labour productivity has been included. The weighted variable created is an attempt to create a more holistic measure of labour productivity that accounts for both the formal and informal sectors, weighted by their relative sizes in the labour force. It is posited that the formal and informal sectors in SSA contribute significantly to the overall economy and thus this research aims to capture the total productivity of labour across these sectors, as such a weighted variable that combines these two aspects makes theoretical sense. In empirical work, particularly when dealing with developing economies or sectors with significant informal activity, faced with the challenge of incomplete data, creating composite indices or weighted measures is a common approach to overcome such limitations. Challenges to the robustness of this further statistical analysis are a small sample size and the quality of the data, for example, if the informal sector is large and its productivity is systematically underreported, this would skew the weighted measure.

The weighted labour productivity is calculated as follows:

$$WLP = (FLP * (FLP \% \text{ share of LF})) + (\text{Informal LP} * (\text{ILP} \% \text{ Share of LF})) \quad \text{Equation 11.4.1}$$

WLP: Weighted Labour Productivity

FLP: Formal Labour Productivity

ILP: Informal Labour Productivity

LF: Labour Force

Where: Formal Labour Productivity = GDP/Labour Force and Informal Labour Productivity = Informal Output/Informal Workforce

The underlying data was not normally distributed, which is not unusual in real-world data, particularly for economic variables. Although the linear model is statistically significant, it was not robust and as such, the use of scaling was applied to the two variables, the weighted labour productivity and the technology efficiency ratio, and the remaining variables were log-transformed to normalise the data in order to retest the robustness of the model. The below one-step GMM was performed on SSA Data, which also reports the Arellano-Bond test for autocorrelation, the test is applied to the differenced residuals to purge the unobserved and perfectly autocorrelated v_i . The results in Table 12.3.1 show the previous model with the inclusion of the weighted labour productivity variable.

Labour Productivity (log-log)	Coefficient	Std. Error	t-value	p-value	[95% Conf Interval]	Sig
Education Ratio	-0.131	0.043	-3.04	0.002	-0.216 -0.047	***
Employment Ratio	-0.128	0.009	-14.20	0.000	-0.146 -0.111	***
Technology Ratio	-0.262	0.064	-4.10	0.000	-0.388 -0.137	***
Access to Finance	0.103	0.011	9.64	0.000	0.082 0.125	***
Weighted LP	0.027	0.002	17.69	0.000	0.024 0.03	***
Constant	2.129	0.045	47.70	0.000	2.041 2.216	***
Mean dependent var		2.994	SD dependent var		0.427	
Number of obs		44	Chi-square		140736.122	
*** $p < .01$, ** $p < .05$, * $p < .1$						

Arellano-Bond test for AR(1) in first differences: $z = -0.09$ $Pr > z = 0.930$

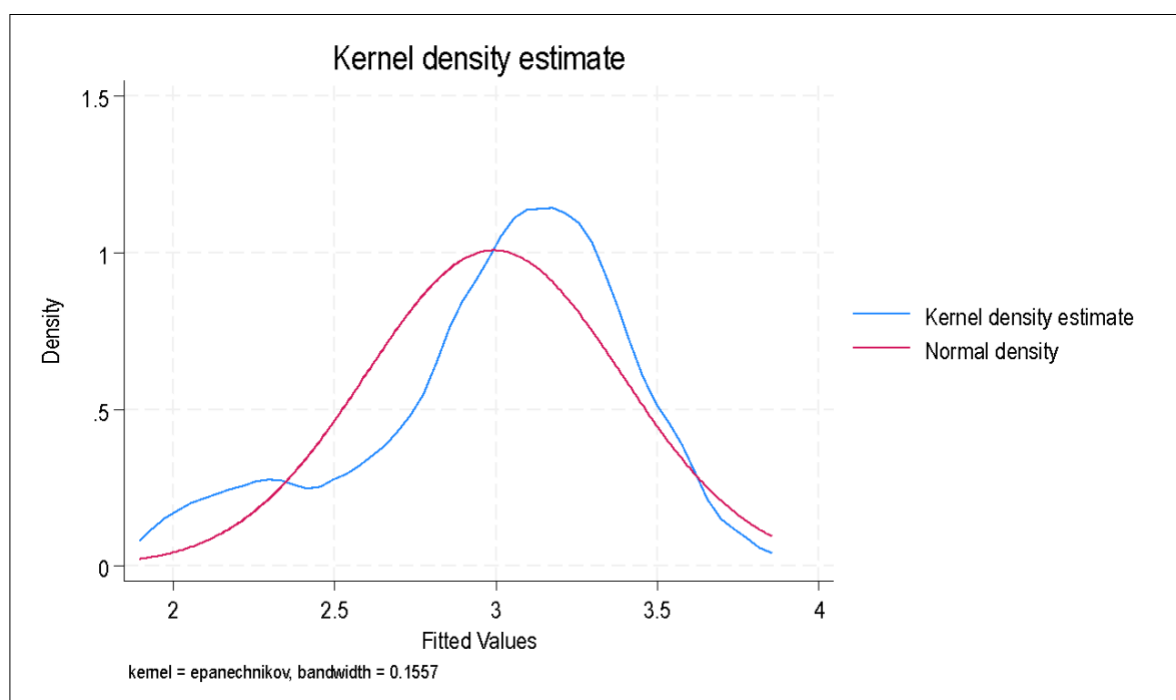
Arellano-Bond test for AR(2) in first differences: $z = 1.01$ $Pr > z = 0.312$

Sargan test of overid. restrictions: $\chi^2(0) = 0.00$ $Prob > \chi^2 = .$

Table 11.4.1 One-Step GMM For Labour Productivity Per Hour With The Weighted Labour Productivity (Not robust, but not weakened by many instruments.)

The Arellano-Bond tests for autocorrelation indicate that there is no first-order (AR(1)) or second-order (AR(2)) autocorrelation in the first differences, which supports the model's specification in terms of the instrument selection.

The Sargan test result suggests that the overidentifying restrictions cannot be rejected, but the output notes that this result is not robust. This lack of robustness is likely due to the small number of instruments relative to the number of groups, and the small sample size. It is also important to note that the Sargan test's validity relies on the absence of autocorrelation and the instruments being exogenous. The Hausman test for endogeneity showed that statistically there was no difference between the OLS and IV estimates, and hence no evidence of endogeneity. After scaling the variables and re-running the Hausman test, the results were consistent with the previous test.



Graph 11.4.1 The kernel density plot

The kernel density plot provided in Graph 4.13 depicts the distribution of the fitted values from the dynamic panel-data estimation, overlaid with the expected normal distribution. The density estimate closely follows the normal density curve, especially around the peak, which suggests that the fitted values are approximately normally distributed. This is a good indication that, at least in terms of the central tendency, the model's predictions are not biased in one direction and that the error terms do not exhibit strong skewness. The weighted labour productivity will therefore be included in the calculations conducted in Chapter 13.

11.5. The uncertainty associated with using labour productivity as a proxy

While labour productivity is empirically and theoretically supported as a key determinant of GDP per capita and, by extension, socio-economic well-being - it is still a proxy, and as such, it captures only part of the broader socio-economic landscape. To address the uncertainty in its use, this research incorporates several methods:

11.5.1. Quantifying Statistical Uncertainty (Model Fit & Error Terms)

Each regression and SEM output in this study includes standard errors and 95% confidence intervals, which give a sense of variability and uncertainty in the estimates. For example, the coefficient for labour productivity in the SEM is 1.210 with a very narrow 95% CI of [1.191, 1.229], suggesting a strong, stable association with GDP per capita. However, in SSA-specific regressions, coefficient estimates show wider confidence intervals, reflecting more contextual variability and uncertainty in the proxy relationship within developing economies.

11.5.2. Model-Specific Error Decomposition (SFA Results)

The Stochastic Frontier Analysis (SFA) explicitly decomposes error into random noise versus inefficiency, allowing one to estimate how much of the deviation from optimal labour productivity is due to unmeasured inefficiency (e.g., governance, infrastructure gaps) versus random error. This helps quantify the extent to which labour productivity may not fully capture SEBs, particularly in SSA, where formal labour productivity might miss large portions of informal value creation.

11.5.3. Proxy Validation through IV Regression (Instrument Strength)

The Instrumental Variable (IV) regressions for labour productivity use R&D and patent receipts as instruments, which pass Hansen's J test for validity. This strengthens the case that the observed relationship is causal, reducing uncertainty from endogeneity, but also implies that the validity of labour productivity as a proxy is only as good as these instruments are representative of SST effects.

11.5.4. Alternative Scenarios & Model Comparison (SSA vs. Global)

The models show that relationships between labour productivity and SEBs differ between SSA and global datasets. This structural heterogeneity adds a layer of uncertainty and suggests that the strength of labour productivity as a proxy depends on context, and should be interpreted alongside other structural indicators (as with the education, finance, and employment ratios).

11.5.5. Inclusion of Weighted Labour Productivity & Informal Sector Output

The creation of a weighted labour productivity metric helps reduce uncertainty by acknowledging that formal labour productivity omits a major component of value in SSA. This adjustment makes the proxy more holistic, and the improved model fit supports its validity.

Although labour productivity is used as a proxy for socio-economic benefit, its application is not without uncertainty. This research addresses such uncertainty through multiple lenses: (i) statistical inference (via confidence intervals and SEM fit diagnostics), (ii) econometric robustness (GMM and IV estimators with strong instruments), (iii) error decomposition (via stochastic frontier analysis), and (IV) model variation across contexts (SSA vs. global data). The addition of weighted labour productivity further strengthens the proxy's robustness by incorporating informal sector dynamics. Nonetheless, labour productivity should be interpreted as a partial but strong indicator of SEBs, with the understanding that certain non-market benefits (e.g., environmental quality, social equity) remain outside its scope.

Part 5

Case Study

12. Case Study

12.1. Decision-Making Matrix

12.1.1. Introduction

In the landscape of strategic planning and investment, particularly within the sphere of government technology initiatives, the use of reliable evaluation tools is paramount. The decision matrix proposed in this research, is designed as a result of this research, and it is a critical management tool for the identification and evaluation of technological programmes within a country. Such tools are instrumental in prioritising projects and strategic innovations, thereby optimising outcomes while minimising risk. This tool attempts to incorporate multiple factors, including but not limited to the available capacity, necessary investments, resourcing, technologies, and anticipated benefits as well as considering the socio-economic impacts, labour productivity, and socio-economic sustainability. Thus it provides a structured and quantifiable method to assess and compare investment opportunities, taking into account the specific economic environment, in other words, it is designed to capture the challenges faced by governments in making investments into SST programmes, with respect to the many other socio-economic challenges within the specific economy.

The following section outlines the proposed Political Decision Matrix as a mechanism for objective decision-making. In the development process of this tool, the research also highlighted the fact that socio-economic investment can be utilised to mitigate programme risk. The value for the impact on labour productivity is derived from the GMM regression on the SSA data as described in the previous section, providing a proxy value for the socio-economic impact on the economy from the investment into SST.

12.1.2. Development of the Decision-Making Matrix

This matrix was designed in consideration of the following step-by-step process:

Assessment of Challenges	Understanding the socio-economic challenges within the specific economy and how SST programs fit within those challenges.
Impact on Labour Productivity	Using regression on the SSA data to derive the values for labour productivity impacts.
Project Length and Political Cycles	Measuring the project length in years and dividing by the length of a political cycle to factor in political risk, particularly the political risk to projects over extended political cycles.
Socio-Economic Benefit Expenditures	Allocating the planned expenditures for the programme into the socio-economic categories that they will impact.
Risk Determinants	Obtain the risk factors from the Risk Scoring Matrix.
Case Study Application	Using the MeerKAT Telescope project data from inception (2008) to completion (2018) as a case study for the matrix.
Comparative Analysis	Completing the Political Decision Matrix a second time with data from a subsequent project, the MeerKAT Extension Project, for comparative purposes.

Table 12.1.2.1 Development steps of the Decision-Making Matrix

This Risk Scoring Table provides a method to quantitatively evaluate different aspects of a programme's potential impact, allowing for a more objective decision-making process. The scores reflect how advantageous or disadvantageous the programme is in each category, with the implication that higher scores in financial, resource, and time impacts have a higher risk profile. The Risk Scoring Table is the first step towards compiling the Decision-Making Matrix. Below in Table 13.1.2.3 is the Risk Scoring Table with the determinants for government decision-making regarding investments in SST programmes and explanatory notes to this table may be found in Table 13.1.2.2 The Risk Scoring Table elements are broken down as follows:

Government Decision Determinants	These are the categories against which each programme is evaluated and they include Available Resources, Opportunity Cost of the Programme, Reputation and Key Stakeholders
Direct Financial Impact	This column assesses the immediate financial implications of the investment. It factors in the cost against the government's available budget or expected returns.
Resource Impact	This evaluates how the programme will affect the available resources. This might include human resources, technology, materials, and other assets necessary for the programme.
Time Impact	This measures the influence the programme will have on timelines, such as project completion, political cycles, or other time-sensitive goals.
Score	This is an overall weighted average score that is calculated based on the individual scores of the above determinants.
Scoring Range	Each determinant is scored on a scale from low (1) to high (5).

Table 12.1.2.2 Elements of the Risk Scoring Table

Government Decision Determinants	Direct Financial Impact	Resource Impact	Time Impact	Score
	Scoring range between low=1 and high = 5			
Available Resources				
Opportunity Cost of the Programme				
Reputation				
Key Stakeholders				

Table 12.1.2.3 Risk Scoring Table

Government Decision Determinants	Direct Financial Impact	Resource Impact	Time Impact
Available Resources	The institutional and governance budget available to house, manage and implement a programme of this kind. This may incorporate private sector resourcing.	The human and technical resourcing available to undertake the project and the development programmes that are required. Insufficient	Does the project utilise human resources for an extended period? It can be the case that employment is created but the project life can be short and leave resources unemployed.

		resources that have to be developed carry a high risk until they are developed	
Opportunity Cost of the Programme	Are there competing programmes? What are the funding constraints?	Are resources being newly developed, imported, provided by industry or drawn from other sectors or projects?	How long will funds be out of circulation and how long will resources from other sectors be utilised?
Reputation	Large scale science and technology projects bring a level of prestige but in terms of reputation this implies relationship building based on proven capacity in terms of developing partnerships, and collaboration. The chances that funding may run short for a number of reasons is a high risk early on.	Early in the project, no progress has been made and as such promises are unproven. Resourcing challenges can take time to present themselves. Risk is high in the early phases.	What socio-economic challenges is government faced with and what are the time frames in which these need to be addressed, or phrased differently, what are the project time frames in terms of the provision of socio-economic benefits.
Key Stakeholders	Too many stakeholders and a large variety of stakeholders are challenging.. Adhering to budget takes time to prove and fiscal challenges take time to present themselves and such risk is high to start and reduces over the project life.	Early in the project, no progress has been made and as such promises are unproven. Risk is high in the early phases.	In large scale and long term projects, stakeholders can become frustrated or develop distrust with measurable benefits taking too long. Communications and expectation management is essential.

Table 12.1.2.4 Notes to Complete the Risk Scoring Matrix

The Decision-Making Matrix below will be updated with the average risk scores for each Government Decision Determinant. The Decision-Making Matrix includes several indicators related to the socio-economic impact of an SST programme. Each indicator is assessed across various dimensions:

Impact on Labour Productivity per Hour (LP Impact)	This shows the estimated change in labour productivity per hour as a direct result of the programme, with specific ratios given for different sectors like education, employment, technology efficiency, and access to finance.
Socio-Economic Benefit Spend (% of Project Spend)	This column represents the percentage of the total project spend that is allocated towards socio-economic benefits, as a way to quantify the direct investment back into the economy or society.
Resource Impact, Budget Impact, Reputation, Key Stakeholders	These columns contain scores or assessments of how the programme affects these areas.
Project Years	This is related to the duration of the project.
Sustainability Portion of Impact	This column seems to provide a quantified value of the programme's sustainability impact, which could be an important measure of the programme's long-term viability and benefits.

Table 12.1.2.5 Indicator Dimensions

The matrix provides outputs as aggregated and derived metrics:

Weighted LP	This is a weighted average of the labour productivity impacts, taking into account the different percentages spent on socio-economic benefits. The value is calculated as per the Weighted Labour Productivity Equation 4.2 presented in Chapter 4.6.
Political Cycles	Reflects the number of political cycles the project spans. This can be an important factor in understanding the political stability and continuity of the project.
LP Impact	This is the cumulative impact of the programme on labour productivity.
Project Risk Score	This is a weighted index score to measure the overall risk of the project.
Sustainability Value	This number could represent a summary measure of the programme's overall sustainability impact, taking into account environmental, economic, and social sustainability factors.

Table 12.1.2.6 Matrix Outputs

12.1.3. Application of the SST Decision-Making Matrix: MeerKAT Case Study (Ref Year 2008)

This first case study applies the data as was available at the start of the MeerKAT programme in 2008, this will later be contrasted with the results from a repeated process, utilising data that was available in 2018. The Risk Scoring Table 13.1.3.1 below was completed as per SKA Bid Documentation and SARAO risk registers produced in 2008. Additional notes to the case study are found in Table 13.1.3.2 below.

Government Decision Determinants	Direct Financial Impact	Resource Impact	Time Impact	Score (Average)
	Scoring range between low=1 and high = 5			
Available Resources	4	3,5	4	3,8
Opportunity Cost of the Programme	4	4	4	2,3
Reputation	3	4	3,5	3,5
Key Stakeholders	4	2	3	2,7

Table 12.1.3.1 The Risk Scoring Table – MeerKAT Case Study 2008

Government Decision Determinants	Direct Financial Impact	Resource Impact	Time Impact
Available Resources	Insufficient resources were available which implied a significant financial commitment to the HCD programme.	Insufficient resources were available and an education pipeline had to be implemented. This posed a high risk which reduced over time with the implementation of the HCD programme.	The time to see fruits of the HCD programme was up to ten years and as such at the programme start, this was a significant risk
Opportunity Cost of the Programme	At the time of the programme implementation, although the total programme was large, these funds were distributed annually over a long period. There wasn't a programme foregone for this programme and the potential returns deemed it an acceptable commitment	New national resources were being developed and not drawn from other sectors or projects	There is risk in the time long frames as new potential investment areas cannot be foreseen at the time of commitment
Reputation	At the start of the programme there is reputational risk in having funding challenges during the project, particularly those that cannot be predicted.	Resource failures could significantly impact the programme and reputation of the programme and indeed the country so early	The reputational risk is high at the start but as the programme progresses and schedules are maintained, this risk reduces

	This risk reduces through the programme lifecycle	in the programme this is a risk as engineering, science and construction challenges have not yet been encountered.	
Key Stakeholders	There was risk due to the large number of stakeholders and balancing the requirements of all and maintaining budget constraints is a challenge, particularly in early project phases.	Too many stakeholders can be a large risk, particularly through early decision making phases. There was risk due to variety of stakeholders from the science community, industry, local communities to government	Managing expectations is challenging with a long time frame and many stakeholders. Particularly when the demonstrable results can take many years to measure.

Table 12.1.3.2 Notes to The Risk Scoring Table – MeerKAT Case Study 2008

The scoring and evaluation system categorises the risk associated with socio-economic benefit (SEB) investment and sustainability values of projects are summarised in the steps below:

Adjusted Risk Scoring System

Step 1: Assign Initial Risk Values:

Average Risk Value obtained from the risk scoring table:

Low Risk (Average Value under 1.8): 1 point

Medium Risk (Average Value between 1.9 and 3.2): 2 points

High Risk (Average Value above 3.3): 4 points

Step 2: Adjust Risk Based on Project Duration:

Project Duration:

More than 3 cycles: High Risk (4 points)

1-5 years: Low Risk (1 point)

6-9 years: Medium Risk (2 points)

10-18 years: High Risk (3 points)

Over 18 years: Very High Risk (4 points)

Step 3: Adjust Risk Based on Political Cycles:

Number of Political Cycles:

1 cycle: Low Risk (1 point)

2-3 cycles: Medium Risk (2 points)

Step 4: Calculate the Total Risk Score: Combine the scores from the Risk Value, Project Duration, and Political Cycles in the Decision Making Matrix.

Step 5: Assign Scores Based on SEB:

Low SEB (< 10%): 1 point

Medium SEB (11%-25%): 3 points

High SEB (> 26%): 5 points

Step 6: Calculate the Total Sustainability Score: Combine the SEB score and the total risk score using the following formulae:

Total Risk Score

Total Risk Score=(Risk Value+Project Duration Score+Political Cycle Score)

Total Sustainability Score

Sustainability Value=SEB Score + Total Risk Score

Step 7: Decision Threshold

The threshold decision is set based on the decision criteria for implementation of the project or investment:

Yes: Sustainability Value \leq 12

No: Sustainability Value $>$ 12

Table 13.1.3.4.a Adjusted Risk Scoring System Steps

SEB Category	SEB Score	Risk Value	Project Duration Score	Political Cycle Score	Total Risk Score	Sustainability Value
Low SEB (< 10%)	1	1	1	1	3	4
Low SEB (< 10%)	1	1	2	2	5	6
Low SEB (< 10%)	1	4	4	4	12	13
Medium SEB (11%-25%)	3	1	1	1	3	6
Medium SEB (11%-25%)	3	2	2	2	6	9
Medium SEB (11%-25%)	3	4	4	4	12	15
High SEB (> 26%)	5	1	1	1	3	8
High SEB (> 26%)	5	2	2	2	6	11
High SEB (> 26%)	5	4	4	4	12	17

Table 13.1.3.4 Political Decision Making Results Table – MeerKAT 2008

Risk Score: This is calculated from the decision matrix and quantifies the risk level of the project. In the MeerKAT 2008 example, the average risk score was 3.16, with 2 political cycles and project implementation duration or investment period of 10 years.

Socio-Economic Benefit Investment: This represents the percentage of the project spend allocated towards socio-economic benefits. In this case, it was 22%.

Sustainability Value: A metric representing the long-term environmental, social, and economic impacts of the project. The given value is 9.

Based on the evaluations completed and concluded in table 13.1.3.4, the project would be classified as medium risk with a medium level of SEB investment, indicating a relatively safe investment with an above average amount of the budget allocated to socio-economic benefit investment. It is designed to be a well-balanced approach that indicates the project is sustainable and socio-economically beneficial while maintaining a manageable level of risk.

Indicators	Impact on Labour Productivity per Hour	Socio Economic Benefit spend (% of project spend)	SST Spend (% of project spend)
Education Ratio	-0,131	5%	
Employment Ratio	-0,128	6%	
Technology Efficiency Ratio	-0,262	8%	
Access to Finance Ratio	0,103	3%	
Weighted LP	0,027		
Constant	2,129		
Project Implementation (Years)	10,00		
Political Cycles	2,00		
Risk	3.16		
Total Spend		22%	78%
Impact on LP	2,097 %	Adjusted Impact on LP	1,742%
Sustainability Value			9

Table 12.1.3.3 SEB in terms of Labour Productivity

The regression equation from the SSA dataset regression provided the coefficients for the impact of the Education, Employment, Technology Efficiency and Access to Finance ratios on Labour Productivity. The coefficients representing the percentage impact on Labour Productivity of a 1% increase in each of the variables is then multiplied by the percentage breakdowns of project expenditure according to the proposed ratios. This calculation provides the Labour Productivity impact which is then further adjusted by the weighted labour productivity, project risk, inclusive of project years and political cycles, to provide the Adjusted Impact on LP, the estimated real impact on labour productivity over the course of the project years. The Political Decision-Making

Matrix retrospective assessment of the MeerKAT project, utilising data that would have been available in 2008, shows that the programme was expected to have a positive impact on labour productivity and was intended to provide a significant portion of its budget towards socio-economic benefits.

12.1.4. Comparative Results

According to estimates the closed input-output income multiplier is 1.68 and the employment multiplier is 6900 (Schröder, Storm, 2020), and as such impacts due to a fiscal stimulus of R1 billion of extra spending will generate R1.68 billion extra income, creating 6,900 new jobs. The aggregate multiplier was estimated higher by Makrelov et al., (2018) at a value of 2.5. Schröder (2020) however suggested that when both the induced consumption effect and the induced investment effect are included, and endogenising the investment, the magnitude of the aggregate multiplier is raised, but that this would be an over estimate. According to the independent Socio-Economic Impact And Perceptions Of The MeerKAT/SKA Telescope Project 2023 report, as a result of capital expenditure, a total impact of R5,7 billion was experienced and regarding production, a total GDP contribution of R1,9 billion was made. Regarding operational expenditure, a total impact of R13,1 billion was experienced and with regard to producing a total GDP contribution of R6,7 billion was made. As a result of capital expenditure, a total of 6 223 FTE jobs have been created, while operational expenditure generated a total of 13 989 FTE jobs. Thus the case study supports the findings of the political decision making matrix.

These results were used in a simple calculation shown in Table 12.1.4.1 below, in order to estimate the labour productivity change due to these contributions, which aligns to the results in Table 12.1.3.3.

GDP and Employment in 2015:**GDP: 4,012 billion ZAR**

Employment: 16 million jobs

Labour Productivity in 2015:

Initial Labor Productivity=GDP/Employment=5,363 billion ZAR/16.5 million workers≈250750 ZAR per worker

New GDP and Employment after Contributions:

New GDP: 4,012 billion ZAR+2 billion ZAR=4,014 billion

New Employment: 16000000 jobs+20,212 jobs=16020212 jobs

New Labour Productivity:

New Labour Productivity= 16020212 workers/4,014 billion ZAR≈255161 ZAR per worker

Change in Labour Productivity:Change in Productivity = $(255161 - 250750) / 250750 * 100 = 1,76\%$

Table 12.1.4.1 Labour Productivity Change Calculation

The overall impact of adding 19,8 billion ZAR and 20,212 jobs to the economy is 1,76%. The comparative year chosen for this illustrative example was 2015 as this was 80% of the way through the project allowing for the majority of spending and accrued jobs during the 10 year period from 2008 to 2018.

The investment made into the MeerKAT project not only enhanced labour productivity in South Africa through direct increases in GDP and employment but also by improving key productivity determinants such as those captured in the education, employment, technological efficiency, and access to finance ratios. By investing into higher education, the workforce becomes more skilled and adaptable, directly contributing to increased productivity. Focusing on shifting employment from low-productivity sectors to high-productivity sectors ensures better utilisation of labour resources. Enhancing technological capabilities and efficiencies through R&D investment and innovation fosters a more productive economic environment. Improving institutional integrity access to financial resources for businesses supports innovation and expansion, thereby driving productivity growth.

Table 13.1.4.2 below shows a breakdown of the annual contribution to the labour productivity directly through additions to GDP and jobs. The calculation assumes the bulk of these additions occurred between 2012 and 2015 for simplicity and shows the increase to labour productivity as 0,365%. This research asserts that by acknowledging the impacts of the proposed ratios, the investment into the MeerKAT project created a multifaceted impact, leading to sustained labour productivity improvements to the value of 1,74% overall, of which 0,365% is due to direct additional GDP and jobs and $1,742\% - 0,365\% = 1,377\%$ is due to the contribution of indirect

socio economic impact expressed as labour productivity over the project life. The overall addition to labour productivity over the period from 2008 to 2017 is 998,51 ZAR per worker.

Year	Additional GDP by MeerKAT Project (billion ZAR)	Additional Employment by MeerKAT Project (jobs)	RSA New GDP (billion ZAR)	RSA New Employment (million)	New Labour Productivity (ZAR per worker)	Change in Labour Productivity (ZAR per worker)	Percentage Change in Labour Productivity (%)
2008	0	0	3,906,00	14,27	273,721,00	-	-
2009	0	0	3,906,00	14,27	273,721,00	0	0,000%
2010	0	0	3,906,00	14,27	273,721,00	0	0,000%
2011	0	0	3,906,00	14,27	273,721,00	0	0,000%
2012	5,94	6,063,6	3,911,94	14,28	274,020,92	299,92	0,110%
2013	3,96	4,042,4	3,915,90	14,28	274,220,66	199,74	0,073%
2014	5,94	6,063,6	3,921,84	14,29	274,520,06	299,4	0,109%
2015	3,96	4,042,4	3,925,80	14,29	274,719,51	199,45	0,073%
2016	0	0	3,925,80	14,29	274,719,51	0	0,000%
2017	0	0	3,925,80	14,29	274,719,51	0	0,000%

Table 12.1.4.2 Calculation of Annual LP Change due to the MeerKAT Project

To better explain the impact, it is highlighted that the relative scale and long-term cumulative benefits of consistent productivity improvements over time, despite the small immediate change. Since the project consistently contributes to a multiplier effect with ongoing operations, innovation, education programmes and science outputs, increase in labour productivity are compounded. Over a decade, the compounded impact of consistent productivity improvements, although small each year, resulted in overall improvements to labour productivity, demonstrating the project's substantive long-term impact on economic efficiency.

12.1.5. Application of the SST Decision-Making Matrix: MeerKAT Extension Case Study (2019)

SEB Category	SEB Score	Risk Value	Project Duration Score	Political Cycle Score	Total Risk Score	Sustainability Value
Low SEB (< 10%)	1	1	1	1	3	4
Low SEB (< 10%)	1	1	2	2	5	6
Low SEB (< 10%)	1	4	4	4	12	13
Medium SEB (11%-25%)	3	1	1	1	3	6
Medium SEB (11%-25%)	3	2	2	2	6	9
Medium SEB (11%-25%)	3	4	4	4	12	15
High SEB (> 26%)	5	1	1	1	3	8
High SEB (> 26%)	5	2	2	2	6	11
High SEB (> 26%)	5	4	4	4	12	17

Table 12.1.5.1 The Political Decision Matrix – Comparative table MeerKAT 2019

The example in Table 13.1.5.1 above shows that the low risk associated with the MeerKAT Extension project (Decision making in 2019), whereby in partnership with the Max Planck Institute, 14 additional dishes were to be added to the MeerKAT telescope. In terms of socio-economic benefit, the ongoing socio-economic interventions that SARA0 undertook already from the MeerKAT Telescope project were excluded and only those associated with the Extension project itself were included. This then provides a comparative case of low-risk and low socio-economic inputs. The overall sustainability value is acceptable (6) as per Table 5.12 above. Although the socio-economic returns are low, the science products are the objective and as such science returns are acceptable. This example demonstrates that there is a motivational and agenda-

driven process that can follow the matrix results, but the justifications for deviation from the matrix results should be robust.

The decision matrix is a tool for analysing the multi-faceted impact of large-scale projects and can help policymakers make more informed decisions by considering a range of factors from economic impacts to social benefits and beyond

12.2. The SDEB Implementation Framework

It is a challenge to incorporate or rather describe quantitatively the qualitative aspects of the economic environment and those of science and technology project investments. In addition to this challenge, although proxies may be used to quantify the economic environment, and proxies may be developed for the project aspects, a sufficient data set on the economic environment or project investments is not available for SSA countries to run a fully robust statistical analysis.

Thus this research proposes the qualitative implementation framework, the SDEB framework, derived from the MeerKAT case study. It is a self-reinforcing cycle consisting of three phases, namely the intervention phase, the development phase and the growth phase.

The intervention phase incorporates humble beginnings such as science awareness programmes, outreach and engagement activities with the public and stakeholders. Activities categorised as outreach develop awareness of science-based programmes and their possible benefits to everyday people. With increasing awareness, greater social support and participation can be leveraged. The social license to operate had a significant impact on many projects around the world and has been a strong focus of the SARA0 stakeholder management and communications strategies. These interventions in turn lead to education activities, such as supporting Science, Technology, Engineering, Maths and Art (STEAM) education within the school system as well as bursaries and research at a university level. Ultimately, a full human capital development programme is implemented, including additional development, such as young professional development and technical skills training.

The development phase has two parts that may occur collaboratively or independently in parallel, and these produce the project infrastructure. The first can be described as facilitated development; this occurs when a science programme leverages its prestige or requirements to enable new capacity or capabilities to be developed without directly becoming involved or necessarily funding the new economic activity. The second is localisation: this is the leveraging of state procurement or local industrialisation to produce goods locally, which entails the development or expansion of domestic production capacity and capabilities in order to assemble or manufacture parts, components or finished goods. This result is an investment into new or additional capacity in domestic manufacturing.

The growth phase addresses the challenge with regard to fostering innovation. This is not simply measured in terms of university degrees granted, research papers published or patents awarded. The goal is to use the extraordinary basic research and creativity of researchers and to ‘translate’ this through appropriate development and commercialisation.

Edwin Mansfield (1998) published a survey of 77 US companies operating in seven countries, in which he found that 11 percent of new products and nine percent of new processes could not have been developed without a substantial delay, in the absence of academic research. Based on this observation, Mansfield estimated the rate of return from public money invested in academic research to be 28 percent. He noted later that the trend was accelerating and that the success was becoming unceasingly dependent on science. In a follow-up study published in 1997, Mansfield noted that 15 percent of new products and 11 percent of new processes had been significantly aided by academic research. Sustainable interventions, development and growth cannot occur independently of one another and form a cyclic reinforcing relationship. The multiplier effect is a tool we use to measure the increase in final income arising from any new injection of spending. Every time there is an injection of new demand into the circular flow, there is likely to be a multiplier effect. Thus this cyclic process is self-reinforcing.

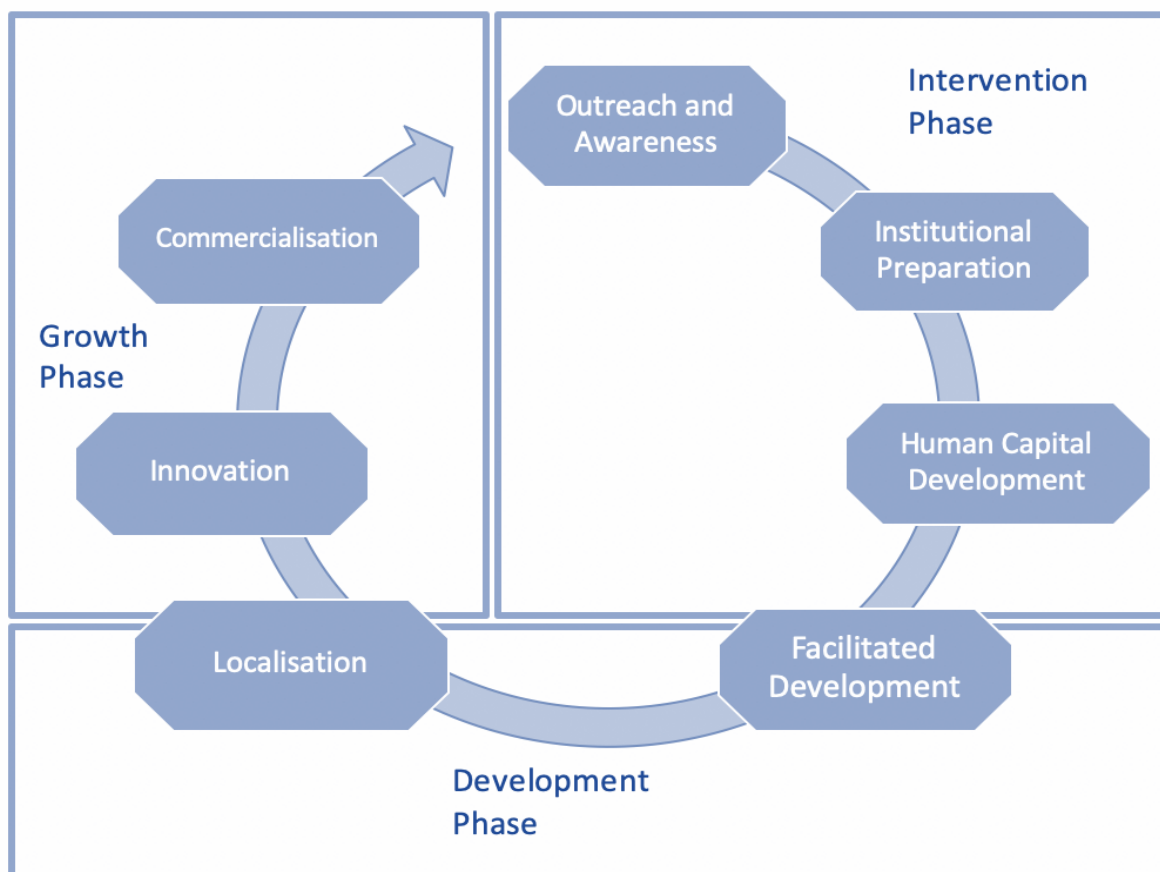


Figure 12.2.1 The SDEB Cycle

12.2.1. MeerKAT Case Study of the Science-Driven Economic Benefit Cycle

To illustrate the Science-Driven Economic Benefit (SDEB) framework, the MeerKAT radio telescope project is examined as a case study. This allows for a practical exploration of how science and technology infrastructure projects can generate sustainable economic benefits in a developing context. The SDEB framework, as outlined earlier, consists of three interconnected phases—intervention, development, and growth—that together form a self-reinforcing cycle of socio-economic transformation.

Each of these three phases contains specific steps or subcomponents that describe the processes through which science-driven investments catalyse broader economic development. In total, there are 13 key steps, spread across the three phases, as summarised in Table 13.2.1.

To support understanding of how these phases function holistically, Figure 13.2.1 presents a visual representation of the SDEB framework. The figure simplifies the 13 steps into seven thematic boxes, each representing a cluster of activities or objectives that contribute to the broader phase it belongs to. These boxes serve as an accessible summary of the implementation logic and illustrate how initial interventions like awareness and education lead to infrastructure and industrial development, which in turn stimulate commercialisation, partnerships, and innovation. The arrows between phases and boxes indicate the feedback loops and multiplier effects that characterise the cyclical and iterative nature of the framework.

The framework does not represent a linear process but a dynamic and reinforcing cycle, where outcomes from the growth phase can in turn fuel future interventions, creating long-term development impact.

Table 13.2.1 below provides a detailed breakdown of the framework’s three phases and the 13 associated steps as they were applied to the MeerKAT project.

Intervention Phase	
1	Objective Development and Analysis
2	Institutional Buy-In
3	Policy and Frameworks
4	Project Planning and Schedule
5	Budget, Feasibility and Funding
6	Governance and Risk Assessment
Development Phase	

1	Infrastructure
2	Local Community Development
3	Technology, Innovation and Industry Development
4	Human capital Development
Growth Phase	
1	Progress and Partnerships
2	Commercialisation
3	Performance Assessment

Table 12.2.1 Phases and Steps of the SDEB Framework

12.2.3. **Intervention Phase**

The intervention phase is split into six steps that can be undertaken in a phased approach, either in parallel or in series but all six steps must be completed prior to the beginning the development phase.

1. Step 1: Objective Development and Analysis

Undertaking large scale public projects or mega projects requires significant objectives definition, however these objectives cannot be limited to the project, they have to be aligned to national objectives. These projects are doomed from the start if the planned project outcomes are not aligned to the needs of the economy. They also cannot produce outcomes that the economy is unable to absorb or sustain. Context awareness and sensitivity to context on the part of project decision makers is vital for both the successful planning, appraisal and delivery of projects as well as the suitable treatment of contextual risks, uncertainties and complexities.

The MeerKAT project had well-defined objectives prior to the project's start. The following six key objectives were in place by 2012 when South Africa was awarded the bid to co-host the SKA (National Treasury Submission volume 1, 2008):

1.1. South African reputation

The objectives pursued in regard to South African Reputation were provided by the South African Bid Documents to host the SKA included improvement of the international perception of South Africa as a destination for high-technology investment, boosting South Africa's international science and research profile and consolidating Southern Africa as a world-wide hub for astronomy.

1.2. MeerKAT Telescope

The objectives pursued in regard to the MeerKAT Telescope were provided by the South African Bid Documents to host the SKA included building a unique and world-leading telescope to consolidate South Africa's position as a hub for astronomy prior to the construction of the SKA. The MeerKAT was designed to be the best centimetre-wave radio telescope in the world – which was seen to allow South African scientists to produce breakthrough science and attract world-leading scientists and engineers to work with South African scientists and engineers. In addition to developing close working relationships between South African researchers, students, engineers and universities with the best universities and institutes in the world in science and engineering

related to the MeerKAT and the SKA. Another objective was to confirm South Africa's competence and capacity to build the SKA in Southern Africa.

1.3. Human Capital Development

A ten-year HCD strategy had been developed as part of the South African SKA Programme Bid. This strategy was aligned with the SA Department of Science and Technology (DST) Ten Year Strategy. Between 2005 and 2008, sixty-four student bursaries for post-graduate study and seven post-doctoral fellowships were awarded for projects related to the SKA and MeerKAT. The HCD Programme had three major objectives as provided by the Bid Documents:

- Ensure that there are sufficient highly-skilled PhD scientists and PhD and MSc engineers in South Africa to be able to design, construct and operate the MeerKAT and the SKA, and to utilise these instruments effectively when they start to do science. The programme includes both the training of students in South Africa and the APCs, as well as attracting skilled scientists and engineers to work in South Africa.
- Contribute to the high-level objectives of the DST and the National Research Foundation (NRF), by providing a significant input of PhDs into the economy, academic teaching, and by contributing to remedying the demographic imbalance in skilled researchers in South Africa.
- Develop and test models to improve science and maths teaching in under-resourced schools and bring students through school and undergraduate study into post-graduate study in related fields such as physics and engineering.

1.4. Mission-driven innovation

Academic and industry collaboration on key aspects of the MeerKAT technology were already advanced in 2008 when the Bid was submitted. Planned skills, technologies and infrastructure that were to be developed in the South African SKA Project were seen as appropriate to enable key activities in the global knowledge economy. The objectives included the development and testing a model of mission-driven innovation and to work with South African industry to develop new skills and expertise and new intellectual property. By doing so the plan was to build a critical mass of high-level expertise in cutting-edge technologies that are not limited to radio astronomy and will be important in the next decades, as well as placing South African industry and universities in an advantageous position to bid for SKA contracts.

1.5. Radio astronomy reserve

The Astronomy Geographic Advantage (AGA) Act was passed by Parliament in 2007. Regulations to protect the proposed SKA site in the Karoo, colocated with the MeerKAT site, were then being drawn up in collaboration with the telecommunications operators in order to:

- Establish a radio-quiet astronomy reserve in the Karoo, which would be the site for the MeerKAT telescope and the SKA and for other experiments that require radio quiet
- Attract other experiments to the Astronomy Reserve (such as C-BASS and HERA which later joined the site as Guest Instruments)

1.6. Collateral Benefits

A socio-economic baseline study was conducted by the University of the Free State and CASE (2007) in the towns around the proposed telescope site, together with more distant towns as controls. The survey showed high levels of poverty, outward migration of economically active people and young people, and a high incidence of women-headed households. There was a high level of foetal alcohol syndrome and other symptoms of poverty.

A study was also commissioned from Quotec²⁹ a UK subsidiary of the CSIR, of the direct and indirect benefits that the construction of the MeerKAT would bring to South Africa. These studies will be repeated at regular intervals throughout the lifetime of the projects.

2. Step 2: Institutional Buy In

Mega projects are unlikely to be able to deliver the full range of change benefits unless accompanied by a suitable institutional, policy and legislative framework that remains in place throughout the project lifecycle.

South Africa entered into the SKA and MeerKAT obligations as part of a strategy to develop astronomy as a science platform in South Africa which has its origins in the White Paper on Science and Technology drafted by the first democratic government of South Africa in 1996. As indicated in the Department of Science and Technology's (DST) Strategic Plan for the fiscal years 2011-2016, South Africa needs to build on its niche strengths, especially those in which it has a geographic or natural advantage, such as astronomy, biodiversity, Antarctic research, minerals processing and palaeontology. It is also noted that the Heads of State and Government of the

²⁹ Quotec Limited is a technology consultancy which has been supporting the exploitation of technology since 1984. They undertake technology related projects for clients in the private and public sectors in the UK and internationally. More information can be found at their website <http://www.quotec.co.uk>.

African Union adopted a Declaration at their 2010 Assembly expressing the African Union's unequivocal support for South Africa to lead the bid to locate the SKA in Africa.

In 2018, The MeerKAT radio telescope, a major component of the Square Kilometre Array (SKA) telescope was added to the list of South Africa's National Key Points (NKPs) as per the National Key Points ACT, 1980³⁰ to protect the country's then investment of over R3 billion.

The project had parliamentary support, to the extent that the MeerKAT and SKA became a Special Infrastructure Project (SIP), SIP 16. The South African Government adopted a National Infrastructure Plan in 2012 and Cabinet established the Presidential Infrastructure Coordinating Committee (PICC). Under the guidance of the PICC, 18 strategic integrated projects (SIPS) have been developed. The SKA has been integrated into the Spatial Development Frameworks (SDF) for the three municipalities in the SKA area of the Northern Cape, namely Hantam, Kareeberg and Karoo Hoogland. In addition, it has been incorporated into the Karoo Region SDF.

The Astronomy Geographic Advantage (AGA) Act of 2007 is legislation that gives the Minister of the DSI the power to protect areas, through regulations, that are of strategic national importance for astronomy and related scientific endeavours. As South Africa is required to provide a site upon which the SKA Observatory may construct and operate the SKA telescope, SARAQ acquired 135,245 hectares of land in the Karoo. The land is being managed by SANParks through a Management Agreement between the NRF and SANParks and has been declared a new Protected Area (MeerKAT National Park).

The Universal Service and Access Agency of South Africa (USAASA) collaborated with SKA SA and the Northern Cape Department of Education to establish a cyber-lab in Carnarvon, at the local high school. The SKA SA explored partnerships with various Sector Education and Training Authorities (SETA) and others to establish a technician and artisan training centre in Kimberley or Beaufort West. South African funding for the AVN was provided by the African Renaissance Fund (ARF) within the Department of International Relations and Cooperation (DIRCO).

Other departments were involved at an early stage to support the project development, for example, the Department of Trade and Industry (DTI) as well as the National Treasury and academic institutions.

³⁰ The National Key Points Act, 1980 is an act of the Parliament of South Africa that provides for the declaration and protection of sites of national strategic importance against sabotage, as determined by the Minister of Police.

3. Step 3: Policy and Frameworks

The SKA Observatory (SKAO) is an inter-governmental organisation, mandated to construct and operate the SKA telescope, to which South Africa is a member state. In addition to the SKA Convention, the SKA Observatory will enter into separate agreements, referred to as the Hosting Agreements, with each of the host countries to enable the fulfilment of its objective to acquire and operate the SKA telescope. The content of the Hosting Agreements were informed by the bid submissions previously submitted by each of the host countries, and the SKA Convention. Key aspects dealt with by the Hosting Agreements include the responsibilities of the SKA Observatory, and South Africa, to enable the construction and operation of the SKA telescope in South Africa, including making available a site, contribution of existing assets and infrastructure by South Africa to the SKA Observatory, to be valued and credited as a contribution by South Africa to the SKA Observatory, and making available assets and infrastructure by South Africa, subject to appropriate commercial terms and conditions.

To operationalise the SKA Observatory's obligations, the Observatory will enter into separate agreements with various parties. The SKA Partnership Agreement is currently being negotiated between the Observatory and SRAO and will establish a partnership responsible for the technical operations and maintenance of the SKA telescope in South Africa. The activities and responsibilities of this partnership will be fully funded by the SKA Observatory. As mentioned previously, South Africa has committed to providing 14 percent of the required funding.

The aforementioned Astronomy Geographic Advantage Act 21 of 2007 was set in place and SRAO is subject to the Public Finance Management Act (PFMA). The NRF and SRAO both hold themselves to a high standard of transparency and undergo regular scrutiny and audit. In addition, SRAO became approved by the International Standards Organisation (ISO) and is ISO:9001 compliant with international management standards.

The management of intellectual property (IP) emanating from publicly financed research and development has become a critical factor in ensuring that the public derives greater returns from the increasingly significant R&D investments made by government. The South African Government introduced the Intellectual Property Rights from Publicly Financed Research and Development Act 51 of 2008 (referred to as the IPR Act) to provide a regulatory framework for the management of this type of IP. The National Intellectual Property Management Office (NIPMO) was established in mid-2011 in terms of the Act to promote and manage the objects of the Act. Intellectual Property Rights from Publicly Financed Research and Development Act, 2008 and the National Intellectual Property Management Office (NIPMO).

3.1. Partnerships and Education

Effective and early engagement with key stakeholders is critical in mega project planning, appraisal and delivery. As mentioned the SKA project in South Africa developed vertical relationships and support from the highest levels of government as well as horizontal support from government departments. SARAo also developed partnerships with academic institutions, civil societies and industry, both nationally and internationally.

Partnerships have been an integral part of the success of the MeerKAT project and a driver behind its socio economic impact. Partnerships allow for collaboration and cross subsidisation whereby limited budget and schedule can be managed effectively.

There were 30 active MOA's between SARAo and their academic, civil and industry partners in 2018. The SARAo HCD Strategy was developed from 2005 and the key principles that have underpinned the capacity development strategy included:

- i. Recognising, and taking advantage of, the opportunity that the SKA and MeerKAT projects provide, as mega-science projects, to attract young people into science and technology research.
- ii. Implementing a pipeline model to provide support at all academic levels, to ensure a continuous through-put of young people moving into relevant studies and research, and having access to a defined study and relevant career path.
- iii. A deliberate focus on addressing gender and race inequality in science and engineering at all levels, by prioritising support to black and women South Africans.
- iv. Supporting academically excellent students.
- v. Supporting internationally recognised researchers and academics to increase supervisory capacity in South African universities.
- vi. Supporting studies and research directly relevant to the science and technology of the SKA and the MeerKAT.
- vii. Offering financial support that is competitive with industry, to attract the best and brightest young people into radio astronomy studies and research, and into academic positions at local universities.
- viii. Creating an interactive, collaborative and skilled community of students and local and international researchers around the SKA and MeerKAT.
- ix. Recognising that although the capacity development programme is primarily aimed at producing skills for the MeerKAT and the SKA, the programme is, inter alia, increasing

the number of highly skilled people available to the general economy in South Africa and the region.

- x. Recognising the needs of the SKA and MeerKAT programmes on an ongoing basis to inform the development and execution of directed interventions – including both HCD and non-HCD related interventions - that enable SARAO to realise its long-term strategic objectives

4. Step 4: Project Planning and Schedule

The planning process prior to the MeerKAT construction included the development of the eXperimental Development Model (XDM), a 15-m diameter radio telescope antenna of innovative design intended to reduce antenna construction cost, followed by the construction of the KAT-7 telescope, completed in 2011. It was essential to develop and test both human and technology capital in this project, prior to the start of MeerKAT construction. The early and significant investment into this preparation led to experience driven management of the MeerKAT project. Systems engineering is a transdisciplinary and integrative approach to enable the successful realisation, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods (INCOSE definition)³¹. SARAO invested in a significant systems engineering team as well as the resources required by this team. Adherence to strict systems engineering principles and procedures, as well as strong interdisciplinary communication were a significant factor in the successful completion of a fully functional telescope within the approved time allocation.

5. Step 5: Budget, Feasibility and Funding

The initial budget in 2010 for the telescope was finalised prior to the construction of the MeerKAT telescope, this was mainly subject to the final design and number of antennas. Numerous independent feasibility and impact studies were completed prior to project inception and through the project lifecycle. The balance between scientific capability and realistic budget and schedule constraints dictated the final budget of ZAR 600 million for the KAT7 prototype telescope, ZAR 2,3 billion for the MeerKAT telescope (inclusive of the ‘in construction period’ SARAO operational costs) and ZAR 220 million for the SKA Land Acquisition in the Karoo area. These costs exclude the budgeted socio economic benefit (SEB) investment of approximately ZAR 1 billion. In essence, 28 percent of the of total MeerKAT investment was made into public and

³¹ <https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition>.

social infrastructure and development by 2018. The areas of socio economic investment included; R&D outside of the scope of the telescope construction, industry support and development, education, upliftment, including activities involving local social investment programs and collaborations as well as economic spending directly with local suppliers and contractors for operational requirements. Local participation in economic opportunities was a driving principle behind industry development and 32 percent of the SARA O SEB investment was directed into public and social infrastructure in the Northern Cape communities (of the 28 percent of the total MeerKAT SEB investment). SARA O established long-term partnerships to support and grow the skills of local Northern Cape SMME's.

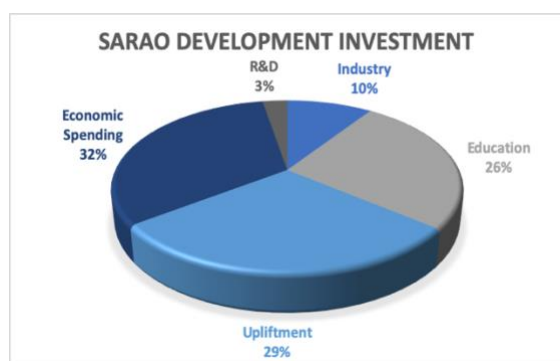


Table 5.1a SARA O Development Investment

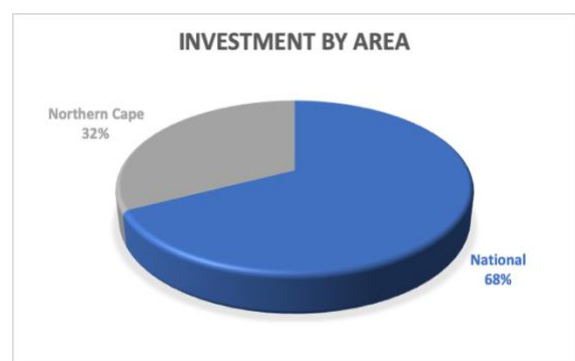


Table 5.1.b Investment by Region

6. Step 6: Governance and Risk assessment

SKA SA holds itself to a high standard of transparency and undergoes regular scrutiny and audit, and as discussed is subject to the PFMA. In addition, the SKA SA is undergoing the process of becoming International Standards Organisation (ISO) compliant with international management standards. A high level of governance is an essential requirement for international collaboration and integration.

Security is an important focus at SKA SA, whether it be personal security, security of assets, or data and network security. A number of organisational policies and regulations have been implemented to ensure a high level of protection and safety. The South African Parliament assented to the Protection Of Personal Information (POPI) Act on 19 November 2013. This Act gives effect to the constitutional right to privacy, by safeguarding personal information when processed by a responsible party, subject to justifiable limitations, and regulates the manner in which personal information may be processed. The governance directorate of the NRF provides support to SARA O in terms of meeting the organisational objectives through the adoption of leading governance principles and practices. The directorate makes certain that the NRF and its

facilities comply with the various requirements as mandated government regulations. In addition, the directorate also provides assurance services concerning legislation, regulation frameworks and best practice. The governance environment is driven by a combination of applicable laws and non-binding rules, most substantially influenced on the government environment derived from the King IV Report on Corporate Governance for South Africa. SARAO management prioritises ethical leadership, stakeholder inclusivity, integrated thinking and integrated reporting. SARAO management also scrutinises risk and mitigation from all levels of the organisation on a quarterly cycle as well as reporting the quarterly measurement key performance indicators and the annual submission of performance plans. These are reviewed and integrated at the level of the NRF and the DSI.

7. Performance assessment at project completion in 2018

In the decade prior to the start of MeerKAT construction, Steps One to Six were completed. What is important to note is that the content of these steps was not set aside upon the entry into the development phase but was rather continually fine-tuned and revisited throughout the project lifecycle. This is an important lesson learned from the project, continuous planning and performance appraisal ensured adherence to budget and schedule as well as inducing significant socio-economic benefits derived from the project.

12.2.4. **Development Phase**

1. Step 1: Infrastructure

It is worth differentiating between the physical and non-physical aspects of infrastructure. For example, in the railway sector the physical infrastructure systems are the tracks plus the stations and depots required for the system to function as a network. The non-physical aspects, would be the institutional infrastructure systems that supports the management, regulation and control of the services, including the information and communication technology (ICT) systems.

The construction phase for MeerKAT included the implementation of the entire required infrastructure from the installation of 110 km of overhead power lines, subterranean power, resurfacing 80 km of road and the complex foundations and components for all 64 antennas. In addition, 80 percent of the full MeerKAT project was locally procured. The construction phase also saw the completion of an underground data centre known as the Karoo Array Processor Building (KAPB) that houses the MeerKAT correlator and computer for the science data processing racks. This high performance computer is the most efficient computer of its kind in Africa, in terms of performance and cost. The 64 15,5 metre antennas, each approximately five stories in height, as well as their installed technologies and cryogenics were completed, integrated and commissioned by the organisational target date of the 31st March 2018. In a short time, the MeerKAT telescope attracted additional international investment and partnerships. Through a partnership with the Max Planck Institute for Radio Astronomy in Germany, the MeerKAT telescope's current scientific capabilities will be enhanced through the addition of further receivers in additional wavelengths, installed on the current MeerKAT antennas, as well as the construction of an additional 16 antennas to be integrated with the current MeerKAT telescope.

2. Step 2: Local Community Development

Investment into the local community of the Northern Cape Province, and in particular identifying opportunities to maximise job creation, investment in local businesses, and training opportunities, was key towards the success of the MeerKAT project. As a result, specific monitoring is done to assess local benefits that accrue to the local community in the nearby towns, in particular Carnarvon (nearest to the SKA site).

Key highlights of investment into the local communities either directly by SRAO or its contractors include 8,785 direct and indirect job opportunities created in the Karoo, 364 technicians trained from the local community; ZAR 255 million spent with local Karoo suppliers, and ZAR 33 million spent on local and emerging contractors, and 56 SMMEs from surrounding towns (Carnarvon, Williston, Van Wyksvlei and Brandvlei) were identified and underwent an accredited business training programme. The training provided training and development, mentoring, assistance with marketing, development of business plans and legal compliance requirements support.

Interventions at a schools level included an outreach and science education reach of approximately 22000 interactions with learners per year and 1500 interactions with educators for the period 2014 – 2018. In 2019, SRAO launched the MeerKAT Creative Community Initiative (MCCI) and 19 artists graduated from the training programme. Some of the graduates were commissioned to design corporate gifts for the SRAO bursary conference. The order was valued at over R100 000. Some of the participants were also selected to sell products at the Craft Design Institute (CDI) store at the Watershed, the craft and design hub at the V&A Waterfront. The graduates will be registered as a cooperative, allowing them to function as a structure and access external funding. Community development grants are also issued on an annual basis in collaboration with the communities surrounding the SKA site. Since 2019, the following partnerships were formed: Swartkop Community Centre was built and developed to house a feeding scheme, a pre-primary school, a library, and a basic healthcare facility; Community development programs focused on youth in Carnarvon, Williston and Fraserburg; Feeding schemes supported in Carnarvon, Williston and Brandvlei; Skills development programs facilitated on a monthly basis (examples include CV writing, SMME training, proposal writing etc.); and the three local municipalities were assisted with the revision of their Spatial development Frameworks to include the SKA.

3. Step 3: Technology, Innovation and Industry Development

The Financial Assistance Programme (FAP) enhanced South African industry competitiveness, internationally and built the experience for the SKA project, required to win SKA procurement contracts. The full FAP investment for the 5 programmes over 6 years was ZAR 147m, summarised in Table 9. Three innovative technologies were developed through the FAP programmes in addition to the SKA design consortia requirements and these are currently in the various stages of commercialisation with applicability to a number of market segments. This was a new programme and the only programme of its kind. It was uniquely designed to overcome the challenges of South Africa industry to participate in the SKA design phase. The challenge was

financial due to the design phase being self-funded participation. FAP was established on a risk-sharing and cost-sharing basis to accomplish this.

Programme	Number of industry participants	Total Programme Value	Spend to Date	Percentage Work Completion
FAP 1	11	51 350 000	50 177 908	100%
FAP 2	2	2 065 000	2 065 000	100%
FAP 3	4	22 950 000	21 942 744	100%
FAP 4	5	33 205 000	26 814 819	100%
FAP 5	4	37 500 000	15 636 563	100%

Figure 12.2.2 FAP Programmes 2022

The commercialisation team works with the Science Data Processing, Electronics and the RFI teams towards the development of technologies and the identification of opportunities, to provide assistance in sourcing partners and funding. As of 2022, eight spin-out technologies are in the various stages of development and commercialisation. These are summarised in Table 13.2.2 below:

Technology	Description
Bespoke compute and storage solution	Combining SARAO expertise and off the shelf solutions, a more cost-effective and bespoke compute and storage solution was delivered to the South African National Space Agency (SANSA) to enable the delivery of a Digital Earth South Africa (DESA) platform. DESA builds on the Data Cube technology developed by Geoscience Australia and to deliver a unique capability to process, interrogate, and present Earth observation data in response to these issues.
Tape Library	The development of a low cost library system has passed critical design review and currently major work is undertaken focusing on optimizing the prototype to get it fully functional for the innovation bridge. Wide commercial opportunities exist for such a library considering the near 10x reduction in price over competing commercial offerings;
IronHive	A low cost, high performance, power efficient compute solution, particularly suited to harsh remote environments. Substantial progress has been achieved on the mechanical design. Significant work is still needed as the development was suspended to focus on MeerKAT. The advanced techniques in this project, including immersion cooling, micro servers and rugged computing have significant application in both the commercial and SKA environments
Object Storage	Whilst the hardware platform is largely complete (as a co-development with Peralex), SARAO's burgeoning expertise with the open source object storage system CEPH is likely to yield a significantly marketable commercial offering. As a combined hardware/software

	platform, it will offer one of the most advanced, and cost effective, storage systems on the market
Data Intensive Solutions	Big Data’ and ‘Machine Learning’ programmes within the SARA0 context seek to develop solutions to the challenges of transporting, analysing, visualising and storage of larger amounts of data than current technologies allow. The applications from this research and development are widespread across many sectors
The Real-time Transient Analyser (RTA)	RTA is under development as a broadband time domain instrument. Presently, scanning the radio frequency (RF) spectrum to sufficiently sensitive levels at reasonable speed is impractical using frequency domain instruments. An RTA system has a wide instantaneous RF bandwidth, capturing RF signals and providing analysis capability with 100percent probability of transient-signal detection over the full processing bandwidth. Another application is in the field of electromagnetic compatibility (EMC) testing. EMC certification to standards from FCC, CISPR, ETSI and various military standards is a requirement for any piece of electrical and electronic equipment marketed worldwide. The RTA can provide a quick measurement capability in these types of tests, reducing measurement time and cost
Fibre optics time transfer	Fibre optics time transfer is an area of active development where spin-off opportunities exist. Already a preliminary patent has been registered for technology developed for the MeerKAT telescope. The MeerKAT design is low cost and accurate and could be exploited in other domains, including passive Radar
COMRAD	A passive radar technology that uses the existing Broadcast FM transmitters (87.5 MHz to 108MHz band) as source transmitters to monitor air traffic. SARA0, in partnership with Peralex (who own the IP), have developed and deployed the ComRAD technology in the Karoo and the system is performing well. The system can be deployed to monitor airspaces around strategic assets such as National Key Points and national parks.

Table 12.2.2 Technologies under commercialisation development

4. Step 4: Human Capital Development Programme

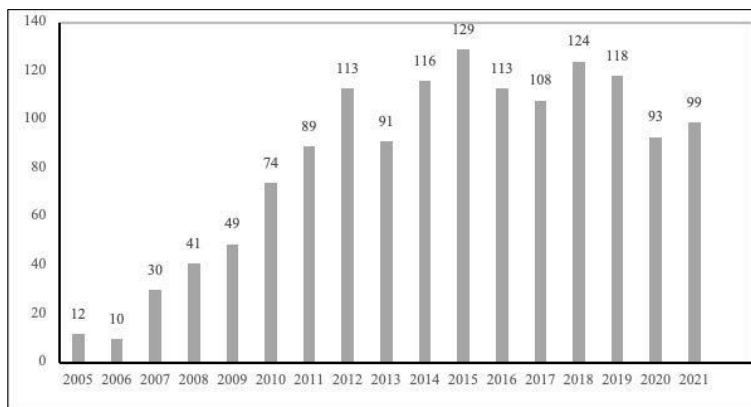
4.1. Methodologies to Achieve HCD Programme Objectives

This section describes the methodologies used by SARA0 to achieve its HCD objectives. These include the implementation of a pipeline model, ensuring support is focused on relevant research and studies, offering competitive scholarships and fellowships, prioritising support to drive transformation in science engineering and technology, and implementing programmes that endeavour to create an appropriately skilled and collaborative community around MeerKAT and SKA. The implementation of the various SARA0 HCD programmes was by the consolidated ‘‘Framework for the Implementation of the Human Capital Development Programme - Version 2: July 2017.’’ The framework includes the processes to be followed for the provisioning and

approval of calls, the review and recommendation of applications, the notification of the outcome of applications, the funding of grants, including carry-forwards, and the monitoring of the progress of the grant holders. In addition to the SRAO HCD Framework, the implementation of the postgraduate programme is instructed by the processes of HCD Programme Performance. There are several outputs of any HCD programme that can be regarded as the key indicators of the success, or lack thereof, of the programme. These specifically include the following with respect to SRAO; the graduation rate of grant holders, the progression of grant holders from one academic level to the next, the contribution of the HCD alumni to meaningful (impactful) employment in relevant sectors and transformation.

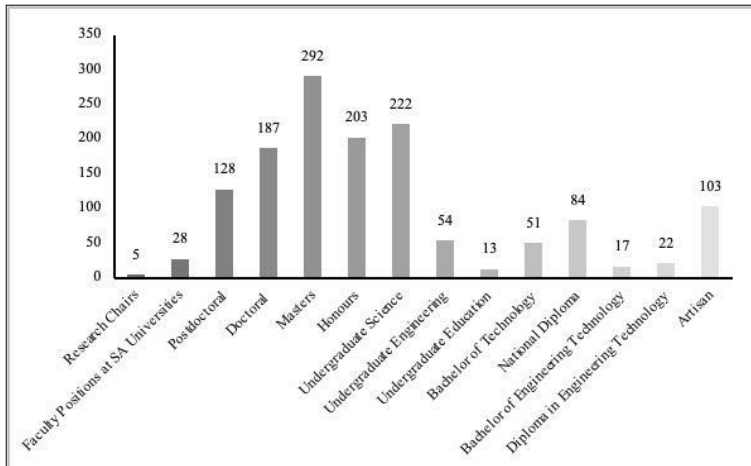
4.2. Summary of Grants Awarded

SRAO awarded 1409 grants between 2005 and 2021. The number of grants awarded by year is provided in Graph 13.2.1 below, with the number of grants awarded by academic level is provided in Graph 13.2.2.



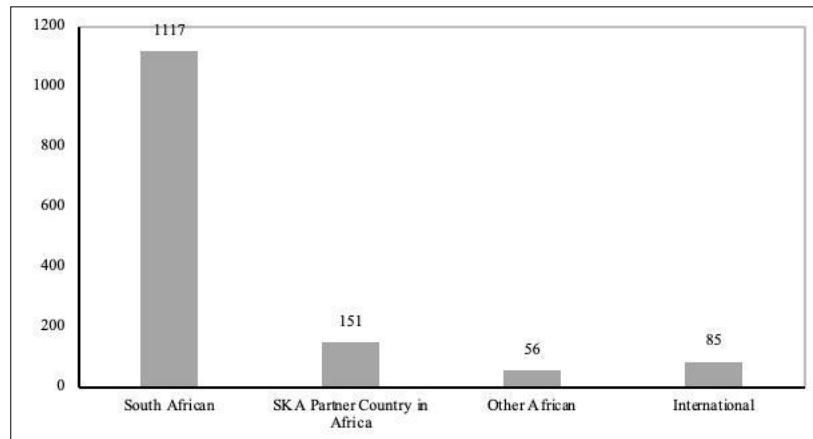
Graph 12.2.1 Number of Grants Awarded by Year (Data Source: SRAO)

In Graph 13.3.3 below, SKA Partner Country refers to citizens from the eight SKA Africa APCs. The “Other African” grant holders are students from non-APC countries in Africa. While SRAO HCD has become stricter on awarding of grants to non-APC countries, it has also supported excellent students from other African nations. The international cohort of grant holders includes grants for visiting professors and postdoctoral fellows.



Graph 12.2.2 Number of Grants Awarded by Study Level (Data Source: SARAQ)

At the beginning of the HCD programme, there were few South African researchers available to supervise students and teach in the universities. The need for this calibre of capacity was largely filled by international researchers and visiting professors. In addition, the majority of the postdoctoral fellowships were awarded to foreign nationals, however, as a direct result of the pipeline model, subsequently South Africans have been applying for, and being awarded these positions.

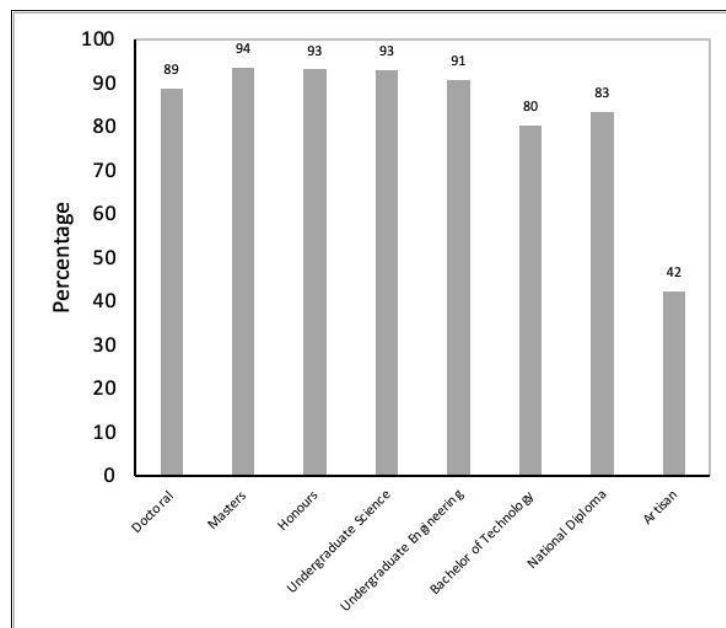


Graph 12.2.3 Distribution of Grants by Broad Category of Nationalities (Data Source: SARAQ)

4.3. Success Indicators

4.3.1. Graduation Rates of Students Funded by SARAQ

An important indicator of whether or not the SARAQ HCD programme has been successful is the number of students graduating from their respective degrees or diplomas. Graph 13.2.4 provides the graduation rate per academic level. In all academic programmes, except for the artisan programme, the graduation rates are above 80 percent. The high graduation rates can be attributed to the key principles of the SARAQ HCD programme; namely selecting academically excellent students, supporting internationally recognised researchers and supervisors, offering full cost of study scholarships that are competitive with industry creating a diverse, interactive, collaborative and informed community of students with local and international researchers around the SKA and MeerKAT.



Graph 12.2.4 Graduation Rates by Academic Level (Data Source: SARAQ)

To understand if the graduation rates of SARAQ-funded students are indeed indicative of a successful HCD programme, SARAQ compares its students' graduation rates with the national averages. This data is presented on page 102 of the "Statistics on Post-School Education and Training in South Africa: 2019" report, published by the Department of Higher Education and Training (DHET) in 2020. The data used is sourced from the HEMIS database (2019). However, a direct comparison is only possible for the Honours level, because the DHET graduation rates are calculated using the number of students who graduated in a particular year, irrespective of the

year of study, divided by the total number of students enrolled at the universities in that same year. As noted in the DHET's publication, these graduation rates serve as proxies for throughput rates of cohorts of students. At the Honours level, the national average rate of graduation is 55 percent, compared to that of SRAO-funded students, which is 93 percent.

4.3.2. Progression Rates

The progression rates for Diploma, Undergraduate and Honours students is calculated as the percentage of SRAO-funded students who completed their respective degrees or diplomas and moved into the next academic level, with continued funding from SRAO. 72 percent of SRAO-funded undergraduates received SRAO Honours scholarships. 70 percent of SRAO-funded National Diploma students received SRAO Bachelor of Technology scholarships. 39 per cent (106) of the Honours students and 29 percent (14) of the Bachelor of Engineering students funded by SRAO received SRAO Master's scholarships. With the high graduation rates for Bachelor of Science Honours students and Bachelor of Engineering students, at 93 percent and 91 percent respectively, one would expect higher progression rates into a Master's degree. The reason for these lower-than-expected progression rates is due to the lower number of SRAO Master's scholarships available, compared to the number of Honours and undergraduate scholarships. The progression rate of Master's graduates into a SRAO-funded Doctoral degree is 42 percent, which is equal to 104 students out of 246. Of the 104 Masters students, 31 are engineering students and 73 are science students. The lower number of engineering students progressing to a Doctoral degree is not unexpected for the sector, where few industries (including SRAO) need engineers with a Doctoral qualification. The progression rate of the Doctoral graduates into a SRAO-funded Postdoctoral Fellowships is 30 percent (38 out 127). The apparent low progression rate is because the number of SRAO postdoctoral fellows is approximately half of the number of SRAO Doctoral scholarships.

5. Performance assessment at project completion in 2018

The MeerKAT Project was completed on time and on budget on the 31st of March 2018. The first image produced from the MeerKAT telescope was verified and applauded by independent scientists globally. Stringent Annual performance plans and staff performance were adhered to throughout the project. Quarterly budget reviews, procurement plans, key performance indicator monitoring and evaluation as well as quarterly risk assessments contributed to the adherence to the initial project parameters and project agility when required.

12.2.5. Growth Phase

The Growth Phase focuses on extended programmes, commercialisation and the increased capacities in terms of impact and science. The MeerKAT telescope, due to the substantial amounts of data it produces, requires advanced data processing systems and infrastructure in order to extract the greatest scientific value from the telescope. Various initiatives are underway to support this, some of which are summarised here³².

SARAO undertook the design and installation of the most efficient and lowest cost high performance computer, of its kind in Africa, to process data from the MeerKAT telescope and DIRISA Tier 2 funding was awarded to a consortium that included SARAO to set up storage and computing infrastructure and activities to service astronomy and other domains. SARAO supports the Inter-University Institute of Data Intensive Astronomy, which is making headway in servicing the needs of some of the MeerKAT large survey projects. In addition to this, SARAO established a collaboration with IBM Research Africa around the use of machine learning for astronomy and exploring its application for MeerKAT and serendipitous discovery.

A sub-project of the DOME initiative was established between SARAO, IDIA, ASTRON and IBM in the Netherlands in order to explore the archiving, movement and processing of MeerKAT and LOFAR data across a prototype regional centre network between the continents. Another important development is the planned African Data Intensive Research Cloud (ADIRC) project has risen in profile since the Minister endorsed it at the ICRI 2016 conference, the programme seeks to secure international funding for a large roll-out across several APCs and into Europe. The international SKA Organisation has endorsed the concept of SKA Regional Centres as a major component of its data system, and SARAO participates on a committee that defines the requirements for such an international network.

The MeerKAT Extension Project, jointly funded by SARAO and the Max-Planck-Gesellschaft in Germany will increase the total number of MeerKAT antennas to 80 and will also increase the maximum distance between the antennas from 8 km to 17 km, thus enabling an increase in sensitivity, spatial resolution and image quality.

In the face of the pandemic, SARAO was mandated to project manage the National Ventilator Project (NVP) which entailed the local design, development, production and deployment of 20 000 low-cost, non-invasive ventilators, breathing apparatus devices, during the pandemic. SARAO has world-leading systems integration and systems engineering capabilities, evidenced by experience gained in the development of complex systems for the MeerKAT radio telescope, a

³² As at December 2022.

precursor to the world's largest Square Kilometre Array radio telescope. This has applicability to projects such as the NPV, space technology projects and other national challenges requiring these skills.

12.2.6. The SKA Project and the SDEB model

It is too early for an assessment of the SKA project in terms of the SDEB model. According to the SDEB model, the SKA project is still in the Intervention Phase. The full Intervention Phase has not been completed, some areas have been addressed rigorously but others have succumbed to pressures and were not adequately addressed. It has been the case in some areas of the project where 'haste has been met with waste'. Due to pressures, both financial and relating to stakeholders, the Development Phase has begun early, in parallel to the Intervention Phase. This does not add to time-saving but inevitably causes later delays and challenges. Looking back at the project from a time point of say 2030, it will clearly show that the preparation phase for the project in fact took over a decade, which according to the SDEB model, it should have. Initially, however, it was believed by project leaders that a 3-year design phase and a five-year construction phase would see SKA Phase 1 project completion. As of the year-end 2022 though, the view is of delays and challenges. There are many valid reasons for these delays, some have already been highlighted, but the current status supports the case for stringent adherence to a strong Intervention Phase. The full analysis can only be studied upon construction completion to analyse the impacts of delays and actions taken. The author is of the opinion that interim status external audits could be completed in order to realign the project to a more efficient alignment with the model phases.

13. Conclusion

The econometric analysis and the SST Impact-Causality Cycle presented in this research provide a framework for understanding the role of space science and technology (SST) in fostering economic development across Sub-Saharan Africa (SSA). This framework underscores the intricate interdependencies of socio-economic factors, labour productivity, GDP per capita, unemployment, and poverty, and the cumulative effects of SST investments on these key indicators. It is shown that labour productivity can be used as a reliable measure for the socio-economic impacts of SST programmes and investments.

As discussed in previous chapters, the key role of institutions and governance as a pillar of deriving benefit from SST, highlights the need for alignment of African SST policies which remains inconsistent, with significant gaps in coordination between regional and national frameworks. While the African Union's space policy offers a foundational guideline, the absence of coherent alignment across SSA nations limits the effective deployment of SST initiatives and the development of African value chains. Addressing these alignment issues is imperative to enable collaboration—a critical driver of successful SST projects. Notably, collaboration among academia, government, and industry is vital, as it ensures synergy between investment, policy development, research, and commercial applications of SST, thereby enhancing socio-economic outcomes.

The additional core pillars identified in this research, namely education, technology and innovation, and equality are foundational for achieving sustainable economic growth from SST investments in SSA. Each pillar complements the others, establishing the structural integrity required to address the complexities of development in the region. Robust institutions and policies that foster an enabling environment, coupled with an education system that provides relevant skills, create the groundwork for maximising SST's potential. Technological advancement and innovation are also pivotal, not merely for driving economic progress but for ensuring that the gains are inclusive, thereby promoting equality and leveraging the region's diverse value chains.

The econometric models presented in this study reveal non-linear relationships between key economic variables and productivity, leading to the adoption of a log-log model to show the elasticities of labour productivity. Despite identifying areas of progress, significant challenges remain. The analysis indicates inefficiencies in financial systems, disparities in educational quality, difficulties in technology adoption, and inefficiencies in labour market allocation—all of which

require targeted intervention. Addressing these weaknesses is crucial to fully realise the impact of SST investments on the broader economy.

The negative correlation between education and productivity, contrary to the theoretical expectations, necessitates a reassessment of educational policies and practices in SSA. For SST to effectively contribute to economic growth, educational systems must be restructured to align closely with the demands of technology-driven industries, thus ensuring that the workforce is equipped to effectively leverage SST investments. Further, the persistent negative relationship between technology efficiency ratios and productivity suggests a significant gap in harnessing existing SST investments for maximum economic benefit. This highlights the necessity of not only providing access to technology but also promoting its effective use and adoption to foster innovation and productivity gains.

A critical insight from this research is that human capital investments will not translate effectively into economic growth unless the broader socio-economic environment, encompassing infrastructure, governance, and healthcare, is also concurrently improved. The International Labour Organisation (ILO) similarly emphasises that skills development must be supported by policies that promote enterprise, employment, and decent work conditions to create an enabling environment for economic growth. The findings of this thesis also emphasise the significant contribution of the informal sector to SSA's economy. Integrating informal labour into the formal economy is an essential step towards inclusive growth, but it must be approached cautiously to ensure that existing livelihoods are not undermined. Policymakers must devise strategies that are both inclusive and adaptive to the unique challenges and opportunities of the informal sector, thereby enhancing its contribution to overall productivity.

The Decision Matrix developed in this research provides a practical tool for assessing the socio-economic impact of SST programmes by incorporating country-specific economic contexts alongside the contributions of formal and informal labour productivity. The quantified sustainability value of SST projects, as formulated through this matrix, offers a tangible measure of socio-economic benefit, reinforcing the notion that SST investments must be sustainable and driven by both economic and social imperatives. The SDEB framework, derived from the MeerKAT case study, demonstrates the efficacy of SST investments as a self-reinforcing cycle of development through intervention, development, and growth phases. This framework serves as a practical model for the implementation of SST investments that can drive meaningful socio-economic progress. South Africa's participation in the Square Kilometre Array (SKA) and the delivery of the precursor MeerKAT Telescope has led to socio economic benefits including the development of home-grown, cutting-edge technologies, human capital development, South African industry development, science returns and will continue to produce more. Growth in

scientific output has increased significantly with research publications increased from below the global average to twice the global average. This project has enhanced South Africa's global reputation for science and technology cooperation and investment. Declaration of the Meerkat National Park facilitates the establishment of multi-disciplinary research platforms and several research activities are underway. An independent socio-economic study has been undertaken by SARAQ to consider the impact of radio astronomy investments in MeerKAT and the SKA project over the period 2011 to 2022³³. This period covers MeerKAT construction and five years of scientific operations. Results of the economic modelling indicate the following impacts: Overall, 23 022 FTE jobs have been created throughout the country, there has been an increase in GDP of R8,9 billion, a R4,6 billion increase in household income and 92 088 people have benefited. In the Northern Cape, expenditure on establishing the SKA is likely to increase the Northern Cape's GDP by approximately R250 million. Preparation for hosting the SKA led to the SARAQ Human Capital Development programme from community upliftment and education initiatives to the 100 grants awarded annually, covering national diplomas through to PhD. To date over 1,600 grants and bursaries have been awarded over the last 16 years. In addition, the programme has increased Africa's female research and skills base in data-driven science and associated technologies needed for dealing with extremely large data sets associated with SKA.

The foreign direct investment over the construction phase and the 50 year operations phase of the SKA will lead to a net positive inflow of Foreign Direct Investment over South Africa's investment into the SKA. The Financial Assistance Programme (FAP) ran for 6 years and R 146 m was allocated to 15 South African companies to participate in the SKA Design Phase on a shared cost and shared risk basis. To date 3 of these companies have been awarded contracts in the early part of the procurement for the SKA Construction phase, to the value of 3 times the entire FAP programme cost. The SKA programme led to the Africa Radio Astronomy Programme driven by South Africa with benefits for South Africa and the eight Africa Partner Countries. In addition, the innovation and commercialisation activities at SARAQ have led to 8 spin off technologies and further innovations continue under development towards commercialisation.

The small sample size with respect to the SSA data set was a limitation to the analysis, however robust theoretical research has provided a counterbalance, which guided the research design, interpretation, and subsequent steps. It is important to note that theory cannot completely compensate for the empirical limitations of a small sample size, and the findings should be validated with future research and the compilation of larger and more representative data samples.

³³ Scientific Study to Gauge the Socio-Economic Impact and Perceptions of the MeerKAT/SKA Telescope Project, SARAQ, 2023.

To deepen the understanding of the Propensity to Value Time in terms of Money (PVTM) in SSA, future research should focus on developing robust proxies that capture cultural attitudes towards time and economic behavior. Variables related to future orientation, work ethic, and saving behavior can be combined to create a composite cultural index. Additionally, national surveys that provide data on how people allocate their time between work, family, and leisure, can further elucidate the relationship between time valuation and economic performance. By incorporating these diverse data sources and employing statistical techniques such as Principal Component Analysis (PCA) to create standardised indices, future studies can quantify the impact of cultural attitudes on economic growth more precisely. This approach will enhance the academic rigor of the research and provide a clearer, data-driven understanding of PVTM, thereby informing policy decisions aimed at fostering economic development in SSA.

Given the challenges in quantifying informal labour productivity and its impacts, innovative data collection methods, including extensive surveys and qualitative interviews, would have to be employed. Empirical analyses using robust econometric models should be conducted to assess how investments into education and R&D influence informal labour productivity. Incorporating variables such as digital adoption, environmental quality, and healthcare access can provide a more holistic view of how these investments translate into broader socioeconomic benefits. Furthermore, the complex relationship between informal labour productivity and the propensity to value time in non-monetary terms remains underexplored and warrants detailed investigation. Each SSA country exhibits unique characteristics and challenges within its informal economy, which significantly contribute to employment and livelihoods. Researchers can explore the dynamics of informal employment, focusing on factors such as access to credit, regulatory environments, and the socio-economic impacts of informality. Further research could explore the long-term trends and the persistence of the observed effects, providing deeper insights into the sustainability of productivity improvements in the informal sector. Comparative studies between these countries can provide insights into effective policy interventions that support the transition from informal to formal economies. Investigating specific industries within the informal sector could also yield more granular insights, aiding in the design of targeted interventions and policies. The findings in the research suggest that shifts in employment from the agriculture sector to the services sector may not directly translate to increased productivity. One possible explanation for this negative relationship is that workers transitioning from agriculture to services might initially face a learning curve, leading to temporary declines in productivity. Additionally, the services sector may require different skills and higher education levels than those prevalent in the agriculture sector, thus impacting productivity negatively in the short term. This unexpected result highlights the complexity of labour dynamics and productivity metrics, thus the need for further

research to explore underlying factors such as skill mismatches, sector-specific education requirements, and the quality of education. Future studies should consider these variables and their long-term effects to provide a more comprehensive understanding of the relationship between education ratios and labour productivity.

Further studies should explore the nuanced relationship between Foreign Direct Investment (FDI) and the informal sector in African economies. Specifically, understanding how the informal sector's characteristics influence FDI inflows and, conversely, how FDI impacts labour productivity within the informal sector warrants deeper investigation. The eclectic paradigm, encompassing ownership, location, and internalization advantages, provides a robust framework to analyse these dynamics. Ownership advantages like technology transfer and managerial expertise can enhance productivity, while location advantages underscore the importance of infrastructure and skilled labour availability. Internalisation advantages may improve efficiency and resource utilisation. However, FDI's impact on informal businesses can be multifaceted, potentially introducing competitive pressures that challenge informal enterprises' sustainability. Additionally, the potential of FDI to formalise the informal sector and create employment opportunities highlights a critical area for policy interventions aimed at fostering inclusive economic growth. Future research should therefore aim to disentangle these interactions and provide actionable insights for policymakers and investors alike.

Socio-economic impact extends beyond economic growth and SST investments can lead to technology spillovers, which benefit various sectors, including the informal economy and non-market activities. It is a limitation that these spillovers may not be reflected in formal labour productivity and as such it is necessary to incorporate a measure of informal impact. A further challenge is that the full socio-economic impact of SST investments may take time to materialise and may extend beyond the scope of formal labour productivity measurements. The PVTM indicator attempts to link economic theory with practical measures of productivity and cultural attitudes towards time and money. It's a multifaceted approach that tries to capture complex socio-economic dynamics. There have been challenges with this approach as the assumption that the interest rate inversely represents the time value of money in a linear fashion may not hold in all economic contexts, especially in volatile economies or where interest rates are manipulated by central banks. The normalisation of the productivity differential by formal sector productivity alone might not account for the size and economic significance of the informal sector, which can vary widely between countries. The indicator still requires substantial empirical testing to validate its effectiveness in predicting or explaining economic behaviour, especially in the context of large-scale, long-term investment projects like those in SST.

The Decision Matrix research also illuminated the fact that socio-economic investment can be utilised to mitigate project risk towards programme sustainability. Another important outcome of this work was that the process of deriving the sustainability value revealed that the socio economic benefit of the project investment can be quantified and expressed in terms of the labour productivity changes due to the project. These results however have to be studied further with more complex modelling over a larger number of case studies.

In conclusion, the case study brought to light the importance of rigorous planning and significant socio economic investment as targeted interventions in SST programmes, in order to maximise the sustainability and derived benefit from such programme. The findings presented in this thesis thus emphasise the need for a cohesive and strategic approach to SST investments that addresses both the direct and underlying determinants of productivity. This requires alignment of SST policies at both regional and national levels, fostering collaboration across sectors, and investing in the foundational pillars that underpin economic growth. By focusing on improving the efficiency of financial systems, refining employment strategies, enhancing the quality of education, and bridging the gap in technological utilisation, SSA can unlock the full potential of SST investments. This approach is crucial for the mitigation of project risk by means of socio economic investment, initiating positive feedback loops that enhance labour productivity, reduce poverty and unemployment, and ultimately increase GDP per capita, thereby setting SSA on a sustainable path towards economic development and prosperity.

13.1. Future Work

This research highlights several areas where future studies can enhance the framework and its practical application.

First, the limited availability of panel data across SSA countries presents a challenge for robust statistical analysis. Future research should aim to compile broader and more representative data sets, including longitudinal data capturing informal labour, non-market activities, and technology spillovers.

Second, further empirical studies are necessary to validate and refine the PVTM (Propensity to Value Time in terms of Money) indicator. This index seeks to quantify cultural attitudes toward time and money, but requires improved proxies and broader regional testing. Incorporating variables such as work ethic, saving behaviour, and future orientation, through both national surveys and principal component analysis, could enhance precision.

Third, the relationship between informal labour productivity and SST investment remains underexplored. Studies employing surveys, econometric models, and qualitative interviews can offer insight into how R&D and education influence productivity in informal economies. Comparative research between SSA countries can also highlight effective policy levers to support formalisation and inclusive growth.

The observed negative correlation between employment transitions (e.g. from agriculture to services) and productivity underscores the need for additional research into skill mismatches, sector-specific education, and transition dynamics.

Further exploration of the role of FDI in informal economies, particularly how investment patterns influence or are influenced by informality will also benefit policymakers. Application of the eclectic paradigm (ownership, location, internalisation) could be used to frame this analysis.

Lastly, given the current complexity of the SSTIF, future work should focus on distilling the model into a simplified composite index or decision-support tool for policymakers. This will ensure that the benefits of the framework can be realised even by governments with limited technical capacity. While this research contributes a new conceptual framework, the SSTIF that comprises the SIC, PDM, and SDEB phases, it is acknowledged that the model has not yet been extensively tested across diverse contexts. The application to the MeerKAT project provides a strong proof of concept, but broader generalisation across Sub-Saharan Africa will require additional testing. As such, the analytical power and practical relevance of the SSTIF must be further validated through comparable case studies across different countries and sectors.

Moreover, while the SSTIF offers a comprehensive approach, it may be overly complex for direct government application in its current form. A future iteration could simplify the model into an

index or decision-support tool to increase accessibility for policymakers. This refinement would allow governments to leverage the SSTIF's insights without needing technical expertise in economic modelling.

Finally, the inclusion of informal sector dynamics in this study, particularly the impact of employment informality on productivity, demonstrates the need for models that reflect the lived realities of SSA economies. Further empirical testing and theoretical exploration are needed to optimise the SSTIF's structure and utility for long-term policy impact.

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Appendices

Appendix A: SST contribution to addressing the challenges outlined by the SDGs

Space-based applications play a pivotal role in addressing various global challenges outlined by the SDGs. Below is an overview of how space science and technology align with each goal, accompanied by examples and full references:

1. No Poverty (SDG 1): Space applications aid in disaster monitoring and response, mitigating the impact of natural disasters on vulnerable populations. For instance, Earth observation data has been utilized to improve coffee quality and productivity in Timor-Leste, thereby increasing the income of local coffee growers.
2. Zero Hunger (SDG 2): Research into space-based agriculture has led to advancements in soilless cultivation methods, such as hydroponics and aeroponics. These techniques, initially developed to grow food in microgravity environments, have been adapted for terrestrial use, enhancing food production in areas with limited arable land. NASA's development of the "Veggie" plant growth system on the International Space Station exemplifies this technology transfer.
3. Good Health and Well-being (SDG 3): Space agencies have developed programs to support astronauts' mental health during missions, which have been adapted for use on Earth. For example, NASA's Behavioral Health and Performance program includes strategies such as teleconferences with psychologists and journaling to maintain motivation and morale. These approaches have informed remote counseling and mental health support services on Earth. Additionally, space missions have necessitated the development of convenient nutritional solutions. The powdered drink mix Tang, although not originally developed by NASA, gained popularity after being used in John Glenn's Mercury flight in 1962 and subsequent Gemini missions. Its association with the space program spurred interest in easy-to-prepare, shelf-stable beverages, influencing the development of similar products for both space and terrestrial consumption.

4. Quality Education (SDG 4): Initiatives like "Amanar: Under the Same Sky" use astronomy to engage and inspire refugee communities, enhancing educational opportunities and promoting resilience through skill development.
5. Gender Equality (SDG 5): Space science programs encourage the participation of women in STEM fields, fostering gender equality and empowering women through education and career opportunities in space-related disciplines.
6. Clean Water and Sanitation (SDG 6): Satellite data assists in the efficient management of water resources by monitoring water quality and availability, which is crucial for providing clean water and sanitation services.
7. Affordable and Clean Energy (SDG 7): Space programs have been instrumental in advancing solar power technologies. For example, NASA has been harnessing solar energy to power spacecraft since the 1950s, leading to significant improvements in solar panel efficiency and durability. These advancements have been adapted for terrestrial use, contributing to the proliferation of affordable and clean energy solutions on Earth.
8. Decent Work and Economic Growth (SDG 8): The space sector drives economic development by creating high-tech jobs and fostering innovation, contributing to economic growth and industrial advancement. Industry,
9. Innovation, and Infrastructure (SDG 9): Space technology advancements lead to the development of new industries and infrastructure, such as satellite communications and Earth observation systems, which are integral to modern economies.
10. Reduced Inequalities (SDG 10): Space-based technologies provide global communication networks that bridge digital divides, offering equal access to information and services, thereby reducing inequalities.
11. Sustainable Cities and Communities (SDG 11): Urban planners utilize satellite data to monitor environmental changes and manage urban development, promoting sustainable and resilient cities.
12. Responsible Consumption and Production (SDG 12): Space habitation has led to significant advancements in recycling technologies. Aboard the International Space Station (ISS), up to 80% of water is recycled, including moisture from breath and sweat, reducing the need for resupply missions and promoting sustainable resource utilisation.
13. Climate Action (SDG 13): Satellites play a crucial role in monitoring climate variables, providing data essential for understanding and combating climate change.
14. Life Below Water (SDG 14): Earth observation satellites monitor ocean health, track marine pollution, and support the sustainable management of marine resources.

15. Life on Land (SDG 15): Satellite imagery aids in tracking deforestation, land degradation, and biodiversity, supporting conservation efforts and sustainable land management.
16. Peace, Justice, and Strong Institutions (SDG 16): Space-based communication and navigation systems support peacekeeping missions and the enforcement of law, enhancing global security and justice.
17. Partnerships for the Goals (SDG 17): International collaboration in space missions fosters partnerships and the sharing of knowledge and resources, exemplifying global cooperation to achieve the SDGs.

Appendix B: Project Failure Review

The literature review on the successes and failures of African science and technology-based projects yielded the contributing factors summarised in the following table.

Success or Failure Impact	Project Area	Description
Failure	Management and Governance	<ul style="list-style-type: none"> ● Haphazard government management ● Ineffective governance ● Lack of unity between partners ● Inability to collect funds from debtors ● Lack of project management/competence (Misic & Radujkovic, 2015) ● Inadequate government support
	Corruption	<ul style="list-style-type: none"> ● nepotism
	Resourcing	<ul style="list-style-type: none"> ● sufficient resourcing ● lack of experience in maintenance and operations
	Poor Planning	<ul style="list-style-type: none"> ● absence of credible feasibility studies ● challenges and risks insufficiently identified up front
	Monitoring	<ul style="list-style-type: none"> ● insufficient performance monitoring
	Project Changes	<ul style="list-style-type: none"> ● abandoning later phases due to early challenges thus the full benefits are not achieved
	Long-Term Follow Through	<ul style="list-style-type: none"> ● Insufficient local capacity building

		<ul style="list-style-type: none"> ● Community failure to uptake technology ● Lack of long-term funding
Success	Partnerships	<ul style="list-style-type: none"> ● Links to universities
	Environment	<ul style="list-style-type: none"> ● Local cultural inclusion
	Social Development	<ul style="list-style-type: none"> ● Reinvestment into social development ● Community ownership
	Property Rights	<ul style="list-style-type: none"> ● Intellectual Property agreements and protection
	Business Development	<ul style="list-style-type: none"> ● Nurturing entrepreneurs
	Governance	<ul style="list-style-type: none"> ● Good governance and transparency ● Government support
	Project Management	<ul style="list-style-type: none"> ● Sound project management ● Regular monitoring and performance review ● Systems engineering planning ● Change management ● Risk Management System
	Resourcing	<ul style="list-style-type: none"> ● Sufficient resourcing ● Resource planning for long-term sustainability

Appendix Table 1 Key Causes of Successes and Failures Identified within African Projects

Changing or unclear user requirements, inadequate executive support, technical incompetence, lack of talent, and cultural problems are amongst the leading challenges to large and mega projects as cited over numerous studies (Collier, 2007; Moyo, 2009). The leaders of organisations tend to set unrealistic project expectations in order to meet political agendas, but they do not take into account the availability of resources and talent, as well as the interdependencies that exist –

between products (technologies and hardware), partners (vendors), processes and people – in order to deliver a successful project.

Corruption, bad governance, and lack of project management capacity have also been singled out as critically damaging to projects and growth in Africa. The evidence suggests that projects may fail in part because of the lack of support afforded the by the national environment in which they are conducted. Project management, with its focus on efficiency, works best in a conducive environment of surrounding infrastructure and institutions. In other words, it is more likely to finish a project on time when resources may be readily and reliably obtained, and where contractual obligations with sponsors, suppliers, and employees can be enforced with speed and fairness. (Lavagnon & Saint-Macary, 2014).

“If the African continent is to achieve its full infrastructure potential, all players – both private and public, domestic and foreign – will need to focus on ensuring that they select the right projects and execute them correctly” (KPMG, 2013:27). These statements are correct but broad, and following on from the examination of African science and technology-based projects, it is clear that the correct execution of the project is essential but project execution is too late a project stage to achieve success and reap socio-economic benefits, if the appropriate planning phases have not been fully addressed. In general, space science and technology projects are not only costly, but stretch over exceedingly long time frames. These are large scale projects, and in some instances, mega projects³⁴. The public investment in terms of cost has to be balanced against the socio-economic benefits in terms of returns in order to provide a sufficient cost-benefit analysis capable of motivating governments to take on the project in the first instance. Project planning and implementation is essential, but it cannot be limited to development of the primary infrastructure (or the primary project). A significant phase of pre-implementation that prepares industry, human capital, technology development and community development, has to be included prior to the execution of the primary project itself. This process is captured in the case study in Chapter , as well as in the proposed Science Driven Economic Benefit model in Chapter 9. In the case of large science and technology projects it is not sufficient to implement instrumentation and infrastructure on time and on budget. As is the case with many of these projects, they do not generate revenue and sustainability is dependent on entrenching the project within the economy via long term socio-economic benefits. It is the case that some projects are able to generate revenues such as the South African Nuclear Energy Corporation (Necsa)³⁵ and the Africa colocation programme (Section 7.5).

³⁴ Megaprojects are large-scale, complex ventures that typically cost a billion dollars or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people (Flyvbjerg, 2014).

³⁵ The South African Nuclear Energy Corporation was established as a public company by the Republic of South Africa Nuclear Energy Act in 1999 and is wholly owned by the State.

What is clear is that programmes without significant involvement of all three of public, industry and academic institutions will not be sustainable in the long term.

The table below shows four large scale successful space science and technology investments and their investment into socio-economic development. Two projects outside of Africa were incorporated for the purposes of comparison as there is limited African data available. In addition, although there are many examples of successful and failed space science programmes, there is little available data with respect to their socio economic benefit expenditure type and value, for comparative purposes.

Country	Programme / Project	Programme Annual Expenditure (USD)	% of National R&D Spend (Annual average)	Socio Economic Benefit (SEB) value (USD)	Percentage of Project spend on (SEB)
Over project implementation period					
South Africa	MeerKAT	255 000 000	1,87%	18 461 000	28%
South Africa	HERA	5 692 000	0,20%	2 000 000	35%
India	EO Space Programme	347 100 000	5,13%	180 000 000	52%
USA	NASA M2M	4 561 920 000	0,78%	14 146 000 000	31%

Appendix Table 2 SST Programmes and their associated socio-economic investments

Appendix C: Statistical Outputs

Table 3:1 SSA Countries: Fixed Effects Regression Outputs for the Economic Growth Model

```

. xtreg lnGDP lnCP lnTFP lnLabourForce, fe
Fixed-effects (within) regression      Number of obs   =    589
Group variable: c_id                  Number of groups =    26

R-squared:                             Obs per group:
  Within = 0.9044                       min =         10
  Between = 0.6394                      avg =        22.7
  Overall = 0.6181                      max =         24

corr(u_i, Xb) = -0.8444                 F(3, 560)      =   1765.51
                                         Prob > F       =    0.0000

```

lnGDP	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
lnCP	.3078485	.0186144	16.54	0.000	.2712859	.344411
lnTFP	.7106171	.0719616	9.87	0.000	.5692696	.8519647
lnLabourForce	1.605725	.0761988	21.07	0.000	1.456055	1.755395
_cons	-7.664997	.8689532	-8.82	0.000	-9.371802	-5.958191

sigma_u	1.5702078	
sigma_e	.17954005	
rho	.98709473	(fraction of variance due to u_i)

F test that all u_i=0: F(25, 560) = 72.71 Prob > F = 0.0000

. estimates store fixed

Table 3:1 SSA Countries: Random Effects Regression Outputs for the Economic Growth Model

```

Panel variable: c_id (unbalanced)
Time variable: year, 1996 to 2021
Delta: 1 unit

. xtreg lnGDP lnCP lnTFP lnLabourForce, re

Random-effects GLS regression           Number of obs   =       589
Group variable: c_id                   Number of groups =       26

R-squared:                             Obs per group:
  Within = 0.8785                       min           =       10
  Between = 0.8373                       avg           =      22.7
  Overall = 0.8299                       max           =       24

corr(u_i, X) = 0 (assumed)              Wald chi2(3)    =    3983.68
                                         Prob > chi2     =     0.0000
    
```

	lnGDP	Coefficient	Std. err.	z	P>|z|	[95% conf. interval]	
	lnCP	.489167	.0170794	28.64	0.000	.455692	.5226419
	lnTFP	.6039203	.0839725	7.19	0.000	.4393373	.7685034
	lnLabourForce	.661366	.0487279	13.57	0.000	.5658611	.7568709
	_cons	2.669271	.5733773	4.66	0.000	1.545472	3.79307
	sigma_u	.27540692					
	sigma_e	.17954005					
	rho	.70176208	(fraction of variance due to u_i)				

```

. estimates store random
    
```

Table 3.1 Hausman Test

```

. hausman fixed random

      _____ Coefficients _____
      (b)          (B)          (b-B)          sqrt(diag(V_b-V_B))
      fixed       random       Difference       Std. err.
-----+-----+-----+-----
lnCP          .3078485      .489167      -.1813185      .0074021
lnTFP          .7106171      .6039203      .1066968        .
lnLabourForce 1.605725        .661366      .9443589        .058582
    
```

b = Consistent under H0 and Ha; obtained from xtreg.
B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 248.38
Prob > chi2 = 0.0000
(V_b-V_B is not positive definite)

The output of the Hausman test (Appendix A) shows that there is a systematic difference between the coefficients estimated by the fixed effects model and those estimated by the random effects model. The chi-squared statistic and p-value are highly significant, this leads to the rejection of the null hypothesis that the random effects estimator is consistent. In this case, the Hausman test indicates that the fixed effects model is more appropriate for the data. This means that the individual-specific effects are correlated with the included regressors, and therefore, the random effects model would produce biased coefficient estimates.

Table 3.2 SSA Countries: Fixed Effects Regression Outputs for GDP per Capita and Labour Productivity

```

. xtreg GDPperCapitaStd LPbyHourStd, fe
Fixed-effects (within) regression      Number of obs   =      687
Group variable: c_id                  Number of groups =      42

R-squared:                             Obs per group:
  Within = 0.6216                       min =          7
  Between = 0.9469                      avg =         16.4
  Overall = 0.9108                      max =         17

corr(u_i, Xb) = -0.7142                 F(1, 644)      =     1057.80
                                         Prob > F       =      0.0000

```

GDPperCapi~d	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
LPbyHourStd	1.217464	.037433	32.52	0.000	1.143958	1.290969
_cons	.0843852	.0081611	10.34	0.000	.0683595	.1004108
sigma_u	.33217252					
sigma_e	.21311138					
rho	.70841097 (fraction of variance due to u_i)					

```

F test that all u_i=0: F(41, 644) = 20.12          Prob > F = 0.0000

```

Figure 3.1 SSA Countries: SEM Output for Business Competitiveness and Labour Productivity

Structural equation model		Number of obs = 1,219				
Estimation method: mlmv						
Log likelihood = -16983.796						
		OIM				
		Coefficient	std. err.	z	P>|z|	[95% conf. interval]
Structural						
NewBusinessDensity						
	PatentApplicbyresidents	-.0025089	.0010143	-2.47	0.013	-.0044969 -.000521
	NetFDIinflows	-.0380609	.0189806	-2.01	0.045	-.0752623 -.0008596
	Domesticcredittoprivatesecto	.0854555	.006644	12.85	0.000	.0724336 .0984774
	_cons	.2239537	.2126928	1.05	0.292	-.1929166 .6408241
LPbyHour						
	NewBusinessDensity	1.347765	.0912502	14.77	0.000	1.168918 1.526612
	_cons	5.152959	.3287273	15.68	0.000	4.508666 5.797253
ICTserviceexports						
	LPbyHour	-.3558497	.0538581	-6.61	0.000	-.4614096 -.2502898
	_cons	10.50735	.5245778	20.03	0.000	9.479192 11.5355
	mean(PatentApplicbyresidents)	43.55503	12.87612	3.38	0.001	18.31829 68.79176
	mean(NetFDIinflows)	4.592772	.2792482	16.45	0.000	4.045456 5.140088
	mean(Domesticcredittoprivatesecto)	19.06943	.6716264	28.39	0.000	17.75307 20.38579
	var(e.NewBusinessDensity)	7.67787	.5934178			6.598602 8.933664
	var(e.LPbyHour)	42.82175	2.874237			37.54318 48.8425
	var(e.ICTserviceexports)	94.20167	4.609016			85.58778 103.6825
	var(PatentApplicbyresidents)	49574.95	4757.392			41075.03 59833.81
	var(NetFDIinflows)	88.85096	3.753386			81.79077 96.52059
	var(Domesticcredittoprivatesecto)	474.6698	20.85068			435.513 517.3472
	cov(PatentApplicbyresidents,NetFDIinflows)	-811.6299	219.895	-3.69	0.000	-1242.616 -380.6437
	cov(PatentApplicbyresidents,Domesticcredittoprivatesecto)	2339.283	191.2034	12.23	0.000	1964.531 2714.034
	cov(NetFDIinflows,Domesticcredittoprivatesecto)	-10.50044	6.256435	-1.68	0.093	-22.76282 1.761953
LR test of model vs. saturated: chi2(7) = 15.01		Prob > chi2 = 0.0358				

Table 3.3 SSA Countries: OLS Regression of Labour Productivity and Business Competitiveness Elements

. reg LPbyHourStd ICTserviceexportsStd NetFDIinflowsStd NewBusinessDensityStd HighTechExportsStd						
Source	SS	df	MS	Number of obs	=	208
Model	103.889737	4	25.9724343	F(4, 203)	=	79.85
Residual	66.0309039	203	.325275389	Prob > F	=	0.0000
				R-squared	=	0.6114
				Adj R-squared	=	0.6037
Total	169.920641	207	.820872663	Root MSE	=	.57033
	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
ICTserviceexportsStd	-.0436056	.04118	-1.06	0.291	-.1248009	.0375896
NetFDIinflowsStd	-.1409427	.08777	-1.61	0.110	-.3140005	.0321151
NewBusinessDensityStd	.5313502	.0393445	13.51	0.000	.4537739	.6089266
HighTechExportsStd	.157004	.0333784	4.70	0.000	.0911912	.2228168
_cons	.0285699	.0404256	0.71	0.481	-.051138	.1082779

World Data Comparison: OLS Labour Productivity and Business Competitiveness Elements

. reg LPbyHourStd ICTserviceexportsStd NetFDIinflowsStd NewBusinessDensityStd HighTechExportsStd						
Source	SS	df	MS	Number of obs	=	1,237
Model	265.48805	4	66.3720125	F(4, 1232)	=	82.47
Residual	991.554615	1,232	.804833292	Prob > F	=	0.0000
				R-squared	=	0.2112
				Adj R-squared	=	0.2086
Total	1257.04267	1,236	1.01702481	Root MSE	=	.89713

LPbyHourStd	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
ICTserviceexportsStd	.1362949	.0220428	6.18	0.000	.0930493	.1795404
NetFDIinflowsStd	-.0634759	.0758582	-0.84	0.403	-.2123015	.0853497
NewBusinessDensityStd	.578953	.0349785	16.55	0.000	.5103291	.647577
HighTechExportsStd	.3517337	.1080408	3.26	0.001	.1397694	.563698
_cons	.2847453	.036792	7.74	0.000	.2125635	.3569272

World Data Comparison: SEM Output for Business Competitiveness and Labour Productivity

Structural equation model		Number of obs = 6,323				
Estimation method: mlmv						
Log likelihood = -123009.54						
		OIM				
		Coefficient	std. err.	z	P>|z|	[95% conf. interval]
Structural						
NewBusinessDensity						
PatentApplicbyresidents		-6.49e-07	1.12e-06	-0.58	0.563	-2.85e-06 1.55e-06
Domesticcredittoprivatesecto		.0827971	.0022799	36.32	0.000	.0783285 .0872657
NetFDIinflows		.0136459	.0044755	3.05	0.002	.0048741 .0224178
_cons		-1.543071	.1617844	-9.54	0.000	-1.860162 -1.225979
LPbyHour						
NewBusinessDensity		2.21396	.0775183	28.56	0.000	2.062027 2.365893
_cons		16.00008	.426082	37.55	0.000	15.16498 16.83519
ICTserviceexports						
LPbyHour		.0142221	.0074382	1.91	0.056	-.0003564 .0288006
_cons		7.12583	.2128556	33.48	0.000	6.708641 7.543019
mean(PatentApplicbyresidents)		12929.44	3963.989	3.26	0.001	5160.167 20698.72
mean(Domesticcredittoprivatesecto)		51.88214	.6398304	81.09	0.000	50.62809 53.13618
mean(NetFDIinflows)		3.999796	.922545	4.34	0.000	2.191641 5.807951
var(e.NewBusinessDensity)		20.50485	.7387092			19.10694 22.00504
var(e.LPbyHour)		311.7364	9.316999			294 330.5429
var(e.ICTserviceexports)		73.36743	1.661919			70.18138 76.69813
var(PatentApplicbyresidents)		7.46e+10	2.27e+09			7.02e+10 7.91e+10
var(Domesticcredittoprivatesecto)		2109.719	46.20935			2021.067 2202.26
var(NetFDIinflows)		4369.854	96.39576			4204.93 4582.911
cov(PatentApplicbyresidents, Domesticcredittoprivatesecto)		4378006	285068.4	15.36	0.000	3819282 4936730
cov(PatentApplicbyresidents,NetFDIinflows)		-1.68e+07	375271.8	-44.88	0.000	-1.76e+07 -1.61e+07
cov(Domesticcredittoprivatesecto, NetFDIinflows)		-711.2472	70.03487	-10.16	0.000	-848.513 -573.9814
Note: The LR test of model vs. saturated is not reported because the saturated model is not full rank.						
.						
.						

Table 3.4 SSA Countries: IV Regression GMM Labour Productivity and Business Competitiveness

```
. ivregress gmm LPbyHour ICTserviceexports (NewBusinessDensity = PatentApplicbyresidents Domesticcredittoprivat
> esecto)
```

Instrumental variables GMM regression Number of obs = 92
 Wald chi2(2) = 154.01
 Prob > chi2 = 0.0000
 R-squared = 0.0328
 GMM weight matrix: Robust Root MSE = 8.6346

LPbyHour	Coefficient	Robust std. err.	z	P>|z|	[95% conf. interval]	
NewBusinessDensity	2.544246	.2064775	12.32	0.000	2.139558	2.948935
ICTserviceexports	.5411507	.2724066	1.99	0.047	.0072436	1.075058
_cons	-2.274123	1.782078	-1.28	0.202	-5.766931	1.218685

Endogenous: **NewBusinessDensity**
 Exogenous: **ICTserviceexports PatentApplicbyresidents Domesticcredittoprivatesecto**

Table 3.5 Correlation Table of Business Competitiveness Elements and Labour Productivity

```
. correl LPbyHour HighTechExports NewBusinessDensity NetFDIinflows ICTserviceexports PatentApplicbyresidents
(obs=92)
```

	LPbyHour	HighTe~s	NewBus~y	NetFDI~s	ICTser~s	Pa~dents
LPbyHour	1.0000					
HighTechEx~s	0.4956	1.0000				
NewBusines~y	0.7684	0.3041	1.0000			
NetFDIinfl~s	-0.3314	-0.2003	-0.2505	1.0000		
ICTservice~s	0.0272	-0.0390	-0.0873	-0.0822	1.0000	
PatentAppl~s	0.4258	0.9092	0.2427	-0.2396	0.0912	1.0000

```
. correl LPbyHour HighTechExports NewBusinessDensity NetFDIinflows ICTserviceexports
(obs=208)
```

	LPbyHour	HighTe~s	NewBus~y	NetFDI~s	ICTser~s
LPbyHour	1.0000				
HighTechEx~s	0.4594	1.0000			
NewBusines~y	0.7476	0.3450	1.0000		
NetFDIinfl~s	-0.2037	-0.1388	-0.1605	1.0000	
ICTservice~s	-0.2133	-0.1073	-0.2254	-0.0628	1.0000

Table 3.6 SSA Countries: OLS Regression Educational Level Enrolments and Labour Productivity

```
. reg LPbyHour Preprimaryenrolment Primaryschoolenrolment Secondaryenrolment Tertiaryenrolment
```

Source	SS	df	MS	Number of obs	=	222
Model	6943.97289	4	1735.99322	F(4, 217)	=	163.26
Residual	2307.45475	217	10.633432	Prob > F	=	0.0000
				R-squared	=	0.7506
				Adj R-squared	=	0.7460
Total	9251.42764	221	41.8616635	Root MSE	=	3.2609

LPbyHour	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
Preprimaryenrolment	-.0364503	.0089712	-4.06	0.000	-.0541322	-.0187685
Primaryschoolenrolment	-.0532858	.0099769	-5.34	0.000	-.0729499	-.0336217
Secondaryenrolment	.1017146	.0161496	6.30	0.000	.0698845	.1335447
Tertiaryenrolment	.4673547	.0471554	9.91	0.000	.3744135	.5602959
_cons	3.155397	1.015649	3.11	0.002	1.153598	5.157196

Table 3.7 SSA Countries: IV Regression GMM Educational Level Enrolments and Labour Productivity

```
. ivregress gmm lnformalLP (lnTertiaryenrolment = lnPreprimaryenrolment lnSecondaryenrolment ), vce(robust)
```

Instrumental variables GMM regression

Number of obs	=	333
Wald chi2(1)	=	233.19
Prob > chi2	=	0.0000
R-squared	=	0.4413
Root MSE	=	.77024

GMM weight matrix: Robust

lnformalLP	Robust		z	P>|z|	[95% conf. interval]	
	Coefficient	std. err.				
lnTertiaryenrolment	.949073	.0621506	15.27	0.000	.82726	1.070886
_cons	6.187414	.1297744	47.68	0.000	5.933061	6.441767

Endogenous: lnTertiaryenrolment
 Exogenous: lnPreprimaryenrolment lnSecondaryenrolment

```
. estat overid
```

Test of overidentifying restriction:
 Hansen's J chi2(1) = 1.45369 (p = 0.2279)

Table 3.8 World Data Comparison: OLS Regression Educational Level Enrolments and Labour Productivity

```
. reg lnLPbyHour Preprimaryenrolment Primaryschoolenrolment Secondaryenrolment Tertiariyenrolment
```

Source	SS	df	MS	Number of obs	=	1,200
Model	1013.14985	4	253.287463	F(4, 1195)	=	968.96
Residual	312.373365	1,195	.261400306	Prob > F	=	0.0000
				R-squared	=	0.7643
				Adj R-squared	=	0.7636
Total	1325.52322	1,199	1.10552395	Root MSE	=	.51127

lnLPbyHour	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
Preprimaryenrolment	.0052073	.0006789	7.67	0.000	.0038754	.0065393
Primaryschoolenrolment	-.0139385	.0012156	-11.47	0.000	-.0163233	-.0115536
Secondaryenrolment	.0226852	.0009114	24.89	0.000	.0208897	.0244735
Tertiariyenrolment	.0059271	.0008625	6.87	0.000	.0042349	.0076194
_cons	1.680268	.1271035	13.22	0.000	1.430897	1.929638

Table 3.9 SSA Countries: Labour Productivity, Unemployment and Enrolment Levels

```
. correl LPbyHour Preprimaryenrolment Primaryschoolenrolment Secondaryenrolment Tertiariyenrolment Unemploymentl
> abourforce
(obs=222)
```

	LPbyHour	Prepri~t	Primar..	Second~t	Teriti~t	Unempl~e
LPbyHour	1.0000					
Preprimary~t	0.4517	1.0000				
Primarysch~t	-0.1122	0.1590	1.0000			
Secondary~t	0.7460	0.6305	0.2215	1.0000		
Tertiariye~t	0.8204	0.6686	0.0384	0.8117	1.0000	
Unemployme~e	0.5724	0.0688	-0.1894	0.4614	0.2708	1.0000

Table 3.10 World Data Comparison: OLS Regression Output Labour Productivity and SST Expenditure

. reg LPbyHourStd PatentApplicbyresidentsStd RNDExpenditureGDPStd PatentreceiptsStd						
Source	SS	df	MS	Number of obs	=	925
Model	471.238457	3	157.079486	F(3, 921)	=	229.37
Residual	630.718496	921	.684819214	Prob > F	=	0.0000
				R-squared	=	0.4276
				Adj R-squared	=	0.4258
Total	1101.95695	924	1.19259411	Root MSE	=	.82754

LPbyHourStd	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
PatentApplicbyresidentsStd	-.4587062	.0467959	-9.80	0.000	-.5505452	-.3668672
RNDExpenditureGDPStd	.606146	.0251383	24.11	0.000	.556811	.655481
PatentreceiptsStd	.3578872	.0596002	6.00	0.000	.2409193	.4748552
_cons	.4254881	.0278242	15.29	0.000	.370882	.4800943

Table 3.11 SSA Countries: OLS Regression Output Labour Productivity and SST Expenditure

. reg formalLPStd PatentApplicbyresidentsStd RNDExpenditureGDPStd PatentreceiptsStd						
Source	SS	df	MS	Number of obs	=	56
Model	45.3821229	3	15.1273743	F(3, 52)	=	17.27
Residual	45.5615037	52	.876182763	Prob > F	=	0.0000
				R-squared	=	0.4990
				Adj R-squared	=	0.4701
Total	90.9436266	55	1.65352048	Root MSE	=	.93605

formalLPStd	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]	
PatentApplicbyresidentsStd	-.1980922	.1865957	-1.06	0.293	-.5725239	.1763396
RNDExpenditureGDPStd	.7683187	.2285595	3.36	0.001	.3096805	1.226957
PatentreceiptsStd	.3447016	.2546516	1.35	0.182	-.1662942	.8556974
_cons	.2308602	.1379295	1.67	0.100	-.0459157	.507636

Figure 4.5 SSA Data: SEM Labour Productivity and Ratios

Structural equation model		Number of obs = 1,237				
Estimation method: mlmv						
Log likelihood = -2893.1474						
		OIM				
		Coefficient	std. err.	z	P>|z|	[95% conf. interval]
Structural						
lnLPbyHour						
lnEducation_Ratio		-.6615701	.2511368	-2.63	0.008	-1.153789 - .1693512
lnEmployment_Ratio		-.7199997	.0702438	-10.25	0.000	-.857675 - .5823244
lnTechnologyEfficiency_Ratio		-.1936223	.0204362	-9.47	0.000	-.2336765 - .1535681
lnAccesstoFinance		-.2911725	.0831081	-3.50	0.000	-.4540613 - .1282836
_cons		2.906433	.2300773	12.63	0.000	2.45549 3.357377
mean(lnEducation_Ratio)		.9785145	.0173998	56.24	0.000	.9444114 1.012617
mean(lnEmployment_Ratio)		.3862378	.0296386	13.03	0.000	.3281472 .4443284
mean(lnTechnologyEfficiency_Ratio)		3.752228	.2201628	17.04	0.000	3.320717 4.183739
mean(lnAccesstoFinance)		-.723263	.056349	-12.84	0.000	-.8337051 -.6128209
var(e. lnLPbyHour)		.1176078	.0380116			.0624197 .22159
var(lnEducation_Ratio)		.141197	.0093116			.1240768 .1606795
var(lnEmployment_Ratio)		1.040591	.0432165			.9592442 1.128837
var(lnTechnologyEfficiency_Ratio)		4.304698	.8851797			2.876797 6.44134
var(lnAccesstoFinance)		1.020849	.0762186			.8818794 1.181718
cov(lnEducation_Ratio, lnEmployment_Ratio)		.2637929	.0169989	15.52	0.000	.2304756 .2971101
cov(lnEducation_Ratio, lnTechnologyEfficiency_Ratio)		-.1390304	.074036	-1.88	0.060	-.2841384 .0060776
cov(lnEducation_Ratio, lnAccesstoFinance)		-.1989983	.0263129	-7.56	0.000	-.2505707 -.1474259
cov(lnEmployment_Ratio, lnTechnologyEfficiency_Ratio)		-.51941	.13404	-3.88	0.000	-.7821236 -.2566963
cov(lnEmployment_Ratio, lnAccesstoFinance)		-.4589428	.0445421	-10.30	0.000	-.5462438 -.3716419
cov(lnTechnologyEfficiency_Ratio, lnAccesstoFinance)		.0658835	.2920102	0.23	0.821	-.5064461 .638213
LR test of model vs. saturated: chi2(0) = 0.00		Prob > chi2 = .				

Figure 4.6 World Data: SEM Labour Productivity and Ratios

Structural equation model		Number of obs = 6,258				
Estimation method: mlmv						
Log likelihood = -21702.244						
	OIM					
	Coefficient	std. err.	z	P>|z|	[95% conf. interval]	
Structural						
lnLPbyHour						
lnEducation_Ratio	-.9810132	.0383235	-25.60	0.000	-1.056126 - .9059006	
lnEmployment_Ratio	-.3280715	.0114614	-28.62	0.000	-.3505355 - .3056076	
lnTechnologyEfficiency_Ratio	-.0315193	.0081387	-3.87	0.000	-.0474708 - .0155678	
lnAccesstoFinance_Ratio	.1413682	.0144412	9.79	0.000	.1130639 .1696724	
_cons	2.623777	.0611203	42.93	0.000	2.503983 2.74357	
mean(lnEducation_Ratio)	.4446958	.0060877	73.05	0.000	.4327641 .4566276	
mean(lnEmployment_Ratio)	-1.000012	.0211887	-47.20	0.000	-1.041541 -.9584825	
mean(lnTechnologyEfficiency_Ratio)	6.87681	.0737839	93.20	0.000	6.732196 7.021424	
mean(lnAccesstoFinance_Ratio)	1.100373	.0237632	46.31	0.000	1.053798 1.146948	
var(e,lnLPbyHour)	.174174	.0071236			.1607569 .1887109	
var(lnEducation_Ratio)	.1595058	.0037674			.1522903 .1670633	
var(lnEmployment_Ratio)	2.692212	.0493925			2.597124 2.790781	
var(lnTechnologyEfficiency_Ratio)	6.306737	.2118723			5.904851 6.735975	
var(lnAccesstoFinance_Ratio)	1.945128	.0498325			1.84987 2.045292	
cov(lnEducation_Ratio,lnEmployment_Ratio)	.450058	.011708	38.44	0.000	.4271107 .4730053	
cov(lnEducation_Ratio,lnTechnologyEfficiency_Ratio)	-.1179123	.0317284	-3.72	0.000	-.1800988 -.0557259	
cov(lnEducation_Ratio,lnAccesstoFinance_Ratio)	-.2628559	.011897	-22.09	0.000	-.2861736 -.2395383	
cov(lnEmployment_Ratio,lnTechnologyEfficiency_Ratio)	.0772346	.105611	0.73	0.465	-.1297591 .2842283	
cov(lnEmployment_Ratio,lnAccesstoFinance_Ratio)	-1.400012	.0416778	-33.59	0.000	-1.481699 -1.318325	
cov(lnTechnologyEfficiency_Ratio,lnAccesstoFinance_Ratio)	1.062222	.1062361	10.00	0.000	.854003 1.270441	
LR test of model vs. saturated: chi2(0) = 0.00 Prob > chi2 = .						

Table 4.14 World Data: IV GMM Regression Results

Instrumental variables GMM regression		Number of obs = 323				
		Wald chi2(4) = 1049.30				
		Prob > chi2 = 0.0000				
		R-squared = 0.7535				
GMM weight matrix: Robust		Root MSE = .52556				
lnformalLP	Robust					
	Coefficient	std. err.	z	P>|z|	[95% conf. interval]	
lnTechnologyEfficiency_Ratio	-.1060824	.0348624	-3.04	0.002	-.1744114 - .0377534	
lnEducation_Ratio	-.5806834	.1243334	-4.67	0.000	-.8243723 - .3369944	
lnEmployment_Ratio	-.3091696	.0270369	-11.44	0.000	-.362161 - .2561782	
lnAccesstoFinance_Ratio	.3675165	.0284653	12.91	0.000	.3117254 .4233075	
_cons	9.519025	.261257	36.44	0.000	9.006971 10.03108	
Endogenous: lnTechnologyEfficiency_Ratio						
Exogenous: lnEducation_Ratio lnEmployment_Ratio lnAccesstoFinance_Ratio HighTechExports						

Table 4.14 Factor Analysis

Factor analysis/correlation		Number of obs =	23
Method: principal factors		Retained factors =	1
Rotation: orthogonal varimax (Kaiser off)		Number of params =	5

Factor	Variance	Difference	Proportion	Cumulative
Factor1	4.27844	.	0.9653	0.9653

LR test: independent vs. saturated: $\chi^2(10) = 168.96$ Prob> $\chi^2 = 0.0000$

Rotated factor loadings (pattern matrix) and unique variances

Variable	Factor1	Uniqueness
lnLPbyHour	0.9658	0.0673
Education~o	-0.9610	0.0765
Employment~o	-0.9436	0.1095
Technology~o	0.7533	0.4325
AccessstoFi~o	0.9820	0.0357

Factor rotation matrix

	Factor1
Factor1	1.0000

Table 4.16. Regression Factor 1 Tourism

```
. regress factor1_sco lnToursim
```

Source	SS	df	MS	Number of obs =	23
Model	17.911986	1	17.911986	F(1, 21) =	98.82
Residual	3.80642826	21	.181258489	Prob > F =	0.0000
Total	21.7184142	22	.987200647	R-squared =	0.8247
				Adj R-squared =	0.8164
				Root MSE =	.42574

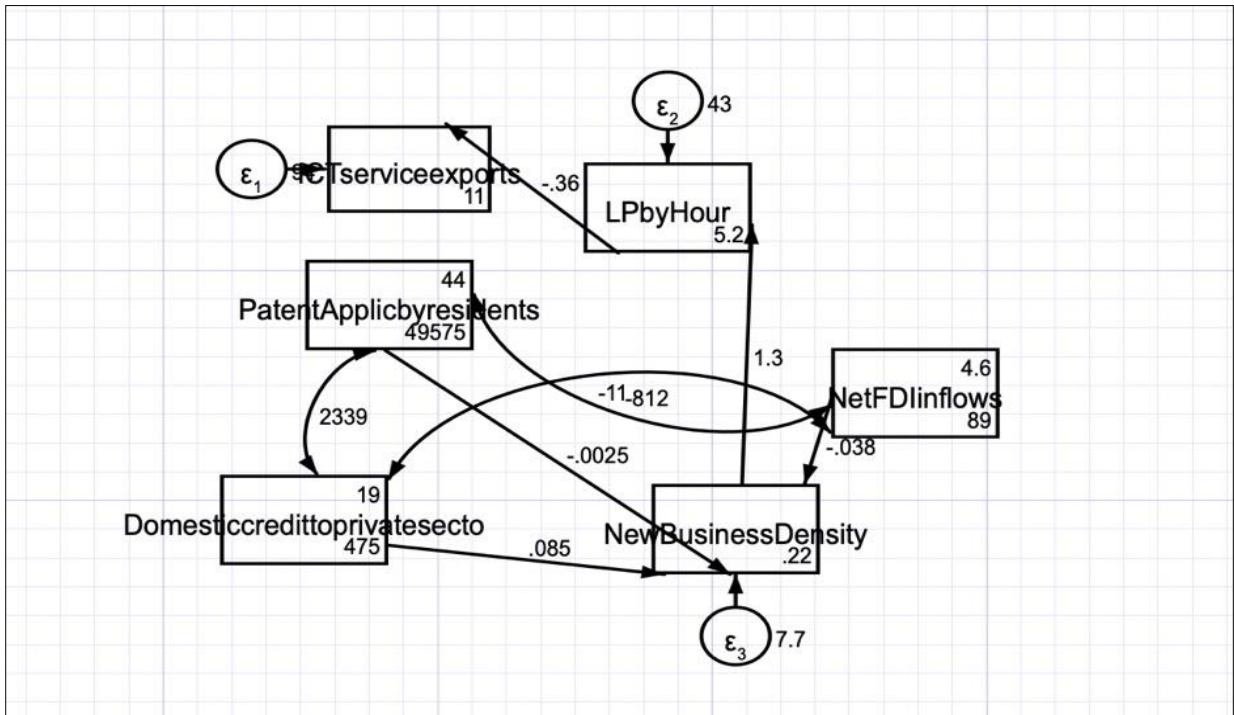
factor1_sco	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]
lnToursim	.5646601	.0568021	9.94	0.000	.4465337 .6827866
_cons	-12.01384	1.211791	-9.91	0.000	-14.5339 -9.493786

Table 4.17 Regression Factor 1 Informal Output

```
. regress factor1_sco lninformalOUTPUT
```

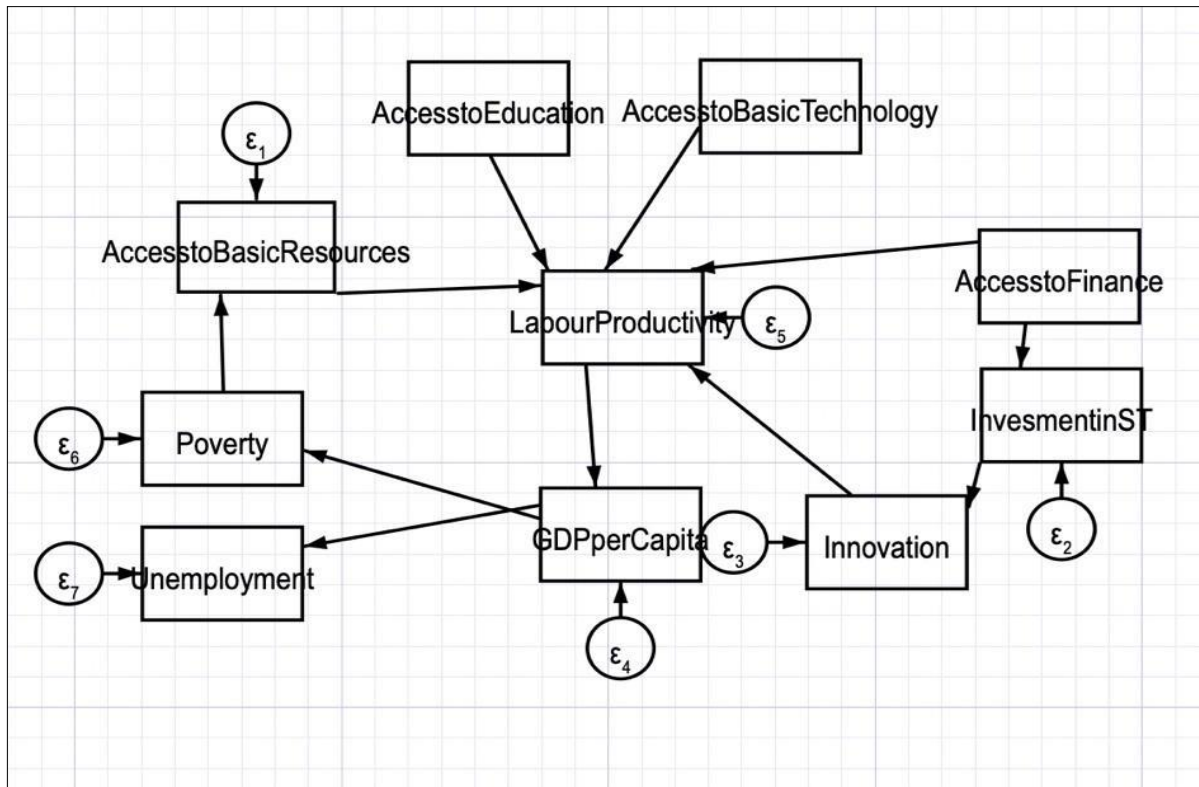
Source	SS	df	MS	Number of obs =	12
Model	.221470515	1	.221470515	F(1, 10) =	20.64
Residual	.107288578	10	.010728858	Prob > F =	0.0011
Total	.328759092	11	.02988719	R-squared =	0.6737
				Adj R-squared =	0.6410
				Root MSE =	.10358

factor1_sco	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]
lninformalOUTPUT	.1005575	.0221327	4.54	0.001	.0512429 .1498722
_cons	-1.648197	.5638817	-2.92	0.015	-2.904603 -.3917899

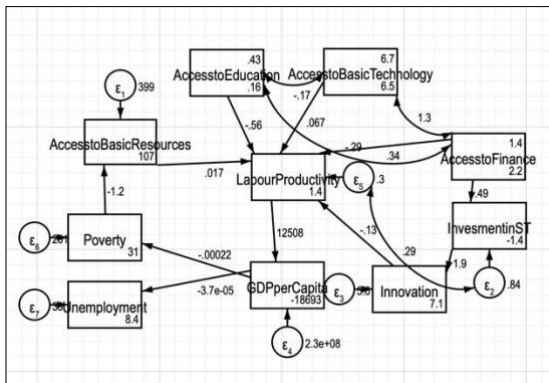


SEM Diagram to model the indicators for Business Competitiveness and Labour Productivity

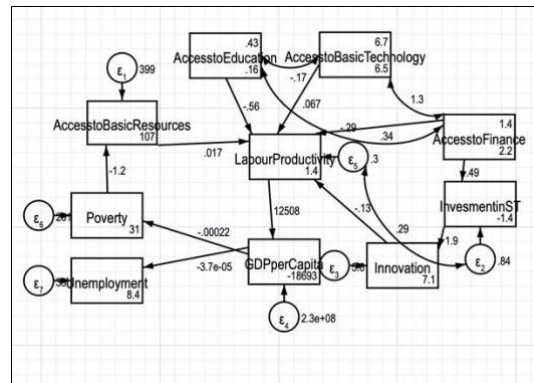
Chapter 11.2 SST Impact Causality Cycle



SEM Model Overview: SST Impact-Causality Cycle (Produced by STATA software)



SEM SKA Africa Partner Countries
(Produced by STATA software)



SEM Developed Economies
(Produced by STATA software)