ENERGY, INEQUALITY AND PRO-POOR GROWTH IN SOUTH AFRICA

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DECLARATION

I, Nicholas N. NGEPAH, hereby declare that the work presented in this thesis is mine, except where acknowledged. I also declare that this thesis or any part thereof has not been submitted in the past, for the award of a degree at any university. Any error in the work is entirely my responsibility.

DEDICATION

To my late Father, Moses Ngepah and Mother, Zingha Victorine

To my Dear and Beloved Wife, Ruth Ngepah

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This work has benefited a lot from the caring guidance of my advisors, Dr. Gisela PRASAD of the Energy Research Centre, University of Cape Town (UCT); Prof. Murray LEIBBRANDT of the School of Economics, UCT; and Prof. Ali A.G. ALI of Arab Planning Institute Kuwait. I sincerely appreciate their relentless support, encouragement and useful comments. I thank the SALDRU and ERC Teams of the UCT for opportunities to present seminars, where useful comments have been given concerning this work. The support from Prof. Nicola Viegi, colleagues at the School of Economics and the Energy Research Centre of the University of Cape Town are highly appreciated.

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Finally all the glory goes to **God** through **Jesus Christ**, who gives insight, good health and long life for all the achievements.

SUMMARY

The effect of energy on inequality and poverty is not well understood and its role in growth-inequality-poverty nexus has not been adequately studied. A country's energy mix can play a significant role in economic growth and poverty alleviation. Policy authorities and donors increasingly lend support to modern energy provision, especially Rural Electrification (RE). This thesis investigates which energy types contribute to poverty alleviation in South Africa and through what mechanisms.

Theory indicates that poverty alleviation comes by growth boosting and inequality reducing policies. As such, the investigation of the pro-poor effects of any policy or factor would naturally culminate in studying the effects on economic growth (or production) and income distribution. Theory suggests endogeneity on one hand between energy and GDP and on the other between GDP and inequality. This necessitates a system of equations rather than the traditional single equations approach. There are other (South Africa-specific) reasons why the inequality-development relationship and the role of energy should be investigated. First, South Africa has been under-researched due to lack of data. Recent data released by the Presidency of South Africa (AMPS Dataset) makes such analysis possible. Secondly, the Kuznets' inequality-development hypothesis can be tested with time series data rather than the cross-section analyses found in earlier literature. Third, energy's role in economic growth or production has been analysed with aggregate energy measures and aggregate GDP. This work argues that such an approach will mask energy type-specific and sector-specific details and undertakes a more disaggregated analysis. Fourth, the multiracial nature of South Africa requires sub-group decomposed inequality rather than national aggregates.

Three levels of analyses are carried out with disaggregated energy types and economic sectors. The first level investigates causality and co-integration between energy and GDP on one hand and between energy and other factors of production on the other. Causality and co-integration are done in the Lag-Augmented Causality and the Auto-Regressive Distributed Lag frameworks respectively. At the second level, the findings of this approach are compared with those of theory-based framework using jointly estimated variable elasticity of substitution production functions and energy demand frameworks. This helps to further examine the impact of energy on growth and the substitution possibilities between energy and other factors of production. At the third level joint estimation of Cobb-Douglas production function per worker, energy demand, (sub-group decomposed) inequality and poverty equations are carried out.

The main findings are that: (1) without controlling for endogeneity in the growth-inequality and energy-production frameworks, single equations are likely to be plagued with simultaneity bias. (2) The elasticities of production and substitution vary over time. Therefore it is necessary to allow these parameters to vary in the production function. (3) All the productive sectors exhibit diminishing Returns to Scale without energy. With electricity, diesel, gas and coal, the scale elasticity increases somewhat, but only in the agricultural sector are there increasing Returns to Scale with the use of diesel. (4) Energy types like electricity, diesel and gas are the most productive and they set the pace for scale elasticity. This implies that if South African Economy is less endowed with these resources, economic growth will be seriously jeopardised.

(5) Various energy types have different effects on output (and also on growth by their contribution to the scale elasticity), inequality and poverty. The effects vary with economic sectors. This implies that aggregate energy measures may not give the true picture of the impact of energy on development. (6) The within and between-group inequalities have positive and negative effects on production respectively, suggesting that in multiracial and fragmented societies, it is important to decompose inequality into sub-group components.

In general, redistribution efforts should focus on between-group inequality component, which is poverty increasing. Efforts to reduce between-group inequality can also be associated with less consumption of energy, since it tends to increase the demand for energy. Access to energy types like electricity, diesel and gas are crucial for economic growth, but for them to yield significant anti-poverty impacts, policy efforts must go beyond energy to (both physical and human) capital development.

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ADF – Augmented Dickey-Fuller

AfDB – African Development Bank

AIC - Akaike Information Criterions

AID – Acquired Immune-Deficiency Syndrome

AMPS - All Media and Products Survey

AR – Auto Regressive

ARDL – Auto-Regressive Distributed Lags

BEE – Black Economic Empowerment

CD – Cobb – Douglas

CES – Constant Elasticity of Substitution

CPI – Consumer Price Index

DA – Department of Agriculture

DFID – Department for International Development

DGP - Data Generating Process

DME – Department of Minerals and Energy

DWH - Durbin-Wu-Hausman

ECM – Error Correction Model

ERC – Energy Research Centre

ERR – Economic Rates of Return

ESMAP - Energy Sector Management Assistance Program

F&D – Finance and Development

FBE – Free Basic Electricity

FGT – Foster Greer and Thorbecke

GDI - Gender Related Development Index

GDP – Gross Domestic Product

GEM - Gender Empowerment Measure

GNP – Gross National Product

HDI – Human Development Index

HDR – Human Development Report

HIV – Human Immune Virus

HPI-1 - Human Poverty Index for developing countries

HPI-2 - Human Poverty Index for OECD countries

HQIC - Hannan-Quinn Information Criterion

HSRC – Human Sciences Research Council

IEA – International Energy Agency

IEG – Independent Evaluation Group

IES - Income and Expenditure Surveys

IFAD – International Fund for Agricultural Development

IMF – International Monetary Fund

KLEMS - Capital, Labour, Energy, Material and Services

kWh – kilowatts hour

LAC – Lag Augmented Causality

LINEX - Linear Exponential

LPG – Liquefied Petroleum Gas

LR – Likelihood Ratio

MDG – Millennium Development Goals

MRTS - Marginal Rate of Technical Substitution

NCV - Net Calorific Value

NEP – National Electrification Program

OECD – Organisation for Economic Cooperation and Development

OLS – Ordinary Least Squares

OPEC – Organisation of Petroleum Exporting Countries

PPP – Purchasing Power Parity

RE – Rural Electrification

RTS – Returns To Scale

SAARF - South African Advertising Research Foundation

SAP – Structural Adjustment Program

SARB – South African Reserve Bank

SASOL - South African Coal, Oil and Gas Corporation

SBIC - Schwarz-Bayesian Information Criterion

SME – Small and Medium-size Enterprise

SSA – Sub-Saharan Africa

STATSSA – Statistics South Africa

TJ – Tera Joule

TOE – Tonne of Oil Equivalent

UKZN – University of KwaZulu Natal

UNDP – United Nations Development Program

UNECA – United Nations Economic Commission for Africa

VAR – Vector Auto-Regressive

VES – Variable Elasticity of Substitution

WDI – World Development Indicators

WDR – World Development Report

1. GENERAL INTRODUCTION

1.1 Introduction

Poverty is a major problem for developing countries especially of the Sub-Saharan Africa. The problem of widespread poverty in Africa is rooted (in addition to fast population growth) in the economic crises of the late seventies and early nineties, during which its economic indicators seriously deteriorated. Economic growth recovery only started by the late nineties. This recovery was marked by high inequality in most countries, leaving behind the poor (Collier and Gunning, 1999). Hence, poverty reduction and improvements of standards of living have become the major priority for Sub-Saharan African countries in the post crisis [1] era. This preoccupation has transcended national and regional objectives to be incorporated into global development and equity concerns. This is evident in the Millennium Development Goals (MDGs) adopted by the United Nations (UN) System in 2000. According to the UN (2002, p 8), the "*development goals set out in the Millennium Declaration express the resolve of the world's political leaders to free their fellow men, women and children from the abject poverty and dehumanising conditions of extreme poverty, to make the right to development a reality for everyone, and to free the entire human race from wants*".

Eradication of extreme poverty and hunger is the first of the eight MDGs[2]. If poverty is broadly considered to include Sen's (1998) concept of capability deprivation, then the rest of the goals would be directly related to poverty, excepting the last goal which is organisational. The most widely studied target

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[1] During the early 1970s and late 1980s, Sub-Saharan Africa experienced widespread economic crises brought about by rising real interest rates, deteriorating terms of trade, and overambitious public investment supported by external debt and distorted incentives. This was followed by Breton-Wood prescribed Adjustment policies aimed at economic stabilisation and Structural Adjustment Programs (SAPs). Research has found a strong link between these SAPs measures and exacerbation of poverty (Collier and Gunning, 1999).

[2] The other goals relate to primary education, gender equality and women empowerment, reduction of infant mortality, improvement of maternal health, fight against HIV/AIDS and other diseases, environmental sustainability and forging a global partnership for development.

is the sub goal of the first MDG. It consists of halving the proportion of people living in extreme poverty (i.e. on less than US$ 1.08 per person per day) by the year 2015, starting from the 1990 level of extreme poverty.

Research and Development experiences point to two prerequisites for meaningful and irreversible poverty reduction. The first is sufficiently high and sustained economic growth (Easterly, 2002). Even if achieved, for high and sustained growth to play an effective role in poverty reduction, the poor must significantly share in the fruits of such growth. Hence the second prerequisite is equality in income distribution or reduction of inequality index (Ravallion, 2004). As such, the investigation of the pro-poor effects of any policy or factor would naturally culminate in studying the effects on economic growth (or production) and the corresponding effect on income distribution. This thesis examines the role of energy in development within the South African economy, by examining production, energy, inequality and poverty connections holistically. The role of this chapter is to present a general introduction to the thesis. The rest of the chapter is structured as follows: section (1.2) looks at the background with respect to the South African economy. In (1.3), the research problem, hypothesis and objective are spelled out. Justification of the research is presented in (1.4), brief description of methodology in (1.5), definitions in section (1.6), while (1.7) concludes the chapter with an outline of the thesis.

1.2 Background

From the nineties to the beginning of the (2007-2009) financial crisis, Sub-Saharan Africa (SSA) made progress in economic growth, averaging four percent per year by the second half of the nineties. According to the report of United Nations Economic Commission for Africa (UNECA, 2000), in 1999, real Gross Domestic Product (GDP) grew by 3.2 percent, up from 3.1 per cent in 1998. At present, the African Development Bank (2008) forecast Africa's growth to be above 5% for 2008. However, a key issue remains that of whether this improvement has the capacity to lead to strong and sustained future growth (Collier and Gunning, 1999). Despite growth recovery, decadal average for the 90s is only at 2.1 percent per year, falling below the average per annum population growth rate of 2.8 percent and far below the 7 percent growth rate needed to halve Africa's poverty incidence by 2015. Besides, the recovery has been marked by high inequality (Collier and Gunning, 1999).

South Africa particularly had enjoyed a century of mining-based high economic growth following the development of the Kimberly diamond fields in the 1870s. Between 1920 and 1970, the escalating international demand for gold yielded a combination of high profits and foreign exchange, which served as springboard for the expansion of the industrial sector. From 1948 to 1973, the average growth rate of real GDP was above 7 percent per annum and employment almost tripled. The average growth rate of employment was 4.3 for the period (Feinstein, 2007: 186).

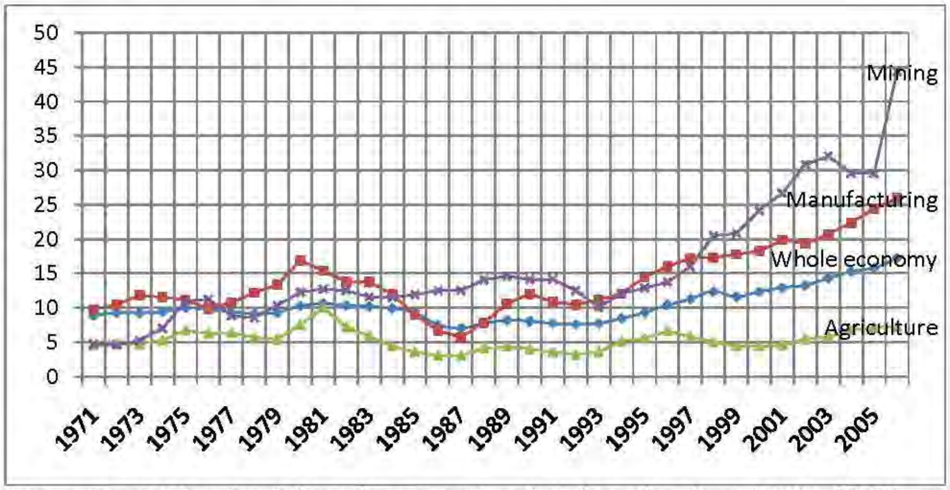
Table 1.1: Percentage Growth Rates of Economic Fundamentals

% growth of:	**1974-1983**	**1984-1988**	**1989-1993**	**1994-1998**	**1999-2006**	**1974-1983**	**1984-1988**	**1989-1993**	**1994-1998**	**1999-2006**
Output										
Real GDP						***Real GDP per capita***				
Whole	2.7	2.0	0	2.8	3.9	0.1	-0.2	-2.4	0.6	2.7
Manufacturing	3.5	2.4	-1.7	2.6	3.5	1.0	0.2	-4	0.4	2.3
Agriculture	-0.4	8.7	1.8	1.5	0.6	-2.8	6.4	-0.7	-0.7	-0.6
Mining	-0.3	-0.4	0	-0.4	0.7	-2.8	-2.6	-2.4	-2.5	-0.4
Inputs										
Gross capital formation						***Employment***				
Whole	3.1	-3.9	-1.8	7.7	5.6	1.9	1	-1.9	-2	1.1
Manufacturing	4.6	-6.7	7.1	7.4	5.3	2.3	1.3	-1.3	-1.9	0
Agriculture	1.3	-4.1	-4.2	4.6	1.7	-2.5	1.7	-2.1	-3.1	-3.1
Mining	11.1	5.4	-10.7	8.8	5.4	1.15	1.4	-5.1	-5.5	-5.5
Factor productivities										
Output per worker						***Output per unit capital***				
Whole	0.75	1	2	4.9	2.8	-0.1	7.2	2	-4.6	-1.3
Manufacturing	1.15	1.1	-0.4	4.7	3.5	0.1	15.6	-6.4	-4.1	-1.5
Agriculture	2.5	7	3.6	5.2	4.7	0.9	16.6	6.2	-2	0.1
Mining	-1.3	-1.7	5.5	5.8	6.9	-7.1	-5.4	13.6	-8.3	-1.7

Source: Calculated using information on GDP, population and capital formation from South African Reserve Bank (SARB, 2009), and employment from SARB (2009), Statistics South Africa STATSSA (2007a) and South African Department of Agriculture (DoA, 2007) .

However, from the early 1970s to the mid 1990s, the economy switched from triumph to distressing decline (Feinstein, 2007, p200). Table 1.1 shows remarkable deterioration in the growth rates of real GDP, real GDP per capita, gross capital formation, employment and factor productivities. These indicators worsened in the decade between 1984 and 1993. There are a number of reasons that can explain this deterioration. Feinstein (2007) groups them into three categories. The first is both the decline in gold mining and sudden plunge in the price of gold (due to the loss of its position earlier in 1973, as ultimate reserve asset for the international monetary system) after 1980, coupled with high and rising cost of production. The second is a combination of adverse external economic and political factors. From the 1970s, the rapidly growing world output and trade of the *golden age* ended, reducing South Africa's international market for export, while inflationary pressures and appreciating local currency – ZAR - (due to rising commodity prices and the two oil shocks[3]) led to South Africa suffering from less manufacturing export competitivity. Thirdly, stronger international hostility to apartheid led to a gloomy prospect of South Africa's financial and political stability and consequently, there was a massive outflow of capital. In such circumstances of growth stagnation, trends in employment also plummeted from the early 1980s as indicated in the employment sub-heading of Table 1.1.

Figure 1.1: Capital Labour Ratios



Source: generated using information on real capital formation from SARB (2009), and employment from SARB (2009), STATSSA (2007a) and DoA (2007).

However, though the economic situation started to ease in the early 1990s,

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[3] Following the activities of OPEC member States, the prices of oil rose fourfold, this was the first oil shock. The second oil shock happened in 1979-1980 after the Iranian Revolution and by 1981, the US dollar price of crude oil had risen to more than ten time that of 1973.

during the period of stagnation and after, employers tended to substitute capital for labour in an attempt to overcome the scarcity of skilled labour[4]. The reduction in the cost of capital equally led to more capital intensive production methods. This tendency has increased from the early 1990s to date (2006) as Figure 1.01 shows. It is most remarkable in the mining sector, followed by manufacturing, with capital/labour ratio being above that of the national economy.

Following the same trend in economic indicators, South Africa's energy mix has been changing. The pre-1990s anti-apartheid foreign sanctions on South Africa made it to rely much on the locally abundant coal, which eased later on. In early 1970s, to late 1980s, a unit of GDP contained higher coal[5] relative to other energy types. This coal content of a unit of GDP has been steadily falling while that of electricity has been rising, and from about 2000, electricity has been the dominant energy type in the economy while that of petroleum has been relatively stable[6]. This situation is the same in the manufacturing sector, while diesel and electricity stand at all time high in agriculture and mining respectively (see Figure A1of Appendix). It is plausible that the changes in energy-mixed, with increasing use of more efficient energy types such as electricity could be at the basis of the increased productivities of both capital and labour, as depicted in Table 1.1.

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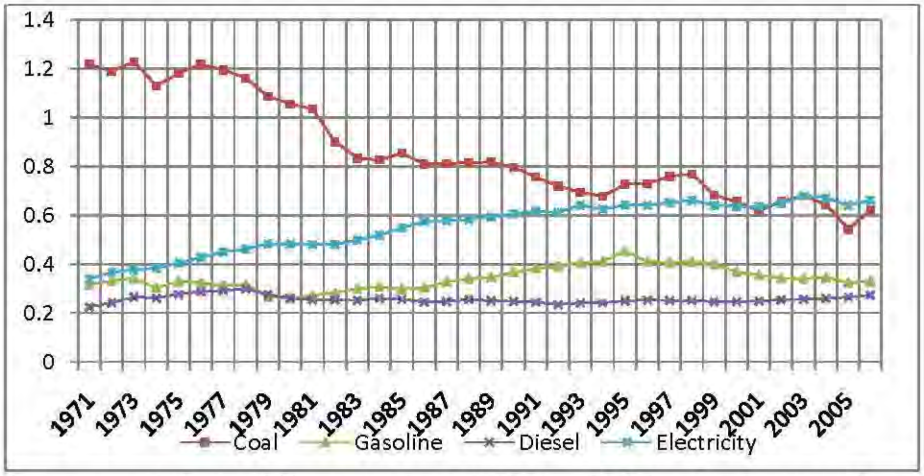
[4] This was encouraged by: the rise in real wages of black workforce, the growing organisation and militancy of black workforce, and the state policies, notably, influx control, which artificially increased urban labour cost by restricting the numbers available for work in urban areas (Feinstein, 2007).

[5] All energy types are considered net of use in the energy sector

[6] This relative stability was ensured by formation of a public corporation in 1950 to convert coal into gas, and then to petrol, diesel and other liquid petroleum products. This corporation, known as South African Coal, Oil and Gas Corporation (SASOL) was formed strategically to counteract some adverse effects of the foreign sanctions.

Figure 1.2: Energy per Unit GDP for the South African Economy



Source: generated using information on real GDP from SARB, and energy types from IEA and South African Department of Minerals and Energy.

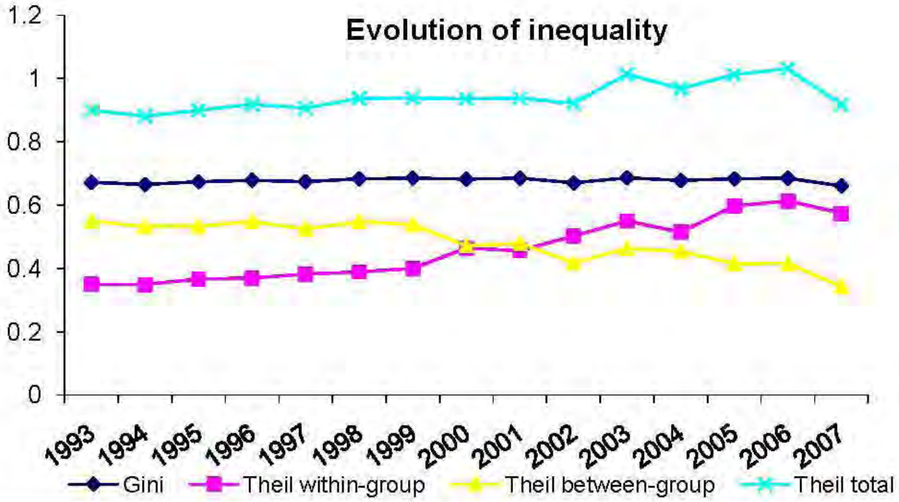
The unequal access to opportunities inherited from apartheid policies and the capital intensive tendencies may underlie the deteriorated social indicators such as poverty and inequality which failed to improve following improvement in economic growth rates and capital formation. However, the various studies on the evolution of poverty in South Africa from 1995 to 2000 show no definite consensus (Table 1.2).

Table 1.2: Poverty Trends in South Africa from 1993-2004

Study	period	evolution
Statistics South Africa (2002)	1995–2000	Increase
Hoogeveen and Özler (2006)	1995–2000	Increase
Leibbrandt et al. (2006)	1996–2001	Increase
Meth and Dias (2004)	1999–2002	Increase
UNDP (2003)	1995–2002	Slight decline
Simkins (2004)	1995–2000	Slight increase
Ardington et al. (2005)	1996–2001	Slight increase
Van der Berg et al. (2007a)	1993–2004	Rise until 2000, slight decline thereafter
Van der Berg et al. (2007b)	1993–2004	Increase until 2002, strong decline thereafter
Meth (2006a, 2006b)	2001–2004	Slight decline

However, a study by Van der Berg et al (2007b) suggests that a turning point may have been attained in 2002, after which poverty has fallen henceforth. This is corroborated by wage increase and increase in black share of employment, black share of government transfers and hence their share in total income and per capita income (Lundahl and Petersson, 2009). The same studies show inequality increasing tendencies. However, this seems to have stagnated during the same period of apparent fall in poverty. Inequality indicators that show sub-group decomposition suggest that while average inequality tends to remain stable, inequality between- and within-groups evolve out of phase, with the former decreasing and the latter increasing. However, the period from 1993 to 1997 seem to suggest that the sub-group quantities were stable during the apartheid era.

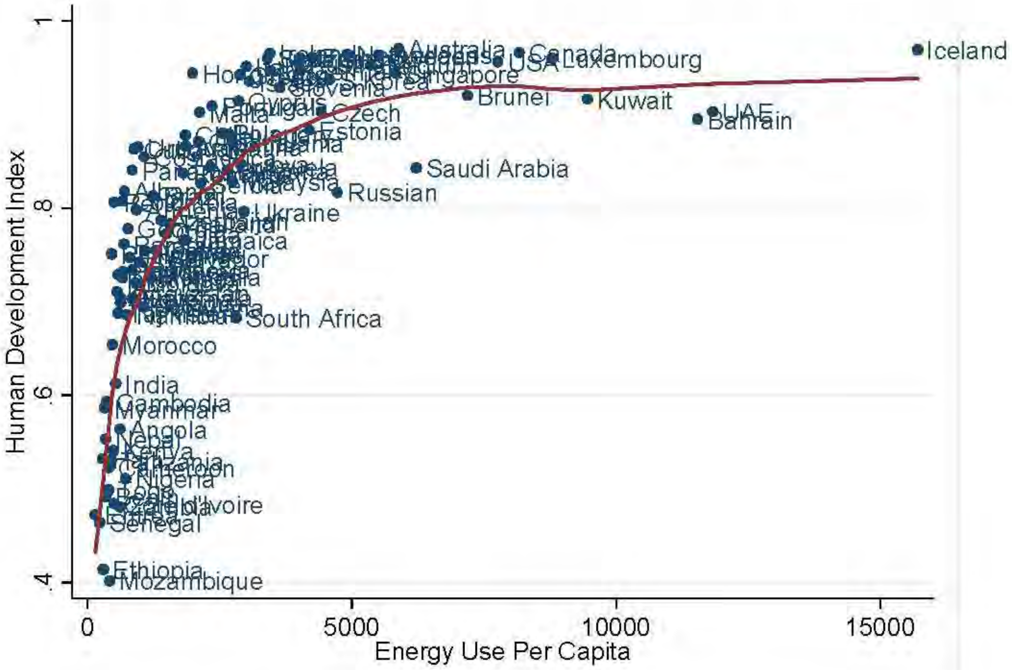
Figure 1.3: Evolution of inequality in South Africa



Source: by author, using data from The Presidency of South Africa (2009).

There is a clear correlation between energy use and levels of development. Figure 1.3 shows that levels of per capita energy consumption and human development index across countries are compatible. Countries like Iceland, Luxemburg, UAE etc, with high levels of per capita energy consumption also have higher human development index, compared to those with low levels of per capita energy use (mostly of Sub-Saharan Africa).

Figure 1.4: Per Capita Energy Use and Human Development



Source: Generated using per capita energy data from Word Bank (WDI, 2008) and HDI from Human Development Report (UNDP, 2009).

Equally, developing countries with high inequality also exhibit a corresponding unequal access by the poor, to modern energy services such as electricity compared to the rich. Figure 1.04 compares electricity access by income groups (poorest and richest quintiles) with inequality index (Gini coefficient) for selected developing countries. South Africa and Panama for example with highest rich/poor disparity in access to electricity (as of 2001) display the widest income inequality, while Pakistan with lowest rich/poor disparity in electricity access shows the lowest Gini coefficient.

Currently (2007), South Africa's access to electricity is at 81.5% (STATSSA, 2007). As of 2000, primary energy distribution constituted 74.8 percent coal (of which about 36 percent is used for electricity generation), 11.6 percent commercial and renewable energy sources (biomass, wind and solar), 9 percent oil, 3.2 percent nuclear, 1.3 percent gas and 0.1 percent hydro[7].

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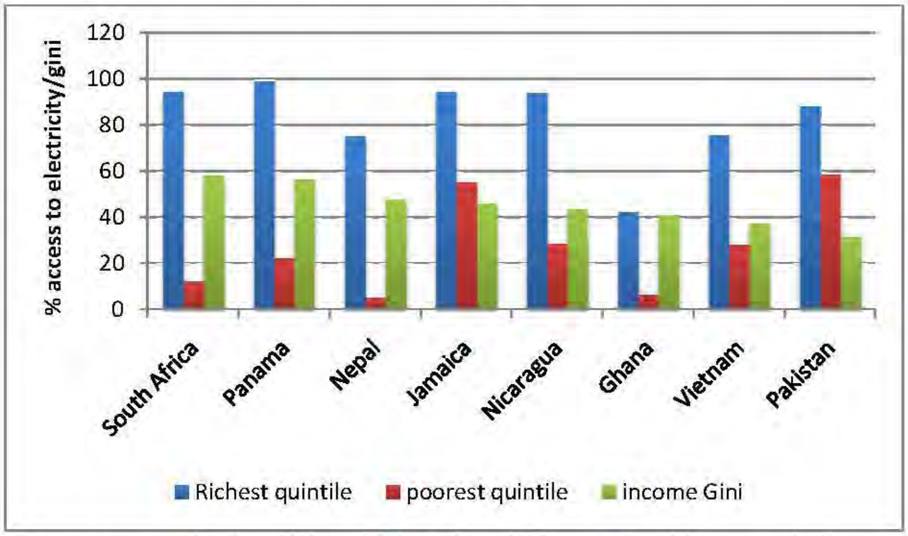
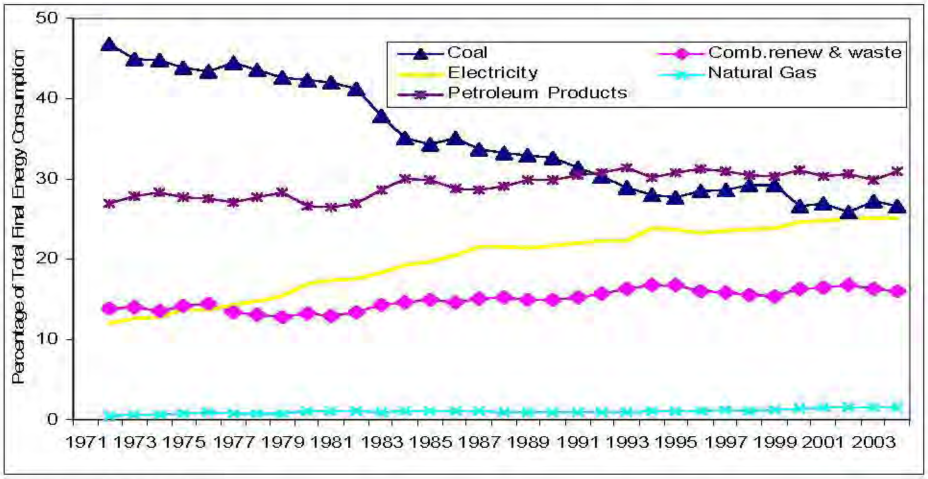
[7] These figures are from South African Department of Minerals and Energy (DME, 2005).

Figure 1.5: Inequality in Electricity Access and Income



Source: Generated using Gini coefficients from WDI and electricity access by income quintile from Human Development Report (UNDP, 2007[8]).

Figure 1.6: The Evolution of South Africa's Energy Mix



Source: IEA (2005)

South Africa's energy intensity is above the world's average, with only ten countries ranking above it. The industrial sector consumes the greatest share of coal (51%) followed by electricity (31%), other fuels (7%) and biomass (6%). In the commercial sector, electricity tops the choice (82.8%), then coal (8.2%) etc. In the residential sector, energy consumption is more diversified, with 37.6% electricity, 29.8 wood, 20.4 coal, 8.9 kerosene, 1.7 Liquefied Petroleum

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[8] The data on electricity access by income groups is based on Dominique Lallement (2005). The data is only indicative, because it is extracted from a bar chart in UNDP (2008). The Gini coefficients for the countries considered are in different years from 2000 to 2005.

Gas (LPG), 1.5 vegetable waste and 0.1% solar[9]. South Africa's National Electrification Program (NEP) was undertaken for socio-political reasons, mainly to redress the inequalities of the past. However, according to UNDP (2006), inequality and human poverty appear to have increased (from human poverty index of 20 in 1998 to 30 in 2004).

1.3 Research Problem and Objectives

The oil shock-basis of the deep and widespread economic crises of the eighties, and the strong stylised co-evolution of energy with economic performance, or at least factors of production (Gunder, 1959; Struckmeyer, 1986; Kander and Schon, 2005), show that energy is essential in economic growth and human well-being. However, the role of energy in economic growth is a theoretical debate and two schools of thought exist (Stern and Cleveland 2004). One is the biophysical (ecological) economics, which considers energy as a fundamental (at extreme, sole) factor of production (Cleveland et al, 1984; and Hall et al, 2001). The other school is the mainstream or neoclassical economics, which considers that technical progress and substitution between factors of production can effectively decouple growth from energy use (Solow, 1974; 1993; 1997).

The effect of energy on inequality and poverty is not well understood and has not received adequate attention in economic research. Energy can impact inequality and poverty in two ways. First, its production uses wage receiving labour. Secondly, energy use in households and communities affect human capabilities (education and health) and incomes of the rich, through production, and of the poor, through Small and Medium-sized Enterprises (SMEs) according to World Bank (2002).

Access to modern and clean forms of energy like electricity is necessary, (though not sufficient) for socio-economic development. A country's energy mix can play a non-negligible role in economic growth and poverty alleviation. For example, electric light extends the day, providing extra hours

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[9] All statistics mention here are from the South African Department of Minerals and Energy (DME, 2006)

for reading and productive activities. Modern cook-stoves save wood collecting time for women and girls, allowing them to reallocate time for human capital development and more productive activities, while equally saving women and children from noxious fumes. Refrigeration can allow local clinics to keep vital medication at hand for prompt response to health needs.

Policy authorities and donors increasingly incorporate energy in their development agenda (World Bank, 2007) hence lending support to modern energy provision, especially Rural Electrification (RE). Since the 1980s, the World Bank has been giving loans to developing countries for RE, with the hope that after the economic benefits, the indebted countries would repay their loans. South Africa, on its own initiative, financed the National Electrification Program (NEP) and subsequently, Free Basic Electricity (FBE) for the poor.

The Independent Evaluation Group (IEG, 1994) of the World Bank, focusing on Economic Rates of Return (ERR), finds that benefits to electrification are not realised. World Bank (2008a) argues that the IEG did not broaden to include social and indirect economic benefits, however, it endorses the view that the larger share of RE benefits in terms of effective use for income generation are captured by the non-poor. No macroeconomic study has been done to assess the growth and poverty effects of the supposed benefits. To make energy policies more pro-poor, it is important to study what and how various energy types contribute to poverty alleviation. Theory indicates poverty alleviation comes by growth boosting and inequality reducing policies. Hence the relevance of the following question: *What poverty impacts have various energy sources and how can these impacts be enhanced for pro-poor development?*

The contribution of energy to poverty reduction depends on the impact of energy on the main arguments of poverty reduction effort, i.e. (sustained) economic growth and access of the poor to the fruits of the growth. Therefore the main objective of this dissertation is to research the impact of energy sources on poverty via the growth and inequality avenues in South Africa. This would help to formulate recommendations on how energy can be used as a tool for pro-poor development. There are three specific objectives:

- Investigate the relationship between various energy types and economic output in disaggregation
- Investigate the relationship between energy types and other factors of production
- Examine the production-inequality- poverty nexus and assess the effect of various energy types on inequality and poverty.

The main contributions of this thesis are the disaggregation of energy types and economic sectors; the focus on the link between energy, inequality and poverty with time series data and the systems of equations approach in order to take care of endogeneity between GDP and energy, and GDP and inequality for South Africa.

1.4 Justification of Thesis

The goal of economic growth, poverty alleviation and sustainable development cannot be successfully achieved amidst uncertainty over the future of fossil fuel in particular and energy in general. There is therefore need for awareness in academia and the policy arena about the contribution of energy to economic growth and poverty in Sub-Saharan African countries which many of the development goals seem to target.

Four factors drive the quest to investigate the role of energy in poverty in an inequality-growth framework. First is the role that inequality in income and access to resources play in socio-political tension and conflicts. Second is the role that energy-related crises have played in recent tensions around the world. Third is the theoretical perception of the relationship between energy and growth which can impact energy-related anti-poverty policies. The fourth is the two-way linkage between inequality and growth, established in theory, which suggest a system of interlinked equations for poverty-growth-inequality empirics.

Poverty can be considered as an expression of inequality in two ways: Firstly, while others are poor, some are non-poor. Secondly, even among the poor, some are poorer than other. Inequality in income and access to factors of production (land, education health, capital, etc) has implications for social tension and economic growth, resulting in conflicts in many societies. First, it is a major source of discrimination and marginalization among individuals of a society; secondly, it may be a non-negligible source of instability in the society. Countries with more acceptable distribution of income are more likely to avoid periods of destructive populist policy (Alesina and Rodrik 1994). There is no doubt that most of the wars and strives in most developing countries are consequences of unequal intra-country distribution of resources. Alesina and Perotti (1993) have found strong and significant increase in socio-political instability due to income inequality, leading to decreases in investment. As resources become more and more scarce, the inequality becomes reinforce therefore even greatly increasing the resulting tension and further reducing growth through reduction in investment.

Some of the most recent examples came through energy and food crises that resulted in loss of lives in areas like Haiti, Cameroon, South Africa, etc. World Bank (1996) has established an extensive linkage between energy choice, household poverty (according to the livelihood approach) and possible contribution to women empowerment. World Bank (IEG, 2008), in a micro-based study finds that benefits to electrification accrue mainly to the non-poor. Therefore it is important to investigate the link between energy types and the arguments of poverty – growth and inequality.

Literature highlights contradistinction theoretical views on the subject of energy-growth relationship (Stern and Cleveland, 2004). There is the ecological economics view, which considers energy as the fundamental (at extreme, sole) factor of production (Cleveland et al, 1984 and Hall et al, 2001; 2003). Sub models in this category are Leontief input-output model with energy as the single primary factor (Kaufmann, 1987), neo-ricardian of Perrings (1987) and O'Connor (1993), assuming fixed proportions of technology and capital, in terms of stocks rather than flows. Empirically, Cleveland et al (1984) uses the biophysical framework and finds a strong correlation between energy use and GNP in the US economy.

In opposition to the ecological view are the mainstream (Neo-classical) growth models. In these models, technical progress and substitution between factors of production can decouple growth from energy (Solow, 1974; 1993; 1997). The fundamental of this category is proposed by Solow (1956). In this basic model, the only cause of continuing growth is technological progress. Another variant of this category is the endogenous growth models which allow the state of technology to respond to changes in one of the variables in the model (Arrow 1962). Empirical works using this framework have all concluded that energy and energy prices have only very minor and insignificant link to economic output (Rasche and Tatom, 1977; Burgess, 1984; Denison, 1979; Denison, 1985; Berndt, 1990). Kaufmann and Azary-Lee (1991) analysed substitution between energy and capital in the same framework and finds very low energy output elasticity. All these studies examine the US economy.

Another body of literature avoids the a priori theoretical restrictions. The earlier version of non-theoretical approaches uses Sims' (1972) causality test. Most of these works scarcely find any causality from energy to output (Kraft and Kraft, 1978; Akarca and Long, 1980; Yu and Hwang, 1984; Yu and Choi, 1985; Ammah-Tagoe, 1990). A more recent version of the non theoretical approach uses the Vector Auto Regressive (VAR) framework of Sims (1980) and Sargent (1979). Lee and Chang (2007) in a panel VAR for 22 developed and 18 developing countries finds a bidirectional relationship between energy use per capita and GDP per capita for developed countries and a unidirectional causality from GDP per capita to energy consumption per capita for developing countries. However, earlier, Wolde-Rufael (2005) finds mixed results for 19 African countries – a mixture of unidirectional, bidirectional and no causal relationships. He suggests country-specific factors accounting for the different directions of causality. One commonality in these studies is the use of aggregate energy measure (total energy use) and aggregate GDP.

Bourguignon (2004) suggests that there is a two-way relationship between growth and inequality. On one hand, he argues that economic growth alters the distribution of resources across sectors, relative prices, factor rewards (labour, physical and human capital, land etc). On the other hand, some authors had shown that inequality is associated with lower growth. One of the main channels through which inequality weakens growth is tensions and conflicts (Alesina and Rodrik, 1994; Alesina and Perotti, 1993; Persson and Tabellini, 1994). This suggests that a system of equations may be appropriate for poverty-growth-inequality empirics, rather than a single equation framework.

South Africa has often been neglected in earlier development-inequality analysis for lack of data. The multiracial and apartheid heritage of South Africa makes it a special case that may not yield the same results like the traditional single (average) inequality measure. Therefore, in this regard, South Africa merits a separate treatment. The choice of South Africa at this time is also guided by availability of recently published data by the Presidency of the Republic and also by well developed energy policies and a diversified energy portfolio. South Africa's energy policy is increasingly including the support of renewable, cleaner and environmentally friendly energy types, hence the development of a National Biofuels Strategy. The objective of this policy strategy is to address the issues of poverty and economic development from an energy angle. It aims at linking the second economy to the first, which entails job creation in underdeveloped areas. It is believed that encouraging biofuel feedstock production will stimulate agricultural production in the former "homelands" where agriculture was undermined by apartheid.

1.5 Methodology

This section gives a brief highlight of the methodology followed to achieve the objectives of this thesis spelled out in section (1.3). The methodology is designed to look at the impact of energy types on other factors of production on one hand, and output/growth and inequality (as arguments of poverty) on the other. For the effect of energy types on output and other factors of production, it revisits the vector autoregressive approach of causality and co-integration using disaggregated energy types and economic sectors. The purpose is twofold.

First, to determine the degree and direction of causality between various energy types and real GDP (in aggregate and various productive sectors) on one hand, and energy and other factors of production (namely, labour and capital) on the other hand. This is done in the lag-augmented causality framework developed by Toda and Yamamoto (1995) which presents clear advantages (such as reducing the risk of wrongful identification of integration order) over the traditional Granger causality method due to Granger (1969) and Sims (1972).

Second is to assess whether there are any long-run or co-integrating relationships between the energy types on one hand and GDP and other factors of production on the other. Co-integration relationships are investigated using the Auto-Regressive Distributed Lag (ARDL) or bound test approach developed by Pesaran et al (2001). This method has several advantages (discussed in section 3.2.2) over the previously applied tests (Engle and Granger, 1987; Johansen, 1988; and Johansen, 1995 and Johansen and Juselius, 1992).

After the Lag-Augmented Causality and the Auto-Regressive Distributed Lag (ARDL) co-integration frameworks, a theory-based Variable Elasticity of Substitution (VES) production function is adapted to compare with the relatively less theoretical ARDL setup. For this purpose, the Vinod (1972) type non-homogenous production function with three inputs (capital, energy and labour) and classical energy demand framework in simultaneous equations setting are considered in order to reconcile growth and energy demand theories. The framework allows for calculating three important parameters of production theory. First are the elasticities of substitution between (total and disaggregated) energy types and other factors of production (capital and labour). Second is the output elasticity of respective inputs. Third are the Returns to Scale (RTS) with and without the energy types. In such framework, these parameters are also allowed to vary with time and factor proportion.

In assessing the impact of energy on poverty, a per capita Cobb-Douglas production function is adapted to include inequality and energy. Ahluwalia's (1976) inequality functional form is extended to include government expenses and energy. In a multiracial society like South Africa, inequality within-groups and between-groups are likely to affect (and respond from) growth in different ways and average inequality measure may not be able to reveal the details. So inequality is disaggregated into between and within-group components. These are jointly estimated with poverty equation adopted from Son and Kakwani (2008).

Data for this work are as follows: annual energy data are from the International Energy Agency spanning 1971 to 2005. Complementary energy data for 2006 is sourced from the South African Department of Minerals and Energy. Productive sectors analysed are whole economy, manufacturing, agriculture and mining. For the whole economy, energy types available are total energy, electricity, kerosene, diesel, gasoline, gas and coal. They are total energy, electricity, diesel, gas, kerosene and coal for manufacturing; total energy, electricity, diesel, kerosene and coal for agriculture; total energy, electricity, liquid petroleum and coal for mining. All energy types are measured in Tera Joules (TJ). Energy types are considered in net of uses in the energy sector[10].

GDP and capital formation and total government expenses (both in million at constant 2000 ZAR) are from the South African Reserve Bank (SARB) dataset. The SARB reports total private sector, manufacturing and mining employments, but only in indices (from 1971 to 2006) at 2000 base year. Statistics South Africa (STATSSA) provides total and sector-wise real employment figures only from 2000 to 2006. These values are used together with the SARB indices to generate real private sector, manufacturing and mining employment data (in thousand persons)[11].

Agricultural employment data is taken from the Abstract of Agricultural Statistics, published by the Department of Agriculture[12]. Population data is from the World Development Indicators (WDI) of the World Bank (2008c). Aggregate energy price series is measured by Consumer Price Index (CPI) for

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[10] For example, coal is taken in exclusion of that used in electricity and petroleum sectors

[11] This is done under the assumption that the SARB private sector employment data depicts the actual variations in the series.

[12] Missing values are interpolated with the assumption of linear evolution of the series.

energy, taken from STATSSA, electricity prices are from ESKOM Tariffs (in South African cents/kWh), while prices for the other energy types are from the department of minerals and energy and are expressed in indices.

Data for poverty and inequality are from the South African Development Indicators (2009) published by the Ministry of National Planning at the Presidency of South Africa. The poverty[13] and inequality data in this publication are based on the bi-annual (All Media and Products Survey – AMPS) data, collected by the South African Advertising Research Foundation (SAARF). All the estimations are done using STATA 9.

1.6 Definitions and Concepts

The definitional and conceptual issues in this work relate specifically to poverty and its arguments i.e. inequality and growth. These definitions are given below, starting with poverty, then inequality and pro-poor growth.

Poverty

Poverty defies objective definition because of its multi-dimensional nature. Ravallion and Bidani (1994) refer to poverty as lack of command over basic consumption needs. Sen (1997) defines it as the lack of certain capabilities, such as the inability to participate with dignity in society. The World Development Report (1990) refers to poverty as the inability to attain a minimum standard of living. However, with Walton (1990), poverty can be generalised as insufficient participation in the productive process and the benefits of economic growth for one reason or the other. All of these concur to the main characterization of poverty, i.e. whether individuals or households have enough resources and abilities to meet their current needs. Various theories of poverty follow the different definitional choices adopted. According to Hagenaars (1987), poverty definitions can be classified following their employment in research and policy into three broad categories.

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[13] The dataset used generated poverty data using poverty line of ZAR 388 per month in constant 2008 ZAR.

Poverty as having less than an objectively defined absolute minimum: This leads to absolute poverty conceptualisation with indices derived from absolute poverty lines. Absolute poverty can be defined as an individual's or a household's inability to meet basic consumption needs irrespective of general standard of living. This is based on subsistence - as minimum needed to sustain life - which implies that anyone is poor if s/he has not got enough to live on. The foundational works of absolute or subsistence poverty concepts have been attributed to Townsend (1979) and Sen (1984; 1997). Absolute poverty comparisons would classify any two individuals with the same standard of living into the same category (as poor or non poor), irrespective of the time and place considered nor whether any public action had been implemented within the domain of reference (Ravallion, 1996).

Poverty as having less than others in society: Such definition highlights the notion of relativity. Relative poverty refers to the position of an individual or household in relation to the average income or expenditure of the society. Poverty is then a lack or shortfall of means relative to the mean of others. Hence the notion of relative poverty hinges on relative deprivation or inequality. Sen (1981, pp. 15-16) defines relative deprivation as '*…situations where people possess less of some desired attribute, be it income, favourable employment conditions or power, than do others*'. In the relative view, welfare depends on both own consumption and mean consumption of the society (Ravallion, 2008). While Sen (1983) acknowledges the merits of the relative views, over the absolute conceptualisation of poverty, he argues that ultimately poverty must be seen primarily as a core absolute notion. He highlights the notion of capabilities and particularly, that absolute deprivation in terms of a person's capability relates to relative deprivation in terms of commodities, incomes and resources (Sen, 1983: p. 153).

Poverty line: Poverty line is a threshold or cut-off point in the distribution of a given welfare indicator below which a household or an individual is regarded as poor. Efforts of determining poverty line follow various poverty conceptions. They can be monetary (consumption-based) or non-monetary. The practice of setting poverty line in poverty analysis dates back to Booth

(1889) and Rowntree (1901). Both of them used the basic needs approach which involves determining the absolute minimum of various basic needs or their monetary equivalence. Even though alternative methods exist, there are two fundamental ways of setting poverty lines. These are in terms of absolute and relative poverty. Although there is a multiplicity of methods for poverty line derivation, none is void of criticisms. Once the challenge of deriving poverty line is overcome, the next is how to integrate the modalities in question with respect to the defined poverty line in order to logically construct indices of poverty measure for poverty monitoring.

Poverty Measurement: Generally, poverty measurement ties closely to the definition of poverty that one adopts. In this light, two broad categories exist – the welfare-based approach, dominated by money-metric standards and the non-welfarist or "capability" approach (Lipton and Ravallion, 1995; Deininger and Squire, 1998). The welfarist approach makes use of the link between income and utility or living standard such that a measure of poverty is determined by the relationship between ones income and the poverty line. It generally consists of two interrelated steps (Sen, 1976; 1980). The first consist of indentifying the poor, requiring the construction of a poverty line to distinguish the poor from the non-poor. The second consist of aggregating poverty experiences into a poverty measure, relying on the notions of average and relative deprivations[14] (Sen, 1976). Concisely, the evolution of poverty measurement has involved the construction of a poverty index that satisfies a growing set of ethical properties or *axioms*. The development of poverty measures are reviewed below according to their weaknesses and strengths in satisfying various properties or axioms

The most fundamental, widely used, and oldest poverty index is the poverty head count ratio (H). It is a measure of the proportion of people living below the poverty line. Even though it has been in extensive use both for inter-temporal comparison and international contrast of poverty (Sen, 1981: 32), the poverty headcount ratio suffers from two main weaknesses. First, it does not

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[14] Average deprivation is the proportional deviation of the mean income of the poor from the poverty line while relative deprivation defines the inequality among the poor.

take into account distributional effects among the poor. Secondly, it violates two basic axioms proposed by Sen (1976, p.219): ***Monotonicity Axiom**: given other things, a reduction in income of a person below poverty line must increase the poverty measure;* ***Transfer Axiom**: Given other things, a pure transfer of income from a person below the poverty line to anyone who is richer must increase the poverty measure.*

Another very widely used and equally classical measure of poverty is the poverty or income gap (g). It is the measure of the aggregate shortfalls of incomes (y) of all the poor from a defined poverty line (z). Unlike the poverty headcount, this index satisfies the monotonicity axiom, however, it violates the transfer axiom. That is, it is insensitive to transfers among the poor as long as such transfers take none of the poor to or above the poverty line. Besides, it so focuses on the aggregate shortfall that it fails to account for the proportion of the poor.

Sen (1976, p.223) proposes other axiomatic poverty measures[15]. However, the useful practice of breaking down a population into subgroups (ethnic, geographical and others) places an additional requirement to poverty index besides these axioms. That is the way a given poverty measure relates subgroup poverty to total poverty is important. It should be expected that a decrease in poverty of one subgroup, all other things being equal, should decrease poverty for the population as a whole. The way to achieve this is to adopt a poverty measure such that total poverty is a weighted average of subgroup poverty levels, i.e. *additively decomposable* (Foster, Greer and Thorbecke, 1984)

Foster et al (1984) suggest a set of poverty measures that is additively decomposable with population-share weights and satisfies the basic axioms of

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[15] ***Ordinal Rank Weights Axiom:** The weights $v_i(z,y)$ on the income gap of person i equals the rank order of i in the interpersonal welfare ordering of the poor;* ***Monotonic Welfare:** the relation > (greater than, defined on the set of individual welfare numbers $\{W_i(y)\}$ for any income configuration y is a strict complete ordering, and the relation > defined on the corresponding set of individual incomes $\{y_i\}$ is a subset of the former, i.e., for any i, j: if $y_i > y_j$, then $W_i(y) > W_j(y)$.* ***Normalised Poverty Value Axiom:** If all the poor have the same income, then* $P = HI$ where P is poverty index, H is headcount and I is poverty gap normalised by the product of the number of poor and the poverty line.

Sen and justified by a relative deprivation concept of poverty. For an increasing ordered vector of household incomes $(y_1, y_{2,} ..., y_n)$, a strictly positive poverty line *z*, i^{th} household's income shortfall $g_i = z - y_i$, number of poor households $q = q(y; z)$ and total number of households $n = n(y)$ and for $\alpha \geq 0$, the FGT class of poverty measures P_α is defined as:

$$P_\alpha(y;z) = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{g_i}{z}\right)^\alpha \qquad (1.01)$$

The parameter α can be considered as a measure of poverty aversion, with larger values laying greater emphasis on the poorest of the poor. P_0 is poverty headcount ratio (or incidence); P_1 is poverty gap and P_2 is poverty severity, obtained when $\alpha = 2$. Although other poverty measures have been proposed[16], The Foster Greer and Thorbecke (FGT) class of measures has been the most popularly used. In addition to its simplicity of computation, its attraction lies in its satisfaction of most of the desirable properties, decomposability and subgroup consistency. No index of poverty is without criticism. In a nutshell, the choice of a particular type of index for academic and policy exercise depends on the case being studied, data availability and ease of manipulation, while meeting minimum basic criteria. For data availability reasons, the choice for this work is the FGT class of measures.

Inequality

Inequality is a broader concept than poverty in that it is defined over the entire population. Inequality may be appraised in various domains. However, the most considered dimension is that of income, obviously because of the consideration of income as an indicator of welfare. Inequality in income may *simply mean differences in income, without regard to their desirability as a system of reward or undesirability as a scheme running counter to some ideal of equality* (Kuznets 1953, p.27). Some of the common indices developed to

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[16] For instance UNDP (1999) constructs five indices based on the capability approach – the HDI, Human Poverty Index (HPI-1) for developing countries, HPI-2 for OECD countries, Gender Related Development Index (GDI) and Gender Empowerment Measure (GEM). The shortfall of the HDR indices is that it lacks fine-tuning of conceptual underpinning, development of better measurement tools and making the approach more useful for policy purposes.

capture these differences are Lorenz curve, the Gini, Theil index and the Atkinson family of indices.

The Lorenz curve, named after Lorenz (1905) has been for several decades, the most popular tool especially for income inequality comparison. For incomes *Q(q)* and bottom *p* proportion of the population, the Lorenz Curve *(L(p))* can be defined as:

$$L(p) = \frac{\int_0^p Q(q)dq}{\int_0^1 Q(q)dq} = \frac{1}{\mu}\int_0^p Q(q)dq \qquad (1.02)$$

where μ is the sum of incomes over all the population. The Lorenz curve is therefore the cumulative share of all income held by the cumulative proportion (*p*) of the population when individuals are ordered in increasing income. The Lorenz Curve ranges from 0 *(L(0))* to 1 *(L(1))*, is increasing in *p*: $\frac{dL(p)}{dp} = \frac{Q(p)}{\mu}$ and convex: $\frac{d^2L(p)}{dp^2} = \frac{dQ(p)}{\mu dp} \geq 0$

The Gini coefficient is the most widely used measure of inequality with attractive properties for policy analysis. If there is perfect equality in income, then the cumulative share of total income held by any bottom *p* proportion of the population would be *p*. Then, $L(p) = p$ since the population shares and shares of total income would be identical. With respect to perfect equality, inequality deducts $p - L(p)$ share of total income from the bottom 100p% of the populations. Therefore the wider the shortfall between *p* and *L(p)*, the wider the inequality of income. The Gini coefficient is given by the average distance between cumulated population shares and cumulated income shares, which is twice the aggregation of the deficit between population shares and income shares across all *p* from 0 to 1. This is equivalent to the ratio of the area between the line of perfect equality and Lorenz curve and the area under the Lorenz curve.

$$G = 2\int_0^1 (p - L(p))dp \qquad (1.03)$$

A value of 0 corresponds to perfect equality (everyone having exactly the same income) and 1 corresponds to perfect inequality[17] (where one person has all the income, while everyone else has zero income).

Theil's (1967) measure of inequality stems from the information theory, which incorporates three main components. The first is a set of possible events each having a given probability of occurrence. The second is an information function *(h)* to evaluate events according to their associated probabilities. The third is the concept of entropy, which is the expected information in the distribution. The specification of *h* then relies on three axioms:

a. An event of certain occurrence has zero valued information: $h(1) = 0$
b. There is diminishing valuation of information with increasing probability: $p' > p \Leftrightarrow h(p') < h(p)$.
c. Information (events) are additively independent in probabilities: $h(pp') = h(p) + h(p')$

Theil (1967) defines an information function based on the three axioms above: $h(p) = -\log(p)$. For an ordered distribution of incomes $y = (y_1 ... y_n)$ with mean μ, in a population of *n* individuals, the first Theil's index is given as:

$$T_1(y:n) = \frac{1}{n}\sum_i \frac{y_i}{\mu}\log\frac{y_i}{\mu} \tag{1.04}$$

And also the second Theil's index or mean logarithmic deviation (MLD):

$$T_2(y:n) = -\frac{1}{n}\sum_i \log\frac{y_i}{\mu} \tag{1.05}$$

The interesting characteristic of the Theil indices of inequality measures is that of satisfaction of basic properties and particularly, decomposability. This property is very useful when analysing inequality in a population partitioned along identifiable characteristics such as race, gender, occupation, geographic

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[17] In cases where per capita income or consumption includes negative values - such as the case of self employed workers or farmers who may occasionally suffer net loss of income – the Gini index may be greater than one.

location etc. The Theil measure is preferred over Gini index in this work because it satisfies the property of decomposition into within and between-groups, which is very relevant for the case of South Africa.

Pro-poor Growth

The debate over the conditions necessary for economic growth to improve the lives of the poor or circumstances under which growth can be declared pro-poor has resulted in some consensus. The first is that the poor evidently share in increasing aggregate income as well as suffer from economic slow-downs (Dollar and Kraay, 2002). However, there are different view points over the exact conceptualization and measurement of pro-poorness of growth. The *absolute* and *relative* concepts have been the most prominent in policy arena. The absolute concept constitutes the *strong absolute* – which requires that the absolute income gain of the poor be more than those on the average or of the rich (Klasen, 2005) - and the *weak absolute* - which requires that growth be pro-poor if the suitably aggregated growth rate of the poor is greater than zero (White and Anderson, 2000). With the relative concept, growth has to be relatively biased towards the poor, leading to faster poverty reduction (Kakwani and Pernia, 2000).

The second consensus is that poverty reduction is fastest in situations where income growth is accompanied by falling inequality (Bourguignon, 2004). However, it is difficult to argue that inequality reduction in the absence of growth can result in poverty reduction. Ravallion (1997), Bourguignon (2004) and Son and Kakwani (2003) have established that high inequality reduces the impact of growth on poverty reduction. It has also been noted that poverty reduction depends on poverty line. Son and Kakwani (2008) suggest a pro-poor growth rate as the difference between the growth rate of societal mean income and the rate of change of inequality, such that if inequality decreases (increases) in a given period, then the pro-poor growth rate is greater (less) than the actual growth rate for that period. This is the approach from which the poverty framework for this thesis is adopted.

1.7 Outline of Thesis

This thesis is organised into six chapters. The general introduction to the thesis has been done in chapter one, with the statement of the research problem, objective and a brief overview of methodology. Chapter Two briefly examines the position of growth and poverty reduction debates in recent literature. It first looks at two main theoretical views in investigating the role of energy in production - the mainstream (neoclassical) and biophysical theoretical perspectives. It then explores the literature on non-theoretical methods (of Vector Auto-Regressive). It follows with a critical review of production functions, while highlighting the benign option - Variable Elasticity of Substitution production functions - to be used. The literature examination continues with the linkages between energy, inequality and poverty, followed by pro-poor growth debates, before concluding with highlights of unresolved issues.

Chapter Three tackles the relationship between energy types, Gross Domestic Product (GDP), and other factors of production (capital and labour). It first examines the question of causality in a more novel - Lag-Augmented Causality – than the traditional Granger approach. This is followed by co-integration analysis in a relatively more advantageous – Auto-Regressive Distributed Lag – approach, compared to the traditional VAR frameworks. Related data is discussed followed by interpretation of analysis; while in conclusion, the main findings of the chapter are highlighted.

In Chapter Four, Vinod (1972) type VES production function is adapted to energy and production. In this framework, the issues of factor substitutability, Returns to Scale (RTS) and economic growth are addressed with emphasis on the role of the respective energy types in the various economic sectors. A two-input model is first developed, with capital and labour only. In the next stage, the substitution elasticity between the two factors helps to specify the appropriate VES functional form with three inputs (including energy). The three inputs VES is then estimated jointly with a classical energy demand framework for the various energy types. Related data is discussed and the main findings of the chapter are highlighted, comparing the results with the findings of Chapter Three.

Chapter Five extends a per capita Cobb-Douglas production function to include inequality and energy. This is estimated jointly (in simultaneous equations framework) with energy demand, inequality and poverty equations. Data issues specific to this chapter are dealt with, followed by analysis and interpretation of results. Highlights of main findings conclude the chapter.

Chapter Six concludes the thesis by recapitulating the main issues and findings of the analysis. This is followed by implications of the findings for research and policy.

2. LITERATURE REVIEW

2.1 Introduction

The objective of this chapter is to briefly examine the position of growth and poverty reduction debates and the relationship with energy in literature. There is consensus in theory and experience that economic growth and the resulting distribution of its fruits are the two means by which poverty reduction occurs (Easterly, 2002; Ravallion, 2004; Bourguignon, 2004). It follows that the analysis of the impact of any policy or activity on poverty reduction should naturally look at the corresponding effect on production (growth) and inequality. It is in this manner that the role of energy is surveyed. Mainstream economic growth theories have relegated energy as a factor of production, to a dismal position. This is mainly due to three assumptions – notably, that the productivity of the different factors of production be equal to their respective cost shares; that technological progress can effectively decouple energy use from economic growth and that energy be regarded as an intermediate factor of production. However, the biophysical theory drops these assumptions and accords a more central role to energy in the production process. Apart from few studies that have documented the benefits of electrification, the role of energy in inequality and poverty is not well exploited (Prasad, 2006; World Bank, 2001)

Literature related to energy and production is discussed in section (2.2). Production frameworks (with their relative weaknesses and strengths), from which a basis will be chosen for the analysis of production and growth impacts of energy, are explored in section (2.3). Following this, is the review of the role of energy in poverty (section 2.4). The notion of pro-poor growth is explored in section (2.5), where the interaction between growth and inequality is surveyed, followed by the formalisation of pro-poor growth in an empirical framework. Section (2.6) concludes the chapter by highlighting unresolved issues regarding the topic of pro-poor growth and energy.

2.2 Energy and Production

Historical facts have shown the importance of energy as a driver of economic growth. The first example that sparked the industrial revolution is the 18th century Britain, which due to scarcity of charcoal, adapted to the use of coal as an alternative fuel. Coal-fired (capital) equipments like the steam engine replaced the horse-powered pumps, allowing for increase in productivity. The resulting general fall in prices (including coal itself) led to increase in demand for all goods. Again in the 19th century in Western Pennsylvania, the discovery of petroleum stimulated the development of the internal combustion engine. Again, falling costs boosted the demand for both energy and other goods. Clearly, since the 18th century, fossil-fuel and electric power driven capital machinery have been both substitute and booster of human and animal labour (Ayres, 2001).

Increasing research is being done on the role of energy in economic growth or at least output, following the works of Schurr (1982; 1984), which hypothesise that in the early twentieth century, electrification contributed significantly to the growth of labour and multifactor productivity in the U.S. economy. Conceptual approaches that have been followed for empirical works in literature can be classified into three broad categories – neoclassical, biophysical and non-theoretical.

2.2.1 Mainstream Theoretical Perspectives and Empirics

The distinction between primary and intermediate inputs has played a major role in how mainstream growth theorists view the role of energy in production. They consider capital, labour and land as primary inputs and energy and material as intermediates. This implies that return to different factors of production accrue eventually to the three primary inputs (Stern, 2004). The result of the neoclassical assumption that the productivity of a factor be equal to its cost share in production is that only the primary inputs – capital and labour – receive all the focus, with energy receiving a dismal and indirect role (Stern and Cleveland, 2004). Growth theorists have always assumed variously defined technical progress as the main source of labour productivity growth.

However, technical progress is one of the major energy using processes of development (Jorgenson, 1984).

Empirically, a number of works have added energy to the traditional capital and labour, in either a Cobb-Douglas or Constant Elasticity of Substitution (CES) production frameworks. The first to take this approach was Berndt and Wood (1975) who also included material and services in the so-called KLEMS[18] production function. Following this, others have analysed previously ignored substitution and complementarity possibilities. These works like the mainstream foundation, still constrain the marginal productivity (output elasticity) of each input to be proportional to its cost share. As such, energy elasticity was found to be low (0.04 for the US and 0.058 for OECD). By implication, energy prices could not have a significant effect on economic growth (Denison, 1979; Gallop and Jorgenson, 1973). Hannon and Joyce (1981), with various Solow-like model specifications, augmenting with energy, or electric power or combination (capital + energy) obtained similar results in the above, for the US. Later, Jorgenson (1984; 1988) used a transcendental logarithmic production function type of KLEMS with electric energy. He observed that energy prices had a very strong negative effect on economic growth in the US and Japan during the energy crisis in the 1970s. However, this has been refuted by many economists (Ayres, 2001), since falling energy prices in the 1980s did not boost real growth.

2.2.2 Biophysical Theoretical Perspectives and Empirics

The biophysical (ecological) school has proposed a heterodox approach to production theory in response to the mainstream formulation. The main characteristic is the abandoning of the assumption that factor productivities must be equal to factor shares. This view follows on the work of Georgescu-Roegen (1971). Biophysical Models (with empirical variants based on the

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[18] In KLEMS, K stand for capital, L for labour, E for energy, M for material and S for services.

Leontief's input-output production function[19]) argue that energy is the fundamental (at extreme, sole) factor of production in an economy. In the biophysical view, the necessity of labour, capital or exogenous technical progress is not required to characterise the best fit of historical output data, not just in the US, but also in other economies (Cleveland et al 1984; Constanza and Heredeen, 1984; Constanza, 1991; Cleveland, 1992 and Kaufmann, 1992). Empirically, these works find strong correlation between energy (in heat value) and economic growth, with little or no role for capital or labour. However, as Ayres (2001) remarks, a simple correlation between energy consumption and growth does not necessarily imply causality. This fact could as well mean that energy use is the consequence and not the cause of economic growth. The address to this concern is explored in the non-theoretical approaches.

More recent works have explored two more types of production functions, both of which drop the assumption of equality of factor productivities and cost shares. The one is Beaudreau (1998) who suggests an output production function of two factors – physical work *W(t)*, with direct relation to efficiency-adjusted energy consumption, and Supervision *S(t)*, which refers to organisational or managerial activities. For empirical purpose, he takes electricity generation as proxy for physical work and indirect production labour[20] as proxy for supervision. Specifying a Cobb-Douglas with capital, labour and electric power, he finds electric power productivity of 0.537, 0.606, and 0.747 for US, Japan and West Germany respectively.

The other is the suggestion of Daly (1992 and1997), Georgescu-Roegen (1970, 1971 and 1979) and Kummel (1989), to start from a KLE-type generic production function, satisfying the conditions for constant Returns to Scale[21].

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[19] A generalised form can be represented in demand (C), with respect to income or output (Y) and prices (p$_i$ and p$_j$ as follows: $C = Y\sum_i\sum_j \gamma_{ij} p_i^{\frac{1}{2}} p_j^{\frac{1}{2}}$, where γ_{ij} are parameters.

[20] Calculated as the difference between total manufacturing labour and direct production labour (Ayres, 2001)

[21] Homogeneity of degree one.

An interesting possibility of such production function is the Linear Exponential (LINEX) family of functions:

$$q = q_0 k^{\alpha} l^{\beta} e^{\gamma} \exp^{\left(a_1 \frac{k}{l} + a_2 \frac{l}{k} + b_1 \frac{l}{e} + b_2 \frac{e}{l} + c_1 \frac{e}{k} + c_2 \frac{k}{e}\right)} \qquad (2.01)$$

Where *k, l, e* denote capital, labour and energy, *a, b,* and *c* are technology related parameters and $\alpha + \beta = 1 - \gamma$ are productivity parameters. Kummel et al (2000) use a two-parameter parsimonious specification of (2.01) in industrial production time series for West Germany (1960-1989), Japan (1965-1992), US (1960-1993). They find energy productivity of 0.50, 0.45 and 0.54 for the respective countries. These estimations have been considered to *match the observed output with extraordinary precision* (Ayres, 2001, p. 827). This has led to the conclusion that in the past, energy's contribution (at almost negligible cost) to production has been attributed to other factors. However, as Ayres (2001) remarks, a simple correlation between energy consumption and growth does not necessarily imply causality.

2.2.3 Non-Theoretical Approaches

This body of literature avoids the a priori theoretical restrictions applied to energy-production/economic growth analyses. This approach involves investigation of causality relationship and actual statistical testing in Vector Auto-Regression (VAR) time series frameworks.

Statistical tests that have been carried out to address the question of causality make use of the framework developed by Granger (1969) and Sims (1972). This is based on the premise that if *x* causes *y*, then a change in *x* will be followed by a change in *y*. These works either found causality running from output to energy use or arrived at inconclusive results (Kraft and Kraft, 1978; Akarca and Long, 1980; Yu and Hwang, 1984; Yu and Choi, 1985; Ammah-Tagoe, 1990). However, accounting for energy quality changed the results of subsequent causality findings (Cleveland et al, 1984). Using US Gross Domestic Product (GDP) data from 1947 to 1990 in a multivariate framework with labour, capital and energy use, Stern (1993) carried out two Granger causality tests. The first, without quality adjustment yields causality from GDP to energy use. In the second, he uses the Divisia index, in which both standard thermal equivalent measures and fuel prices (as proxy for quality) are used for weighting the various fuels. Accounting for energy quality caused a reversal in the direction of causality. Later, extending the same data to 1994, Cleveland, Kaufmann and Stern (2000) confirm the finding. They also argue that the decline in energy/GDP ratio in the US can be explained by the quality adjustments in energy index in terms of fuel substitution.

However, later versions of VAR models have produced mixed results in developed and developing countries on the one hand and among developing countries on the other. In a panel VAR for 22 developed and 18 developing countries, Lee and Chang (2007) obtain a two-way causal relationship between per capita energy and GDP in developed countries and a unidirectional relationship from GDP to energy for developing countries. Earlier, Wolde-Rufael (2005) finds a mixture of unidirectional, bidirectional and no causal relationships in 19 African countries. He explains the different directions of causality in terms of country-specific factors. A common factor in these studies is the use of aggregate energy measure and aggregate GDP.

2.3 Review of Production Functions

Production functions are an important tool of economic analysis (and the role of energy), especially in the neoclassical sense. In its fundamental form it is generally conceived as the technical relationship between output produced and inputs employed. Of the two efficiencies implied by production functions – technical and allocative - , economists generally assumed technical efficiency as achieved (Libenstein et al, 1988). With this assumption, production function is described as the relationship between the maximal technically feasible output and the inputs required for that output (Shephard, 1970). Because the production process uses several types of inputs in physical units to produce (often) several types of output (joint production), the relationship between outputs and inputs is essentially physical. Since these various physical units of inputs and outputs cannot be aggregated, production functions often use their monetary values.

The earliest explicit algebraic formulation relating output to inputs in the form $P = f(x_1, x_2, ..., x_m)$ is attributed to Phillip Wicksteed in 1894, but also to von Thunen in the 1840s in form $P = f(F) = A\Pi_1^3(1 - e^{-a_i F_i})$, where F_i are capital, labour and fertiliser inputs, a_i are parameters and P is agricultural production, A is a productivity parameter and Π a product operator (Humphrey, 1997).

Between early 1950s and late 1970s, when production functions gained much interest among economists, various empirical specifications relating inputs to output were proposed. Besides the unitary elasticity of substitution (or Cobb-Douglas) production function, the wide surge in the formulation of production functions and their analysis gave rise to the Constant Elasticity of Substitution production (CES) Functions. These two –Cobb-Douglas and the CES – frameworks are the main functional forms that have gained wider acceptance in empirical and theoretical literature, however, due to their limitations, they have served as bases for further generalisations to the Variable Elasticities of Substitution (VES) production functions. These three groups of functional forms are briefly explored in the following sub-sections.

2.3.1 Unitary Elasticity of Substitution Functions

The Cobb-Douglas (C-D) production function generally attributed to Cobb and Douglas (1928) is also known as unitary elasticity of substitution function because it restricts the elasticity of factor substitution to unity. It came to light due to the effort of Paul Douglas and Charles Cobb to fit US manufacturing data (from1889 to1922). The resulting formulation has been extremely popular among economists. It can be written as:

$$Y = AK^{\alpha}L^{1-\alpha} \tag{2.02}$$

where Y is output, K is capital and L is labour, α: $(0 \leq \alpha \leq 1)$ a parameter and A: $(A > 0)$ the level of technology. It is possible to demonstrate that this functional form as stated exhibits constant Returns to Scale. If markets are assumed to be competitive and factors are rewarded at their marginal products, then the parameters α and $1 - \alpha$ are synonymous to capital and labour shares of output respectively. With unitary elasticity of substitution, any changes in factor proportions is exactly offset by corresponding changes in marginal productivities of inputs, as such, factor shares remain constant for any capital-labour ratio, implying also that income shares will be constant over time.

Arrow et al (1961) argue that the Cobb-Douglas assumption of unitary elasticity of substitution leads to unduly restrictive conclusions. They provide theoretical examples as to why input elasticity of substitution should also assume a zero value. The first is that the Harrod-Domar economic growth model[22] depends critically on a zero elasticity of substitution assumption. Secondly, varying elasticities among sectors imply reversal of factor intensities at different factor prices, with different consequences for international trade and factor returns, but either zero or unitary elasticities of substitution lead to constancy in ranking of factor proportions. Thirdly, the hitherto perceived constancy of labour share of income in the US that served as the basis for assuming unitary elasticity of substitution in the analysis of relative shares of factor incomes has been refuted by Solow (1958).

However, unitary elasticity assumption has no theoretical basis in the Cobb-Douglas framework. The correct elasticity is purely an empirical question. Modern economists (Fraser, 2002; Arrow et al, 1961) have questioned the methodological soundness of the earlier studies that lent support to the initial empirical results of Cobb-Douglas (1928). Arrow et al (1961, p.225) have argued that *technological alternatives are numerous and flexible in some sectors, limited in others; and uniform substitutability is most unlikely*. They confirm this by an observation that capital-labour proportions show more variation among countries in some sectors more than others. Following these criticisms, Arrow et al (1961) develop the Constant Elasticity of Substitution (CES) production function, of which the Cobb-Douglas framework is a special case.

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[22] The Horrod-Domar model is named on the basis of the works of Harrod (1939) and Domar (1947). The key parameters of the framework are savings-output and capital-output ratios. The characteristic and powerful outcome of the Harrod-Domar logic is that even for the long run, the economic system is at best balanced on highly unstable equilibrium path of growth (Harrod, 1939, p.16). This outcome is a consequence of the fixed proportion assumption which allows for no capital-labour substitution in the production process.

2.3.2 Constant Elasticity of Substitution Functions

The Constant Elasticity of Substitution (CES) production function is easily derived from the redefinition of the elasticity of substitution. The elasticity of substitution (σ) between capital (K) and labour (L) for example is the measure of the ease with which more capital may be used in the place of labour or vice versa, defined as the percentage change in factor proportions resulting from a unit change in the Marginal Rate of Technical Substitution[23] (MRTS). Formally,

$$\sigma = \frac{\%\Delta(K/L)}{\%\Delta MRTS} = \left[\frac{d(K/L)}{dMRTS}\right] \cdot \left[\frac{MRTS}{(K/L)}\right]$$

(2.03)

Following Klump and Preissler (2000), equation (2.03) can be rewritten as

$$\sigma = \left[\frac{d(K/L)}{dMRTS}\right] \cdot \left[\frac{MRTS}{(K/L)}\right] = \frac{f'(k)\left[f(k) - kf'(k)\right]}{-kf''(k)f(k)} \qquad (2.04)$$

where f, f' and f'' are zero, first and second order partial derivatives with respect to k of the production function $f(k)$, and $k = K/L$. The solution of the underlying partial differential equation in k is

$$y = \frac{Y}{L} = f(k) = \gamma_1\left[k^{\rho} + \gamma_2\right]^{1/\rho} \qquad (2.05)$$

or

$$Y = f(K,L) = \gamma_1\left[K^{\rho} + \gamma_2 L^{\rho}\right]^{1/\rho} \qquad (2.06)$$

where γ_1 and γ_2 are constants of integration, and $\rho = (\sigma - 1)/\sigma$. If $\alpha = 1/(1+\gamma_2)$ and $C = \gamma_1(1+\gamma_2)^{1/\rho}$, then equation (2.06) becomes the standard CES production function of Arrow et al (1961):

$$Y = C\left[\alpha K^{\rho} + (1-\alpha)L^{\rho}\right]^{1/\rho} \qquad (2.07)$$

where C is a measure of technical progress, $0 \leq \alpha \leq 1$ and $1-\alpha$ are distribution parameters that can be used as determinants of factor shares, ρ is

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[23] The MRTS is the rate at which a factor (e.g. labour) can be substituted for another (e.g. capital), while holding output fixed along an isoquant, i.e. the slope of the isoquant at a given point.

a substitution parameter, used to derive the elasticity of substitution. Though other variants of CES production functions which allow technological change to affect factor productivities (Barro and Sala-i-Martin, 2004[24] and David and van de Klundert, 1965[25]), have been suggested, the above form by Arrow et al (1961) has been prominent.

There are two main issues related to the CES production function. The first is the constancy of the elasticity of substitution (between inputs) along and across isoquants. In practice, there is possibility of variations in σ as argued by Revankar (1971). This variation depends on output and or combinations of inputs (Hicks, 1932 and Allen, 1956). The second issue is the definition of the elasticity of substitution when more than two inputs are used in production. For example, in case of three inputs, there will be three elasticities, which would increase with increase in inputs. It has been shown by Uzawa (1962) and McFadden (1962 and 1963) that it is impossible to obtained a functional form for a production function with an arbitrary set of constant elasticities of substitution when there are more than two factors of production. This is now known as *the impossibility theorem of Uzawa and McFadden.*

2.3.3 Variable Elasticity of Substitution Functions

In attempts to overcome the limitations posed by unitary and constant elasticities of substation production functions, various studies have endeavoured to generalise the C-D and/or CES production functions to give room for variability of elasticities of substitution. A renowned generalisation is that proposed by Revankar (1971), generalised from CES. In his attempt to improve on the simplicity of the expression of the elasticity of substitution and to ensure a certain degree of linearity, Revankar (1971) diverges somewhat from earlier attempts[26] of Variable Elasticity of Substitution (VES) production

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[24] This variant which is formalised as $Y = C\left[\alpha(bK)^{\rho} + (1-\alpha)((1-b)L)^{\rho}\right]^{1/\rho}$ allows for biased technological change but has been criticised by Klump and Preissler (2000) for not following directly from the definition of the elasticity of substitution.

[25] This variant sets $A_K = \gamma_1$ and $A_L = \gamma_2\gamma_1^{\rho}$ which are respectively, capital and labour augmenting technical progress, to obtain $Y = \left[(A_K K)^{\rho} + (A_L L)^{\rho}\right]^{1/\rho}$

[26] See Halter et al (1957), Liu and Hildebrand (1965) , Bruno (1968)

functions. His variant of VES production functions with two inputs – capital (*K*) and labour (*L*) -, technology factor (*A*) and parameters ρ, δ, and μ is as follows:

$$P = AK^{\rho(1-\delta\mu)}[L + (\mu - 1)K]^{\rho\delta\mu} \qquad (2.08)$$

Revankar (1971) imposes the following restriction on the parameters:$A, \rho > 0; 0 < \delta < 1; 0 \leq \delta\mu \leq 1$ and $\frac{L}{K} > \frac{1-\mu}{1-\delta\mu}$. The function for elasticity of substitution (σ) is given by:

$$\sigma(K, L) = 1 + \frac{\left[\frac{\mu-1}{1-\delta\mu}\right]K}{L} = 1 + \beta\frac{K}{L} \qquad (2.09)$$

Though Revanker's VES production function contains the linear production function, it still contains a degree of non-linearity in parameters and cannot easily be generalised to more than two inputs. Vinod (1972) proposes a Cobb-Douglas generalisation based on the log-quadratic production function suggested by Kmenta (1967). The basic version for two inputs x_1 and x_2, output y and parameters $a_k(k = 0, 1, 2, 3)$ is:

$$y = e^{a_0}x_1^{a_1+a_3 lnx_2}x_2^{a_2} \qquad (2.10)$$

When $a_1 = 1 - a_2$ and $a_3 = 0$, (2.10) becomes the Cobb-Douglas function. If the terms involving $\ln{(x_1)^2}$ and $\ln{(x_2)^2}$ are included, then (2.10) becomes the Kmenta (1967) log-quadratic formulation.

The virtues of Vinod's (1972) version are that (1) it allows for variable elasticity of substitution; (2) it imposes no restrictions on data nor parameters; (3) the specification is linear in parameter and flexible; (4) can easily be extended to more than two inputs (5) it measures other properties of production, for example output elasticity, elasticities of substitution and Returns to Scale with different factor proportions. Because of these virtues, and the fact that it can be estimated with Ordinary Least Squares (OLS), and can easily be incorporated into simultaneous equations frameworks, it is adapted in this work for the estimation of production functions in chapter four.

Due to these qualities, various authors find it easier to apply compared to the other functional forms (see for example, Lopez, 1997; Kouliavtsev et al 2007).

2.4 Energy, Inequality and Poverty

Although energy is crucial for addressing the needs of the poor, its poverty impact awareness has been confined largely to abstract conceptualization and anecdotal experiences (Ramani et al, 2003). As a result, the specific contributions that energy makes or could make to the lives of the poor are not well understood.

One of the most conceptually comprehensive overview of the role of energy choices on poverty is given by the energy ladder model. This model proposes three distinct phases in fuel switching. The first is characterised by universal reliance on biomass. In the second phase, the model hypothesises movement to "transition" fuels such as kerosene, coal and charcoal in response to higher incomes, urbanisation and biomass scarcity. The final phase is the switching on to LPG, natural gas or electricity for cooking (Barnes and Floor, 1999; Barnes and Qian, 1992; Hosier and Kipondya, 1993; Leach, 1992). Using data for eight countries, Heltberg (2004) finds that modern fuel use is associated with higher incomes. However, the energy ladder model is conceptualised to explain more of what determines household or individuals' decision to switch from one fuel source to another rather than the impacts of such fuel or their substitution on household income (or its arguments).

ESMAP (2002) has identified large-scale electrification programmes in both rural and urban areas in developing countries as a vehicle for promoting equity and economic development. The significant areas that electrification affects are low cost and expanded use of lighting, access to information (TV and Radio), improved return on education and wage income, time saving on various household chores and improved home business productivity. Another effect relates to benefits from improved farm income through pump irrigation. Depending on farm size and other factors, Barnes, Fitzerald and Peskin (2002) record about 50% income gains from improved irrigation in India.

Currently (2007), people living below the lower international poverty line (US$1 income per day) spend up to a third of their income on energy services. Using poor quality energy such as biomass and fossil fuels (kerosene and coal) in households has led to many health problems such as asthma and increased susceptibility to chest infections (Lallement 2005), which impacts human capital.

Macro-economic studies of electrification in the Philippines conducted by ESMAP (2002) quantified the benefits that accrue to households following electrification. Electricity, which was a cheaper[27] form of energy compared to traditionally used fuels, allowed household energy budgets to decrease through access to higher and less expensive forms of lighting, as well as radio and television use. Access to electricity also increased education levels – this also led to increased real wages in the newly electrified areas. Productivity gains increased for already established businesses and many new small businesses were established (Prasad, 2006).

Other studies have shown that access to electricity, as well as increased incomes have enabled households to move away from traditional fuels such as biomass and kerosene to electricity (Davis 1998), though multiple fuel use still continues in these households. This movement up the "energy ladder" allows households to obtain the benefits extended from using electricity, such as cleaner air, reduction of fires and poisoning, as well as better services provided by schools and clinics due to electrification (DME and ERC, 2002). An extensive linkage between energy choice, household poverty according to the livelihood approach and possible contribution to women empowerment has been established by the World Bank (IEG, 2008).

World Bank (2008a), in a micro-based study finds that benefits of electrification accrue mainly to the non-poor. It suggests that there is a need for provision of complementary services to accompany electrification to the poor. In general, the effect of energy consumption on inequality seems scarce in literature.

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[27] This may not be the case for African countries.

2.5 Pro-poor Growth

The question of whether economic growth is good for the poor or under what circumstances growth can be declared pro-poor has of recent been a subject of academic and policy debate (Bourguignon, 2004; Bruno et al, 1998; Dollar and Kraay, 2002; Eastwood and Lipton, 2001; Ravallion, 2001; United Nations, 2000 and World Bank, 2002). The answer to this question necessitates the clarification of pro-poorness. As a result of the debate, some consensus has emerged.

The First consensus is on the importance of growth on poverty reduction. Historically, countries with high and prolonged period of economic growth also experienced the fastest reduction in poverty rates (Dollar and Kraay, 2002). In this light, the poor evidently share from increasing aggregate income as well as suffer from economic slow-downs. However, despite consensus over this point, there is a great deal of debate concerning the exact conceptualisation and measurement of pro-poorness of growth. Though a number of pro-poor concepts have been put forth[28], the *absolute* and *relative* concepts have been the most prominent in policy debates.

The absolute concept is of two types. The first - the *strong absolute* - requires that the absolute income gain of the poor be more than those on the average or of the rich (Klasen, 2005). White and Anderson (2000) demonstrate that this requirement implies that growth rate of the poor would have to be larger by a factor of the ratio of the initial incomes of the non-poor and the poor. As such, it is a difficult requirement to meet. The second - the *weak absolute* - requires the suitably aggregated income growth rate of the poor be greater than zero. Proponents of the latter subclass argue that for poverty reduction, only high income growth for the poor matters, not the relative position to the non-poor[29].

The relative concept suggests that growth is pro-poor if the growth of income of the poor is higher than the average income growth rate. This implies that

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[28] Ravallion and Chen (2003), Son (2004), Kakwani and Pernia (2000), Hanmer and Booth (2001), McCalloch and Baulch (1999), White and Anderson (2000), Klasen (2003), Duclos and Wodon (2004).

[29] For example, high but unequal growth recorded in China can be considered preferable to low but equitable growth in Ghana if absolute income growth of the poor is higher in China than Ghana.

growth has to be relatively biased towards the poor, such bias (with constant average growth would lead to faster poverty reduction. Proponents of relative concept of pro-poor growth - among whom are Kakwani and Pernia (2000), McCulloch and Baulch (1999), Ravallion and Chen (2003) – argue that such will be the case only if inequality reduces. This leads to another consensus.

The second consensus is that poverty reduction is fastest in situations where income growth is accompanied by falling inequality (Bourguignon, 2004). However, it is difficult to argue that inequality reduction in the absence of growth can result in poverty reduction. Ravallion (1997), Bourguignon (2002) and Son and Kakwani (2003) have established that high inequality reduces the impact of growth on poverty reduction. It has also been noted that poverty reduction depends on the poverty line.

However, the main challenge - as noted by Bourguignon (2004) – in establishing development policies is whether or not there is any interrelation between growth and inequality.

2.5.1 Growth – Inequality Nexus

The type of relationship that may exist between growth and inequality is very crucial to the pro-poor debate. If there is no link between both quantities, then it will be possible to pursue growth and redistribution policies separately without jeopardising either. On the other hand, if there is a link between them, then there must be some trade-off. The nature of the trade-off will depend on the type of link. Empirically, the specification of pro-poor regression models will depend on the nature of relationship existing between growth and inequality. There has been increasing interest on the investigation of the growth-inequality nexus in recent literature. On the one hand are those who pursue the Kuznets' (1955) inverted U-shape hypothesis, which seeks to deepen understanding on the distributional consequences of growth (Ahluwalia, 1976a; Justman and Gradstein, 1999). On the other hand and relatively recently, are those who look at feed-back in the above relationship, i.e. the growth impact of inequality (Galor and Zeira, 1993; Persson and Tabelini, 1994; Alesina and Rodrik, 1994).

2.5.1.1 Inequality Impact of Growth

The first influential argument for the impact of growth on inequality is the work of Kuznets (1955). He hypothesises that at the early stages of growth in developing countries, inequality increases, and then starts to fall. Since then, this hypothesis has gained interest among researchers (Oshima, 1970; Ahluwalia, 1976a; Robinson, 1976). Basic mechanisms have been proposed to explain this hypothesis. First, Kuznets suggests labour market imperfections, productivity differentials across economic sectors and the changing importance of the various sectors in the economy. Particularly, in a two-sector economy – low inequality, poorer rural sector and high inequality, richer urban sector -, growth occurs by rural-to-urban labour migration. The model starts with all population in the rural sector. As the first workers migrate, inequality first increases, and then falls with the last workers leaving the rural sector. Stiglitz (1969) explained the same hypothesis within a neoclassical framework of growth and distribution in which individual accumulation behaviour and changing factor rewards (due to diminishing returns to capital) account for the U-shape in the evolution of inequality with development.

Besides the basics, other directly or indirectly related mechanisms have been suggested. One is the institutional channels in which institutions, social relations, culture etc, tend to be modified by growth through various ways. The most simple, exemplified in Justman and Gradstein (1999) is by means of non-homothetic[30] preferences such that the demand for social services changes with income growth. People subsequently become politically more active, leading to change in the distribution of political power and evolution of institutions. North (1990) has highlighted the possibility of transaction costs – which hinder institutional change – becoming more affordable with economic growth. Bourguignon (2004) observes that the process of urbanisation that follows economic development occurs naturally with the evolution of social relations.

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[30] Preferences or utility is homothetic when the expenditure shares of different consumption goods are constant as income increases, otherwise, it is non-homothetic.

Empirical works that lend support to this hypothesis made use of cross-country datasets from 1950s to 1970s and regress a measure of inequality against suitable function of mean income. Some examples are Adelman and Morris (1973), Ahluwalia (1976b) and Ram (1995). Ahluwalia (1976b) estimates inequality as a function of log of per capita income and its square to capture the quadratic effect in a cross section data, and confirms the existence of an inverted U-shaped relationship. Anand and Kanbur (1993a and 1993b) propose other functional forms and show that Ahluwalia's (1976) estimates are not robust to functional form variations. Bruno et al (1999) argue that there may be important country-specific factors (including past inequality), determining current inequality, which may also be correlated with current income levels, leading to biased estimates. This relationship was verified for the 1970s, but as more and better data became available, it was not verified for later periods. Bruno et al (1999) replicated the specifications and found no evidence of inverted U-shape in latter cross-sections. Bourguignon and Morrisson (1998) use unbalanced panel data for developing countries and found that this hypothesis is not verified. Deininger and Squire (1996a) use unbalanced panel with about ten year intervals[31]. A simple pool regression of Gini with respect to per capita income and its inverse give a significant inverted U-shape. However, decadal differencing to account only for time changes gives an insignificant curvature. The introduction of country fixed-effects[32] causes the U-shape to disappear completely.

As Bourguignon (2004) remarks, all the above discussions do not imply that growth has no significant impact on inequality, but rather much presence of country-specific factors in the inequality impact of growth. This call for more country-specific (obviously time series) case studies. Bourguignon et al (2003) suggest that indeed growth impacts inequality, a major contributing factor being the difficulty of the poorest households to incorporate themselves into the labour market in the advent of slow growth.

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[31] considered problematic with possible measurement errors (Atkinson and Brandolini, 2001)

[32] Country fixed effects ensure a parallel path for different countries.

2.5.1.2 Growth Impact of Inequality

Even if growth has any impact on income distribution, one other major is whether there is reverse impact. The works of Galor and Zeira (1993), Persson and Tabelini (1994) and Alesina and Rodrik (1994) are pioneers in this area. Though a number of channels exist through which reverse causation could happen, two prominent ones have often been highlighted in literature - credit constraints and political economy - both of which have implications for human and physical capital accumulation.

Credit, Savings and Investment Channel

The underlying mechanism here can be typified by the following: In the credit market, if 10 and 50 percent are the respective interest rates of rich and poor individuals (due to lack of collateral by the poor), then all projects with return rates of 10 percent and above will be undertaken by the rich while only projects of 50 percent and above return rate will be carried by the poor. But if there is redistribution of wealth from the rich to the poorer individuals, it will reduce their need to borrow while allowing them to undertake projects with returns lower than 50 percent. As such, redistribution will lead to higher investment and/or higher return to capital (Bourguignon, 2004: 17). More formalised models (like Galor and Zeira, 1993; Banerjee and Newman, 1993; Aghion and Bolton, 1997) put information asymmetry at the centre of credit constraints. In these models, the evolution of inequality and output is influenced by the limited choice by poor people (and possibly middle class) of occupations and investment due to credit rationing. When the poor are thus prevented from making productive investment (that would benefit them and the society), a low and inequitable growth process can result. Besides, in a Keynesian economy where marginal rate of savings increases with income, or with higher propensity to save from capital returns than labour returns, those at the top end of the distribution may represent the main source of savings (Voitchovsky, 2005). The suggestion here is that growth is not only affected by income distribution, but also the shape of the income distribution curve.

Skills, Incentives and Innovations

In situations where ability is rewarded, there is incentive for more effort, risk taking and higher productivity, resulting in higher growth but with higher income inequality. In such cases, talented individuals will tend to seize higher return to their skills. The resulting concentration of talents and skills in the advanced technology upper income sector becomes conducive for further innovation and growth (Hassler and Mora, 2000). Such incentive can induce greater effort in all parts of the distribution (Voitchovsky, 2005). However, frustration in the lower end of the distribution resulting from perceived unfairness (Akerlof and Yellen, 1990) may counteract the innovation gains. Along the same line, Schwabish et al (2003) find that top end inequality (measured by 90/50 percentile ratio) strongly and negatively impacts social expenditures while the bottom end (captured by 50/10 percentile) show a small positive effect. They suggest that high top end inequality reduces social solidarity, with the rich trying to pull out of publicly funded programs such as health care and education, in preference to private provision.

Though these models do not explain the historical origin of high inequality, they establish the link between persistently high inequality, inefficiencies and slower production.

Political Economy

In this view, high inequality sets the stage for the adoption of distortionary policies which adversely affects investment and generates political instability leading to stifled growth. Two main channels are identified here.

One relies on the notion of the median voter, where wealth inequality increases the gap between the median voter and the average capital endowment of the economy. This leads him to support higher capital tax rates, which in turn reduces incentives to invest in physical and human capital hence reducing growth. Persson and Tabelini (1994) suggest an alternative along this line, in which the rich spend their wealth to lobby for preferential (tax) treatment, leading to more inequality and slower growth.

The other channel is the social conflict and political instability. Alesina and Perotti (1993) have argued that higher political instability can result from high inequality, the resulting uncertainty then reduces investment levels. Rodrik (1996) has noticed that divided societies with weak institutions also witnessed the sharpest fall in post-1975 growth. This situation brought about a weakness in their capacity to effectively respond to external shocks. Also, recent sharp increase in violence in Latin America and Sub-Saharan Africa has been matched with their high inequality. Another channel makes use of possible positive externalities in the consumption of certain goods, whose demand may be reduced by high inequality (Schleifer et al, 1989).

Empirical attempts have been made to test the hypothesis - that high inequality leads to low investment in physical and human capital, resulting in slower growth – which, like the case of the Kuznets hypothesis have also tended to be inconclusive or even contradictory. Various authors have found negative impact of initial inequality on growth. Persson and Tabelini (1994) using data for nine OECD countries found that a one standard deviation increase in income share of the top quintile reduces growth rate by half a percentage point. Other verifications have been made, for a sample of developing countries (Clarke, 1995) and a combination of both, in an extended dataset (Deininger and Squire, 1996b).

Other works have nuanced and even contradicted the above. Fishlow (1996) for example, casts doubt on the robustness of the above studies by controlling for Latin America in the cross-section data used by the above studies. He finds insignificant effect of inequality on growth. Forbes (2000) estimates fixed effect models using decadal country data and find a positive association between inequality and growth. Voitchovsky (2005) controls for the shape of income distribution[33] using the Luxemburg Income Study dataset and recommends that a combination of average, top and bottom end inequalities are necessary to efficiently capture the effect of inequality on growth. However, It can be said that the investigation of the growth impact of

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[33] By introducing 90/75 percentile income ratio for the top end and 50/10 ratio for the bottom end.

inequality also suffer from the same problems of the Kuznets case, requiring more country-specific case studies.

2.5.2 Pro-poor Growth Modelling

In a review of the poverty-growth-inequality relationship by Bourguignon (2004) and Son (2004), the impact of growth on poverty is shown to be a decreasing function of inequality. Building on Kakwani (1993), Kakwani and Pernia (2000) developed an operational pro-poor growth framework. The framework was later updated by Son and Kakwani (2008) as follows. Suppose the degree of poverty P measured by average deprivation is given in terms of poverty line *(z)* and income x by

$$P = \int_0^z p(z,x) f(x) dx \qquad (2.11)$$

Where *p(z,x)* is a general family of additive poverty indices such as Foster et al (1984), and *f(x)* a probability density function. Let *L(p)* be the percentage share of the income of the bottom p percent of the population. For societal mean income $\mu = \int_0^1 x(q)dq$,

$$L(p) = \frac{1}{\mu}\int_0^p x(q)dq \qquad (2.12)$$

Where$L(p) = 0$ when $p = 0$; $L(p) = 1$when $p = 1$; $L(p) \leq 0$ for $0 \leq p \leq 1$; and $\frac{dL(p)}{dp} = \frac{x(p)}{\mu} > 0 \ and \ \frac{d^2L(p)}{dp^2} > 0$: $L(p) = p$ gives perfect equality in income distribution. Based on Atkinson's (1987) relationship between second order dominance and poverty reduction, if $\Delta(\mu L(p)) \geq 0$ for all p, then change in poverty is negative i.e. $\Delta P \leq 0$ for all poverty line and the entire family of poverty measures in (2.11). From the definition of Lorenz curve with mean income of the bottom p percent of the population as: $\mu_p = \frac{1}{p}\int_0^1 x(q)dq$, (2.12) can be rewritten as:

$$L(p) = \frac{\mu_p p}{\mu} \qquad (2.13)$$

Log-linearising (2.13) implies:

$$\ln(\mu_p) = \ln(\mu L(p)) - \ln(p) \tag{2.14}$$

Taking the first difference of (2.14) gives:

$$g(p) = \Delta \ln(\mu l(p)) \tag{2.15}$$

where $g(p) = \Delta \ln(\mu_p)$ is the growth rate of the mean income of the bottom p percent of the population when individuals are ranked by their per capita income, also called the poverty growth curve (Son, 2004). Son and Kakwani (2008) show that if $g(p) > 0$ (< 0), for all p, then poverty has decreased (increased) unambiguously between two periods. They suggest a pro-poor growth rate (γ^*) in terms of the area under the poverty-growth curve:

$$\gamma^* = \int_0^1 g(p)dp = \int_0^1 \Delta \ln(\mu L(p))\, dp$$

$$\text{or } \gamma^* = \gamma - \Delta \ln(G^*) \tag{2.16}$$

where γ is the growth rate of societal mean income and $\Delta \ln(G^*)$ is the rate of change of inequality. If inequality decreases (increases) in a given period, then the pro-poor growth rate is greater (less) than the actual growth rate for that period.

2.6 Conclusion

This chapter aimed at examining the existing literature on production, inequality and poverty reduction while situating the role of energy. The generally agreed theory in literature is that poverty reduction comes from two prerequisites - high and sustained economic growth and reduction of inequality. After reviewing the various issues related to energy and the production process, production functions were briefly explored. The literature on pro-poor growth was then reviewed, looking specifically at the debate on the growth-inequality nexus, and the modelling of pro-poor growth.

It follows from the literature review that there are five unaddressed issues. The first is to control for endogeneity of production/growth and inequality in the pro-poor growth framework. The second is the need for country-specific time series case study for the above growth-inequality link. The third is to control for endogeneity of energy and production in production and poverty frameworks. The fourth is to consider energy types in disaggregation. This can be equivalent to controlling for quality and is necessary because different fuels may have different effects in production, with the possibility of cancelling out when aggregated. The fifth is to look at the effect of various fuels in the different productive sectors of the economy. This is needed because various fuels can also have different effects in different sector.

The question of quality of energy and complementarity or substitutability with other factors of production – capital and labour - would appear to go hand in hand for pro-poor effects. This raises three important issues. If energy and capital are complements, then only access to both will result in effective participation in production. Therefore electrification efforts will not have pro-poor effects without capital availability and vice-versa. If energy (in association with capital) is a substitute to labour (not skills), the increased use of energy and capital in production may result in less employment of unskilled labour[34]. Because technological progress can move capital away from less efficient to more efficient fuels, lack of access to more efficient fuel can be a poverty trap, where the poor are trapped in obsolete technologies.

The contribution of this thesis is to address the above issues. First, the question of substitutability will be investigated in a LAC and ARDL frameworks and then in Variable Elasticity of Substitution (VES) production functions. The results will be used for further specification of capital, labour and energy in empirical frameworks of growth and pro-poor growth. In both frameworks, the possibility of feedback will be controlled by estimating simultaneous equations for production and energy demand on one hand, and production, inequality, energy and poverty on the other. GDP will be disaggregated into sectors in order to detect sector-specific effects and energy will be disaggregated to different fuels to detect the effect of varying quality energy types. These will be done for time series South African data.

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[34] This implies that skill development must go alongside efforts to improve access to efficient forms of energy and capital.

3. ENERGY AND GROWTH IN SOUTH AFRICA: CAUSALITY AND CO-INTEGRATION

3.1 Introduction

This chapter tries to address some of the outstanding issues on energy and economic growth highlighted in the literature. Specifically, it revisits the Vector Auto-Regressive (VAR) approach of causality and co-integration using disaggregated energy types and economic sectors. The purpose is twofold.

First, is to determine the degree and direction of causality between various energy types and real GDP (in aggregate and various productive sectors) on one hand, and between energy and other factors of production (labour and capital) on other hand. This is done in the Lag-Augmented Causality (LAC) framework developed by Toda and Yamamoto (1995) which presents clear advantages over the traditional Granger causality method due to Granger (1969) and Sims (1972).

Second is to assess whether the energy types co-integrate with GDP and other factors of production. Co-integration relationships are investigated using the Auto-Regressive Distributed Lag (ARDL) or bound test approach developed by Pesaran et al (2001). This method has several advantages over the previously applied tests (Engle-Granger, 1987; Johansen, 1988; and Johansen, 1995 and Johansen and Juselius, 1992).

The rest of the chapter is outlined as follows: section two discusses the details of the methodology and data used. In section three, the results and interpretations are presented while section four concludes the chapter.

3.2 Methodology

The review of the methodology used in this chapter follows a twofold purpose. First is to investigate causality and second to analyse co-integration relationships between GDP and the various energy types.

3.2.1 Causality

The notion of Granger causality, after Granger (1969) and Sims (1972) is based on the premise that if *x* causes *y*, then a change in *x* will be followed by a change in *y*. A simple functional form for the determination of causal relationship (in the Granger sense) between variables X and Y is as follows:

$$\begin{aligned} X_t &= \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} X_{t-i} + \sum_{i=1}^{m} \beta_{1i} Y_{t-i} + \varepsilon_{xt} \\ Y_t &= \beta_0 + \sum_{i=1}^{m} \alpha_{2i} X_{t-i} + \sum_{i=1}^{m} \beta_{2i} Y_{t-i} + \varepsilon_{yt} \end{aligned} \qquad (3.01)$$

where ε_x and ε_y are uncorrelated error terms, *m* is maximum number of lags, and α and β are parameters. This is a Wald test of restrictions on α_{2i} and β_{1i} respectively for *X* causing *Y* and vice versa. One of the major setbacks of this test is the difficulty of its applicability in situations where variables are integrated or co-integrated. It has been shown (Park and Phillips, 1989 and Sims et al 1990) that conventional F-statistics does not have the standard distribution and therefore not applicable for levels VAR. For a known order of integration with no co-integration, an appropriate order difference of the VAR may be estimated. In cases of co-integrated series, an error correction model (ECM) can be estimated. However, unit root tests are known to under-perform especially in the presence of structural breaks (Toda and Yamamoto, 1995). Existing test for co-integration (particularly the Johansen-type ECM) is not quite reliable since it has been shown to be very sensitive to values of the nuisance parameter in finite samples (Reimers, 1992 and Toda, 1995). Besides, the ECM-based Granger test involves non-linear parametric restrictions implying that such test may be affected by size distortions due to rank deficiency (Toda and Phillips, 1993).

Toda and Yamamoto (1995) proposed a version of Granger causality which fits level VAR, reducing the risk of wrongful identification of integration order. This approach relies on artificial augmentation of the correct lag order (*m*) by the maximum order of integration (d_{max}) of the underlying series.

$$\begin{aligned} X_t &= \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} X_{t-i} + \sum_{j=m+1}^{d_{\max}} \alpha_{1j} X_{t-j} + \sum_{i=1}^{m} \beta_{1i} Y_{t-i} + \sum_{j=m+1}^{d_{\max}} \beta_{1j} Y_{t-j} + \varepsilon_{xt} \\ Y_t &= \beta_0 + \sum_{i=1}^{m} \alpha_{2i} X_{t-i} + \sum_{j=m+1}^{d_{\max}} \alpha_{2j} X_{t-j} + \sum_{i=1}^{m} \beta_{2i} Y_{t-i} + \sum_{j=m+1}^{d_{\max}} \beta_{2j} Y_{t-j} + \varepsilon_{yt} \end{aligned} \qquad (3.02)$$

The main issues about the estimation of the above system are the determination of the maximum order of integration (d_{max}) and the true lag length (m).

3.2.1.1 Order of Integration

Determining the order of integration of series consists of analysing whether the Data Generating Process (DGP) is stationary or not. Maddala and Kim (1998) give an overview of the various statistical tests for stationarity analysis that have been proposed in literature. The various tests have their strengths and weaknesses under different conditions. The most easily applied and widely used of them are the Augmented Dickey-Fuller (ADF) test after Dickey and Fuller (1979) and the Phillips-Perron (PP) test, after Phillips and Perron (1988).

The ADF test is augmented from an earlier version known simply as Dickey Fuller test. Suppose for example, a first order Auto-Regressive AR(1) process of y:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \varepsilon_t \qquad (3.03)$$

where α are parameters and ε a white noise. The series y is said to be stationary if it does not possess a unit root, i.e. the characteristic root of the process α_1: $-1<\alpha_1<1$, and non-stationary if $\alpha_1=1$. By subtracting y_{t-1} from (3.03), the basic test is carried on:

$$\Delta y_t = \alpha_0 + \rho y_{t-1} + \varepsilon_t \qquad (3.03a)$$

where Δ is difference operator and $\rho = \alpha_1-1$ and the test consist of testing the null hypothesis $H_0 : \rho = 0$ against the alternative $H_1 : \rho < 0$[35]. ADF parametrically corrects for higher order AR process by assuming an AR(p):

$$\Delta y_t = \alpha_0 + \rho y_{t-1} + \beta_1 \Delta y_{t-1} + \beta_2 \Delta y_{t-2} + \ldots + \beta_{p-1} \Delta y_{t-p+1} + \varepsilon_t \qquad (3.04)$$

Like Dickey and Fuller (1979), the Phillips and Perron (1988) test relies on the basic AR(1) specification of (3.03a). The Difference arises from the fact that while ADF parametrically corrects for higher order serial correlation, PP applies a non-parametric correction on the t-statistics of the characteristic root of the AR(1) process ρ to account for serial correlation in the error term ε. This method makes PP test more robust to heteroskedasticity and unknown order autocorrelation. Generally, PP test is viewed as more reliable because contrary to ADF, it is known to be robust to a nuisance parameter and it is not affected by weak dependence and heterogeneity of sample data (Katafono, 2000).

3.2.1.2 Lag length Selection

Selection of the appropriate lag[36] order is another crucial issue in VAR analysis. Information criteria are a standard tool for model selection, specifically, the determination of the appropriate lag length (Lutkepohl, 1991). Information criteria compare the gains (in terms of reduction of residual variance) of using a more generous lag order against the cost of loss of degrees of freedom in a regression model. Suppose an estimated regression variance $\hat{\sigma}^2$ which depends on lag order of the model p, sample size and number of usable observations T, and a loss function depending on p and T. The Information Criteria (IC) which must be minimised is given by:

$$IC(p) = T \ln \hat{\sigma}^2 (p) + p[f(T)] \qquad (3.05)$$

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[35] Only the one sided alternative is specified since explosive series are not conceivable in economic related processes.

[36] It is important to make a little distinction between lag length for VAR (or VECM) and lag length for unit root test. The former is done so as to eliminate autocorrelation in the error term of the entire model while the latter is selected so as to eliminate autocorrelation in variable-specific error terms.

Various choice of *f(T)* give different information criteria. There are three most prominent ones in literature. The Akaike Information Criterions (AIC) results when $f(T) = 2,$ i.e.,

$$AIC = T\ln\hat{\sigma}^2(p) + 2p \tag{3.05a}$$

The Schwarz (Bayesian) Information Criterion (SBIC) is obtained by taking $f(T) = \ln(T),$

$$SBIC = T\ln\hat{\sigma}^2(p) + p\ln(T) \tag{3.05b}$$

Taking $f(T) = \ln(\ln T)$ results in the Hannan-Quinn Information Criterion (HQIC):

$$HQIC = T\ln\hat{\sigma}^2(p) + p\ln(\ln T) \tag{3.05c}$$

In cases where the information criteria disagree, the question arises as to which one to use. While SBIC adopts a stiffer penalty or loss term than AIC, HQIC lies between both. Therefore the trade-off is between the extremes. It has been shown that as $T \to \infty,$ AIC tend to positively overestimate the true lag length than SBIC while on average, for different samples of a given population, the variation in the selected model orders will be greater for SBIC than AIC (Brooks, 2008: 233). Therefore, in finite samples, the AIC might be considered.

3.2.2 Co-integration

When variables are non-stationary, differencing is often applied to achieve stationarity. If this is achieved after first differencing, the variable is said to be integrated of order one I(1) and so on. However, the cost of differencing to is the loss of information about the long-run relationship. Engle and Granger (1987) show that a linear combination of two or more non-stationary series may be stationary (i.e. series are co-integrated). The co-integrating relationship between the underlying variables is their long-run expression.

The commonly used method to determine the long-run relationship is Johansen (1988; 1991 and1995) test based on restrictions on the VAR by co-integration of the series. A VAR that incorporates such long-run equilibrium relationship among variables is known as Vector Error Correction Model (VECM). Suppose an m-order VAR as follows:

$$Y_t = \sum_{i=1}^{m-1} A_i Y_{t-i} + BX_t + \varepsilon_t \qquad (3.06a),$$

where Y_t and X_t are vectors of I(1) and deterministic variables respectively, A and B are vectors of parameters. The corresponding VECM can be specified as follows:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{m-1} \Gamma_i \Delta Y_{t-i} + BX_t + \varepsilon_t \qquad (3.06b),$$

with $\Pi = \sum_{i=1}^{m} A_i - I$, the long-run multiplier matrix and $\Gamma = -\sum_{j=i+1}^{m} A_j$ the short-run response matrix, and I is an identity matrix. According to Granger representation theorem, if the matrix Π has reduced rank, i.e. the rank r<k variables in the vector Y_t, then k x r matrices α and β exist such that $\beta' Y_t$ is stationary and $\Pi = \alpha\beta'$. The rank of Π also represents the relations, each column of β gives a co-integrating vector, while α is known as the adjustment[37] parameter. Johansen (1995) suggests testing for co-integration by estimating an unrestricted Π, then imposing the restrictions of reduced rank and testing by way of Likelihood Ratio (LR).

However, Johansen's method requires that all underlying series candidate for co-integration analysis must be integrated of order one (I(1)). In practise, this is not often the case. For instance in investigating the relationship between energy and other factors of production, capital formation is often I(2). In such case like any other where the order of integration is above one, the Johansen-type test is not suitable (Wolde-Rufael, 2005). Further, given that unit root and co-integration tests are very low against the alternative hypothesis of trend

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[37] In case of any shock, causing deviation of the system from the long-run equilibrium $\beta' Y_t$, α tells how fast the system returns to this equilibrium.

stationarity for unit root and no co-integration for co-integration test, and particularly, Johansen's co-integration test is sensitive to the value of nuisance parameters in small samples (Toda, 1995), the robustness of such test can be significantly attenuated.

Pesaran et al, (2001) developed an Autoregressive Distributed Lag (ARDL) approach to long-run relationship among variables. The basic ARDL framework in error correction (ECM) is as follows:

$$\Delta Y_t = C_0 + \Pi_{yy} Y_{t-1} + \Pi_{yx} X_{t-1} + \sum_{i=1}^{m} \Gamma_{y\,i} \Delta Y_{t-i} + \sum_{i=1}^{m} \Gamma_{x\,i} \Delta X_{t-i} + \varepsilon_t \qquad (3.06c)$$

The methodology of Pesaran et al (2001) consists of the following: (1) Estimating the unrestricted VECM of (3.06c); (2) Testing the hypothesis of joint significance of the restriction of all the parameter elements of the vector Π to zero (no co-integration) against non-zero (co-integration) i.e. $H_0 : \Pi = 0'$ against $H_1 : \Pi \neq 0'$.

The test statistics underlying this procedure is the usual Wald or F-statistics used in conditional unrestricted error correction model for lag level significance test such as the ADF case in (3.04). However, under the null hypothesis of no co-integration between the included variables, the asymptotic distribution of the F-test is non-standard. Pesaran et al (2001) have derived two sets of critical values: one which is applicable when all the series are I(0) and the other when all are I(1). These two sets cover all possible classifications of series into I(0), I(1) or mutually co-integrated. If the computed F-statistic lies above the both critical bounds, then conclusively, the null hypothesis of no co-integration is rejected irrespective of whether the series are I(0) or I(1). Alternatively, if it lies below the lower critical bound, then the hypothesis of level relationship is accepted irrespective of order of integration of series. In contrast, when the F-statistic lies within the upper and the lower bounds, a conclusive inference will only be made if the integration order of the underlying series is known.

The ARDL co-integration procedure has several advantages over the previously applied tests (Engle-Granger, 1987; Johansen, 1988; and Johansen, 1995 and Johansen and Juselius, 1992). First, the ARDL procedure can be applied whether the regressors are I(0), I(1) and/or mutually integrated. This implies that it can avoid unit root pre-testing since it does not need the classification of variables into 1(1) or 1(0). Second, while the Johansen co-integration techniques require large data samples for validity, the ARDL procedure can be more suitably applied to determine the co-integration relation in small samples. Third, while it is not possible to use conventional co-integration procedures with different optimal lags in previous methods, the ARDL procedure allows such. Finally, the ARDL procedure employs a single reduced form equation, while the traditional co-integration procedures estimate the long-run relationships within a context of system equations. These advantages give the approach of Pesaran et al (2001) more ease of computation and robustness, which makes it suitable for application in this work.

3.2.3 Variables and Data

For this chapter, annual energy data from the International Energy Agency spanning 1971 to 2005 are used. Complementary energy data for 2006 is sourced from the South African Department of Minerals and Energy. Productive sectors analysed are whole economy, manufacturing, agriculture and mining. For the whole economy, energy types available are total energy, electricity, kerosene, diesel, gasoline, gas and coal. They are total energy, electricity, diesel, gas, kerosene and coal for manufacturing; total energy, electricity, diesel, kerosene and coal for agriculture; and total energy, electricity, liquid petroleum and coal for mining. All energy types are measured in Tera Joules (TJ). Energy types are considered in net of uses in the energy sector[38].

GDP and capital formation (both in million at constant 2000 ZAR) are from the South African Reserve Bank (SARB) dataset. The SARB reports indices of

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[38] For example, coal is taken net that used in electricity and petroleum sectors

total private sector, manufacturing and mining employments (from 1971 to 2006) at 2000 base year. Statistics South Africa (STATSSA, 2007b) provides total and sector-wise real employment figures only from 2000 to 2006. These values are used together with the SARB indices to generate real private sector, manufacturing and mining employment data (in thousand persons)[39]. The SARB employment data for the entire economy does not include agriculture and the informal sector so total labour force series are taken from World Development Indicators (2008). Table 3.1 presents the summary statistic of variables considered in this chapter.

Table 3.1: Descriptive Statistics of Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Whole Economy					
GDP	36	7.62E+05	1.70E+05	4.96E+05	1.18E+06
capital	36	1.29E+05	2.78E+04	9.39E+04	2.21E+05
Labour	36	1.42E+07	3.61E+06	9.40E+06	2.01E+07
Total energy	36	2.01E+06	3.59E+05	1.38E+06	2.72E+06
electricity	36	4.36E+05	1.64E+05	1.68E+05	7.77E+05
Kerosene	36	6.29E+04	2.65E+04	3.62E+04	1.07E+05
Gasoline	36	2.63E+05	7.64E+04	1.56E+05	3.87E+05
Diesel	36	1.95E+05	4.43E+04	1.11E+05	3.20E+05
Gas	36	9.51E+04	1.17E+04	7.02E+04	1.35E+05
Coal	36	6.27E+05	5.41E+04	5.23E+05	7.30E+05
Manufacturing Sector					
GDP	36	1.33E+05	2.73E+04	7.90E+04	1.92E+05
Capital	36	2.47E+04	7.88E+03	1.12E+04	4.49E+04
Labour	36	1.79E+03	1.70E+02	1.46E+03	2.05E+03
Energy	36	8.44E+05	1.01E+05	6.00E+05	1.07E+06
Electricity	36	2.66E+05	8.61E+04	1.17E+05	4.20E+05
Kerosene	36	3.14E+03	2.29E+03	5.99E+02	1.11E+04
Diesel	36	2.73E+04	5.46E+03	1.74E+04	3.60E+04
Gas	36	8.73E+04	1.22E+04	6.50E+04	1.21E+05
Coal	36	3.82E+05	7.89E+04	2.36E+05	5.44E+05
Agricultural Sector					
Value Added	36	3.27E+03	5.83E+02	2.30E+03	4.21E+03
Capital	36	5.88E+03	1.90E+03	3.35E+03	1.15E+04
Labour	36	8.62E+02	2.23E+02	3.99E+02	1.15E+03
Energy	36	5.72E+04	1.53E+04	3.61E+04	8.56E+04
Electricity	36	1.14E+04	6.62E+03	2.27E+03	2.22E+04
Kerosene	36	1.47E+03	1.05E+03	3.51E+02	3.07E+03
Diesel	36	3.99E+04	5.60E+03	3.29E+04	5.45E+04
Coal	36	2.92E+03	2.07E+03	8.19E+01	8.16E+03

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[39] Assuming that the SARB private sector employment data depicts the actual variations in the series.

Mining Sector					
GDP	36	6.68E+04	2.71E+03	6.15E+04	7.46E+04
Capital	36	1.20E+04	3.53E+03	3.97E+03	1.78E+04
Labour	36	8.62E+02	2.23E+02	3.99E+02	1.15E+03
Energy	36	1.50E+05	3.82E+04	8.11E+04	2.19E+05
Electricity	36	9.67E+04	2.23E+04	4.99E+04	1.25E+05
Liquid petroleum	36	1.62E+04	5.86E+03	1.12E+04	3.24E+04
Coal	36	2.61E+04	1.25E+04	3.96E+03	5.77E+04

3.3 Results and Interpretation

This section presents the results and interpretation of the analysis done in this chapter. Causality results are presented first, followed by co-integration results for the whole economy, manufacturing, agricultural and mining sectors. The results of the unit root test that helped to determine the order of integration are in the Tables A1 to A4 of appendix.

3.3.1 Causality Results

Tables 3.2 and 3.3 respectively report the long-run and short-run results of multivariate optimal lag length (LL) for both Akaike (AIC) and Schwarz Bayesian (SB) information criteria. Both tables also present the respective probability values of Wald test of time trend in the various causality equations (under the t-columns).

Table 3.2: Long-Run Multivariate LL and Significance of Time Trend

	Whole Economy			Manufacturing			Agriculture			Mining		
	AIC	SB	t	AIC	SB	t	AIC	SB	t	AIC	SB	t
Energy	2	1	0.001	2	1	0.000	2	1	0.000	3	1	0.000
Coal	2	1	0.000	3	1	0.000	2	1	0.098	3	1	0.000
Gasoline	2	1	0.000									
Diesel	2	1	0.000	3	1	0.000	2	1	0.079	LP2	1	0.000
Electricity	3	1	0.000	3	1	0.000	2	1	0.120	3	1	0.279
Kerosene	3	1	0.000	3	1	0.000	2	1	0.005	-	-	-
Gas	3	1	0.000	3	1	0.000	-	-	-	-	-	-

Table 3.3: Short-Run Multivariate L L and Significance of Time Trend

	Whole Economy			Manufacturing			Agriculture			Mining		
	AIC	SB	t	AIC	SB	t	AIC	SB	t	AIC	SB	t
Energy	1	0	0.362	0	0	0.055	0	0	0.719	2	0	0.048
Coal	1	0	0.491	0	0	0.014	0	0	0.731	2	0	.0143
Gasoline	0	0	0.324	-	-	-	-	-	-	-	-	-
Diesel	0	0	0.218	0	0	0.031	3	0	0.000	LP 1	0	0.352
Electricity	1	0	0.009	0	0	0.014	0	0	0.227	0	0	0.000
Kerosene	1	0	0.086	0	0	0.046	0	0	0.553	-	-	-
Gas	1	0	0.044	0	0	0.039	-	-	-	-	-	-

Note: values under the t-columns are probabilities that the time trend t is not significant

Models in which the trend variable is significantly different from zero are estimated with trend. This is the case for long-run models of the whole economy, manufacturing, agriculture and mining (except electricity for both). Trended models are specified for all energy types in manufacturing; electricity, kerosene and gas for the whole economy; diesel in agriculture; and total energy and electricity in mining. The d_{max} is the maximal integration order of the variables in each model, (generally one, according to the unit root results in the Tables A1 to A4 in Appendix). The SB information criterion is used for optimal LL for reasons of reducing lost of degree of freedom. These results are used to specify the appropriate long and short-run causality frameworks.

3.3.1.1 Long-run Causality Results

The null hypothesis that there is no causal relationship (in either direction) between energy, output and other inputs is tested and the results reported in Table 3.4. The analysis is done in a multivariate framework. The first rows present the significance probability for causality running from energy to GDP (*Y*), capital (*K*) and labour *(L*). The second set of rows shows causality results from *Y*, *K* and L to energy respectively. The figures are the significance probabilities.

Table 3.4: Long-run Causality Results

	Whole Economy			Manufacturing			Agriculture			Mining		
	Y	K	L	Y	K	L	Y	K	L	Y	K	L
From E to Y, K, L												
Energy	**0.057**	**0.001**	0.309	0.458	**0.011**	0.712	**0.091**	0.459	**0.000**	**0.001**	**0.001**	**0.097**
Coal	0.679	**0.010**	0.219	**0.069**	**0.000**	0.339	**0.016**	0.269	**0.038**	**0.098**	0.643	0.397
Gasoline	**0.001**	**0.067**	**0.019**	-	-	-	-	-	-	**LP0.023**	**0.003**	**0.022**
Diesel	0.754	0.456	0.341	**0.092**	**0.004**	0.755	**0.031**	0.122	**0.000**	-	-	-
Electricity	**0.060**	**0.015**	**0.021**	**0.048**	**0.012**	0.437	0.104	0.112	**0.000**	**0.055**	**0.000**	**0.067**
Kerosene	**0.001**	0.105	**0.085**	**0.085**	0.664	**0.060**	**0.000**	0.174	0.135	-	-	-
Gas	0.183	**0.070**	**0.039**	0.150	**0.000**	**0.001**	-	-	-	-	-	-
From Y, K, L to E												
Energy	0.809	0.334	**0.062**	**0.007**	0.110	**0.026**	**0.000**	0.175	**0.002**	**0.034**	0.596	**0.002**
Coal	0.771	0.182	**0.003**	**0.001**	0.266	**0.001**	0.334	**0.079**	0.528	**0.005**	**0.701**	**0.006**
Gasoline	0.286	0.610	0.615	-	-	-	-	-	-	**lp0.034**	**0.085**	0.336
Diesel	0.506	0.360	**0.028**	**0.000**	**0.088**	**0.071**	**0.000**	**0.006**	**0.022**	-	-	-
Electricity	0.856	0.652	**0.005**	**0.000**	**0.000**	**0.000**	0.138	0.639	0.675	0.489	0.202	0.116
Kerosene	**0.004**	**0.034**	**0.104**	0.144	0.191	**0.097**	**0.002**	0.401	0.337	-	-	-
Gas	**0.062**	**0.049**	**0.000**	0.220	**0.093**	**0.070**	-	-	-	-	-	-

Note: figures are probabilities of rejection of causality. Values in bold are significant at 10% level and less.

In the whole economy, the long-run results show causality running from aggregate energy use to GDP, capital and labour. Electricity causes GDP, capital and labour, but feedback is only for labour. Further, there is no evidence of causality between GDP and coal and diesel. Gas and kerosene, each with GDP are mutually causing each other. There is causality from total energy (coal, gasoline and electricity) to capital formation, without feedback, while no evidence of causality exist between diesel and capital formation. There is one way causality from capital to kerosene and mutual causality between gas and capital formation. Causality runs from labour to total energy, coal and diesel (but from kerosene to labour) without feedback. Gas and labour are mutually causative.

In the manufacturing sector, causality runs from manufacturing GDP to total energy and from kerosene to GDP. There is mutual causality for coal, diesel and electricity each with manufacturing GDP, but no causality between gas and manufacturing GDP. There is mutual causality between diesel, (electricity and gas) and capital. Unidirectional causality runs from total energy and coal use in manufacturing to capital and no causality between capital and kerosene.

Causality runs from manufacturing labour to all the energy types used in the sector, but only kerosene and gas show feedback

In the agricultural sector, there is bidirectional causality between value added and total energy (and diesel and kerosene). Unidirectional causality runs from coal to value added and no causality with electricity. Only one direction causality runs from coal and diesel to agricultural capital formation. Total energy use and all energy types (except kerosene) cause labour in agriculture, with total energy and diesel showing feedback.

Total mining energy and all energy types (except electricity) show bidirectional causality with mining GDP. There is bidirectional causality between liquid petroleum and capital formation, unidirectional from total energy and electricity to capital formation and none for coal and capital. Mutual causality occurs between mining labour and total energy use and one direction from labour to coal.

3.3.1.2 Short-run Causality Results

In Table 3.5, the multivariate short-run causality results are presented. The table is organised in the same order as Table 3.4 and the figures are the respective significance probabilities. The short-run analyses involve the differencing of the variables in the equations of model (3.02). Differencing a series eliminates long-run aspects to the benefit of the short-run.

Table 3.5: Short-run Causality Results

	Whole Economy			Manufacturing			Agriculture			Mining		
	Y	K	L	Y	K	L	Y	K	L	Y	K	L
From E to Y, K, L												
Energy	0.168	**0.001**	0.129	0.321	0.285	0.579	0.139	0.172	**0.043**	0.448	0.357	0.640
Coal	0.169	**0.000**	**0.067**	0.487	0.339	0.335	0.681	0.318	**0.066**	0.498	0.633	0.643
Gasoline	**0.060**	0.149	0.200	-	-	-	-	-	-	Lp0.832	**0.078**	0.816
Diesel	0.702	0.161	0.883	0.315	**0.059**	0.871	**0.009**	0.784	0.141	-	-	-
Electricity	0.105	0.105	0.986	0.959	0.723	0.253	0.644	0.219	**0.018**	0.798	0.173	**0.022**
Kerosene	0.317	0.306	0.128	0.850	0.361	0.581	0.658	**0.061**	0.236	-	-	-
Gas	0.934	0.632	0.983	0.580	0.425	**0.009**	-	-	-	-	-	-
From Y, K, L to E												
Energy	0.929	**0.043**	**0.056**	0.122	0.279	0.172	**0.001**	0.249	0.919	0.126	0.710	**0.016**
Coal	**0.052**	0.111	**0.031**	**0.004**	0.999	**0.022**	0.482	0.138	0.143	**0.060**	0.448	**0.001**
Gasoline	0.277	0.385	0.588	-	-	-	-	-	-	lp0.523	**0.060**	0.794
Diesel	0.879	0.261	0.447	0.109	0.114	0.723	**0.000**	**0.000**	0.542	-	-	-
Electricity	0.990	0.326	**0.005**	0.297	**0.094**	**0.095**	0.319	0.429	0.744	0.456	0.663	0.269
Kerosene	**0.003**	**0.011**	0.596	**0.086**	**0.052**	0.838	**0.002**	0.404	0.434	-	-	-
Gas	**0.059**	0.433	0.875	0.737	0.838	0.103	-	-	-	-	-	-

Note: figures are probabilities of rejection of causality. Values in bold are significant

The whole economy shows unidirectional causality from gasoline to GDP, GDP to coal, kerosene and gas. There is mutual causation for total energy and capital formation, and unidirectional from coal to capital and capital to kerosene. Labour causes total energy, electricity and coal, but only coal shows feedback effect.

In the manufacturing sector, all causality detected are unidirectional, running from GDP to coal and kerosene; capital to electricity and kerosene; diesel to capital; gas to labour and labour to coal and electricity. In the agricultural sector, there is short-run bidirectional causality between diesel and agricultural value added. The rest are unidirectional, from agricultural value added to total energy and kerosene; from kerosene to agricultural capital formation and capital to diesel; total energy, coal and electricity to labour. In the mining sector, short-run mutual causality is between capital formation and liquid petroleum. One-way causality runs from mining GDP to coal, labour to total mining energy and coal use, and electricity to labour.

3.3.2 Co-integration Results

This paragraph presents the results of bound test to determine whether or not there is co-integration between energy and GDP and energy and other factors of production – labour and capital – for the whole economy, manufacturing, agriculture and mining. The analysis is also done with disaggregated energy types. The F-statistics are reported after the long run results for each energy type under the various sectors. The F-statistic is non-standard, so the critical values considered are those tabulated in Pesaran et al (2001, pp. 300-301). The level and ECM results are also reported. Multivariate frameworks are estimated for energy types and GDP. Relationships between energy types and factors of production (capital and labour) in the various sectors of the economy are investigated in a bivariate framework.

3.3.1.3 Whole Economy

Table 3.6 shows the multivariate bound test, level and ECM results for the whole economy.

Table 3.6: Multivariate Bound Test Results for Total GDP[40]

	Normalised on Energy			Normalised on Y					
	Ga	Ker	Gas	Energy	Coal	Ga	El	Ker	Gas
Long-run relationship GDP									
Y_t / E_t	1.731^a	-4.403^a	1.908^b	0.082^a	-1.088^a	-0.139^b	0.196^a	-0.115^a	0.092^b
K_t	-0.457^a	1.135^a	-0.294^c	0.048^b	0.885^a	0.138^a	0.191^a	0.213^a	0.164^a
L_t	-0.369^a	-0.177	0.268^c	0.161^b	0.296^c	0.128^a	0.094^a	0.052^c	0.096^b
C	-3.83^a	-168.4^a	260.0^a	-3.498^a	16.23^a	-29.82^a	-11.31^a	-30.94^a	-24.80^a
t	-	0.144^a	-0.036^a	-	-	-	0.010^a	0.022^a	0.018^a
F-stat	**4.23^c**	**4.14^c**	**4.58^c**	**4.39^b**	**5.83^b**	**6.44^b**	**3.38^c**	**6.35^a**	**6.50^a**
ECM-GDP									
$\Delta Y_t / \Delta E_t$	-0.452	-1.096	1.605^c	0.133	-0.015	-0.036	0.134	-0.093^b	0.039
ΔY_{t-1}	-1.522^b	-1.657^b	0.669	-0.075	-0.150	0.154	0.199	0.104	0.090
ΔK_t	0.378^c	0.590^b	-0.116	0.162^b	0.142^b	0.131^b	0.158^a	0.203^a	0.138^b
ΔK_{t-1}	0.276	0.357	-0.178	0.004	0.003	0.025	-0.022	0.015	0.011
ΔK_{t-2}	0.064	-0.094	0.121	-0.049	-0.080	-0.063	-0.059	-0.060	-0.074
ΔL_t	-0.208	-0.143	-0.113	0.118^c	0.131^b	0.092^c	0.140^b	0.074	0.116^b
ΔL_{t-1}	0.105	0.040	-0.126	-0.037	-0.045	-0.055	-0.038	-0.036	-0.025

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[40] The energy types for which bound test and /or ECM term does not reveal any level relationship are excluded from the result tables. The values are available on request.

ECT_{t-1}	-0.370^{b}	-0.286^{c}	-0.752^{a}	-0.151^{b}	-0.467^{b}	-0.586^{a}	-0.695^{a}	-0.748^{b}	-0.454^{b}
C	0.056^{b}	0.080^{b}	-0.030	0.019^{a}	0.018^{a}	0.019^{a}	0.010	0.021^{a}	0.018^{a}
$\overline{R}^{2}$	**0.51**	**0.20**	**0.26**	**0.56**	**0.56**	**0.62**	**0.64**	**0.61**	**0.57**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively. Non-significant equations have been dropped, this explains why total energy, coal and kerosene does not feature on the left hand-side of the Table.

The F-test suggests that there is co-integration between total energy and GDP, but none between diesel and the latter. The F-statistics for electricity fell between the I(0) and I(1) critical bounds. In such case, the significance of the ECM term is used for inference. This indeed suggests that electricity has significant level relationship with GDP when normalised on GDP. Other energy types are revealed to have significant co-integration relationship with national GDP. When GDP is normalised on, coal, gasoline and kerosene each show negative long and short-run relationship with GDP (but short-run relation is significant only for kerosene). The disequilibrium adjustment rates are 47%, 59% and 75% respectively. Gas use shows a significant and positive level effect on GDP with disequilibrium adjustment rate of 45%. When energy is the dependent variable, GDP exhibits significant positive level relationships with gasoline and gas and negative with kerosene. The respective adjustment rates are 37%, 75% and 29%. The case of gasoline suggests that in the long-run, while economic growth increases gasoline consumption, such increase has a slow down effect on production.

The relationship between energy and other factors of production is analysed at the bivariate level. Tables 3.7 and 3.8 present the bivariate results for capital and labour respectively.

Table 3.7: Bivariate Bound Test Results for Total Capital[41]

	Normalised on Energy					
	Energy	Coal	Ga	Die	El	Gas
Long-run relationship-Capital						
Y_t	0.137^a	-0.201^a	-0.264^a	0.438^a	1.301^a	0.220^b
C	-16.67^a	10.98^a	-45.33^a	-20.86^b	-2.37^a	-8.866^a
t	-	-	0.031^a	0.014^a	-	-
F-stat	**5.66^a**	**3.54**	**5.50^b**	**5.51^a**	**7.01^a**	**3.45^c**
ECM-Capital						
ΔK_t	0.183^b	0.425^b	0.014	0.358^a	0.158^b	0.170
ΔK_{t-1}	0.052	0.035	0.115	-0.072	-0.023	-0.084
ΔK_{t-2}	-0.093	-0.045	0.020	-0.022	-0.113	-0.056
ECT_{t-1}	-0.36^b	-0.293^b	-0.393^b	-0.270^b	-0.053^a	-0.408^b
C	0.015^a	-0.006	0.020^b	0.021^a	0.042^a	0.012
$\overline{R}^2$	**0.37**	**0.31**	**0.24**	**0.38**	**0.33**	**0.15**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

When normalised on capital, no energy type is shown to have significant co-integration relation with total capital formation. However, normalising on energy reveals that total energy use, diesel, electricity and gas have significant long-run relationship with capital. Negative level relationship is revealed between coal (and gasoline) respectively and capital. All short-run relationships are positive but non-significant for gasoline and gas. The disequilibrium adjustment rates range from 5.3% (for electricity) to 40.8% (for gas). No relationship was detected between capital and kerosene.

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[41] The energy types for which bound test and /or ECM term does not reveal any level relationship are excluded from the result tables. The values are available on request.

Table 3.8: Bivariate Bound Test Results for Total Labour

	Normalised on Energy				Normalised on L			
	Coal	Die	El	Gas	Ga	Die	Ker	Gas
Long-run relationship-Labour								
Y_t	0.225^{b}	0.387^{a}	1.498^{a}	0.560^{a}	-0.751^{b}	0.965^{a}	-0.445^{a}	0.733^{a}
C	18.35^{a}	-21.22^{a}	5.761^{a}	15.24^{a}	-44.28^{a}	12.58^{c}	-39.31^{a}	-18.61^{a}
t		0.016^{a}		-0.003^{c}	0.029^{a}	-0.010^{b}	0.025^{a}	0.008^{a}
F-stat	**3.98**	**4.22^{b}**	**30.83^{a}**	**6.35^{b}**	**5.22^{b}**	**2.50^{a}**	**1.68**	**3.75**
ECM-Labour								
ΔL_t	0.485^{b}	0.292^{b}	0.212^{b}	0.161	-0.16	0.407^{c}	-0.103	0.108
ΔL_{t-1}	0.045	0.023	-0.008	-0.091	0.628^{a}	0.561^{a}	0.681^{a}	0.725^{a}
ECT_{t-1}	-0.328^{b}	-0.224^{c}	-0.040^{a}	-0.684^{a}	-0.227^{b}	-0.185^{b}	-0.184^{c}	-0.269^{b}
C	-0.006	0.022^{a}	0.039^{a}	0.015	0.007	-0.002	0.011	0.004
$\overline{R}^2$	**0.26**	**0.17**	**0.30**	**0.32**	**0.37**	**0.37**	**0.29**	**0.31**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

Although the F-statistic does not reject the hypothesis of no level relationship between energy and labour, the error correction term is not significant, implying no level relationship. The results suggest the uses of gasoline and kerosene are associated with less employment in the long-run. Diesel and gas use have positive level effect on employment. When normalised on energy, labour shows positive and significant co-integration effect with coal, diesel, electricity and gas.

3.3.1.4 Manufacturing Sector

In the manufacturing sector, bound test, long-run and ECM formulations in ARDL are estimated for total manufacturing energy, coal, diesel, electricity, kerosene and gas. Each model is estimated first normalising on energy, then on GDP (capital and labour). Tables 3.9 to 3.11 respectively give the bound test and ARDL results for energy types and GDP (in multivariate framework), capital and labour (in bivariate frameworks) for the manufacturing sector.

Table 3.9: Multivariate Bound Test Results for Manufacturing GDP

	Normalised on Energy	Normalised on Y					
	Diesel	E	Coal	Die	El	Ker	Gas
Long-run relationship GDP							
E_t	0.852^a	0.430^a	0.250^a	0.300^a	0.507^a	-0.05^a	0.259^a
K_t	0.019	0.053	0.052	0.080^b	0.120^a	0.131^a	0.082^b
L_t	0.302	0.285^a	0.380^a	0.253^a	0.079	0.561^a	0.299^a
C	-1.441	-26.83^a	-34.12^a	-18.14^a	3.896^a	-21.89^a	-27.92^a
t	-	0.016^a	0.020^a	0.013^a	-	0.015^a	0.017^a
F-stat	**8.79**	**4.63**	**4.44**	**9.27**	**7.22**	**4.85**	**5.58**
ECM-GDP							
ΔY_t	0.877	0.169^b	0.083^c	0.131^b	0.121	-0.019^c	0.127^b
ΔK_t	-0.009	0.009^c	0.004	0.018	0.029	0.025	0.011
ΔK_{t-1}	0.020	0.104^b	0.117^b	0.096^b	0.102^b	0.127^b	0.108^b
ΔK_{t-2}	0.141	-0.130^a	-0.141^a	-0.149^a	-0.131^a	-0.146^a	-0.138^a
ΔL_t	0.231	0.504^a	0.502^a	0.620^a	0.625^a	0.595^a	0.585^a
ECT_{t-1}	-0.685^a	-0.317^b	-0.322^b	-0.392^a	-0.395^a	-0.220	-0.239^b
C	-0.011	0.020^a	0.022^a	0.021^a	0.017^b	0.021^a	0.021^a
$\bar{R}^2$	**0.33**	**0.58**	**0.54**	**0.61**	**0.62**	**0.51**	**0.58**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

When normalised on GDP, all energy types (except kerosene) in the manufacturing sector have significant positive co-integration relationship with manufacturing GDP. In line with the results of the whole economy, kerosene has a negative short and long-run relationship with manufacturing GDP. The equilibrium correction rates vary from 22% to 39.5% in absolute terms. When normalised on energy, positive level relationship is shown only for diesel, with a higher coefficient than when normalised on GDP.

Table 3.10: Bivariate Bound Test Results for Manufacturing Capital

	Normalised on Energy			Normalised on K
	Energy	Die	El	Coal
Long-run relationship-Capital				
K_t	0.194^a	0.410^a	0.705^a	0.424^b
C	11.69^a	6.070^a	5.34^a	-46.66^a
t	-	-	-	0.026^a
F-stat	**3.63**	**2.38**	**3.57**	**3.06**
ECM-Capital				
ΔK_t	-0.003	0.125	-0.021	0.079
ΔK_{t-1}	0.132	0.125	0.108	0.717^a
ΔK_{t-2}	-0.122	-0.084	-0.178^b	-0.163
ECT_{t-1}	-0.215^c	-0.233^b	-0.095^b	-0.275^b
C	0.015	0.016	0.041^a	0.009
$\overline{R}^2$	**0.16**	**0.10**	**0.19**	**0.44**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

Normalised on capital, only coal shows positive co-integration relation with manufacturing capital. Normalising on energy suggests that significant positive level relationships exist between capital and total manufacturing energy, diesel and electricity. For the rest of manufacturing energy types, the hypothesis of no level relationship with capital is not rejected at 10% and less significance level.

Table 3.11: Bivariate Bound Test Results for Manufacturing Labour

	Normalised on Energy					Normalised on L		
	Energy	Coal	Die	El	Gas	Die	El	Gas
Long-run relationship-Labour								
L_t	0.334^c	0.158^c	0.635^a	0.760^a	0.558^b	0.343^a	0.723^a	0.291^b
C	1.037	12.09^a	-24.67^a	-55.94^a	8.76^a	11.63^a	42.25^a	1.359
t	0.006^a	-	0.016^a	0.033^a	-	-0.005^b	-0.023^a	-
F-stat	**4.75**	**6.02**	**4.01**	**2.13**	**3.69**	**5.79**	**2.91**	**8.21**
ECM-Labour								
ΔL_t	0.859^b	2.057^a	0.877	0.565^b	0.341	0.063	0.213^b	-0.053
ECT_{t-1}	-0.211^b	-.0230^b	-0.414^b	-0.233^c	-0.292^c	-0.147^b	-0.176^b	-0.191^a
C	0.012	0.002	0.014	0.034^a	0.010	0.003	-0.004	0.005
$\overline{R}^2$	**0.20**	**0.35**	**0.18**	**0.15**	**0.05**	**0.13**	**0.23**	**0.22**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

Significant positive level relationships exist between labour and manufacturing energy, coal, diesel and electricity. For all the other manufacturing energy types, the hypothesis of no level relationship is not rejected at 10% and less significance level.

3.3.1.5 Agricultural Sector

The energy types considered for the agricultural sector are total energy, diesel, kerosene, electricity and coal. Tables 3.12 and 3.13 present the results in the same way as with the whole economy and manufacturing.

Table 3.12: Multivariate Bound Test Results for Agricultural GDP

	Normalised on Energy	Normalised on Y		
	Diesel	E	Diesel	Electricity
Long-run relationship GDP				
E_t	0.201^c	0.610^a	0.383^b	0.284^a
K_t	-0.019	-0.087	0.039	0.091
L_t	-0.510^a	0.252	0.311^c	0.317^c
C	9.94^a	14.20^a	-16.26^a	16.28^a
t	-	-	0.016^a	-
F-stat	**5.15**	**3.78**	**3.97**	**4.93**
ECM-GDP				
ΔY_t	0.350^a	0.121	0.306	0.007
ΔK_t	0.127	0.159	0.136	0.299^b
ΔL_t	-0.161	0.114	0.064	0.102
ECT_{t-1}	-0.511^a	-0.567^a	-0.723^a	-0.755^a
C	0.001	0.012	0.014	0.017
$\bar{R}^2$	**0.44**	**0.33**	**0.45**	**0.43**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

The agricultural model suggests that there are significant level relationships between GDP and total energy, diesel and electricity in agriculture when normalised on GDP, with disequilibrium adjustment rates of 57%, 72% and 76% respectively. Diesel use also shows significant positive level relationship when normalised on energy. The bound tests for coal and kerosene were not significant.

Table 3.13: Bound Test Results for Agricultural Capital and Labour

	Capital			Labour					
	Normalised on Energy	Normalised on K		Normalised on Energy		Normalised on, L			
	Die	El	Ker	Energy	Die	Energy	Die	El	Ker
Long-run relationship-Capital									
K_t	0.198^{b}	0.294^{a}	0.149^{a}	-0.587^{a}	-0.650^{a}	-0.492^{a}	-0.674^{a}	-0.163^{a}	-0.094^{a}
C	12.29^{a}	11.31^{a}	61.119^{a}	-17.97^{a}	15.181^{a}	12.44^{a}	23.91^{a}	8.55	7.734^{a}
t	-	-	-0.027^{a}	0.017^{a}	-	-	-0.005^{b}	-	-
F-stat	**3.92**	**5.07**	**4.39**	**4.29**	**4.57**	**9.02**	**6.59**	**3.85**	**2.77**
ECM-Capital									
$\Delta K_t / \Delta L_t$	0.188^{b}	0.206	0.030	-0.160	-0.195	-0.044	-0.158	-0.078	0.014
ECT_{t-1}	-0.258^{b}	-0.331^{b}	-0.365^{b}	-0.273^{c}	-0.495^{a}	-0.487^{a}	-0.484^{a}	-0.347^{c}	-0.236^{c}
C	0.007	-0.025	-0.014	0.018	0.003	-0.011	-0.011	-0.007	-0.012
$\overline{R}^2$	0.27	0.18	0.18	0.03	0.018	0.25	0.22	0.15	0.17

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

As for agricultural capital, positive level relationship is shown with electricity and kerosene when normalised on capital and with diesel when normalised on energy. Long-run relationship exists between labour and total agricultural energy, diesel, electricity and kerosene when labour is the dependent variable and diesel when energy is the dependent variable. However, all the long-run relationships detected are negative. This implies the energy use is associated with lower employment in agriculture.

3.3.1.6 Mining Sector

The results of the mining sector are reported in Tables 3.14 and 3.15. The energy types considered are total mining energy, coal, electricity and liquid petroleum. Analysis is done for GDP in multivariate framework (with mining capital, labour and energy) and in a bivariate framework for capital and labour.

Table 3.14: Multivariate Bound Test Results for Mining GDP

	Normalised on Energy				Normalised on Y		
	E	Coal	El	LP	E	Coal	LP
Long-run relationship GDP							
E_t	0.968^a	7.758^a		1.630^a	0.224^a	0.032^a	0.216^a
K_t	0.102^c	0.620^c		0.112^c	-0.067^b	-0.032^b	-0.061^b
L_t	0.395^a	-2.062^a		-0.788^a	-0.031	0.072^a	0.218^a
C	-62.02^a	-2.006		-34.31^a	21.27^a	10.73^a	13.52^a
t	0.030^a	-0.035^c		0.015^a	-0.006^b		-0.003^c
F-stat	**3.07**	**2.81**	**2.32**	**6.59**	**6.76**	**6.43**	**8.49**
ECM-GDP							
ΔY_t	0.869^c	7.425^c		0.758	0.092^c	0.016^b	0.098^c
ΔK_t	-0.016	0.159		0.253^b	-0.068^b	-0.053^c	-0.092^b
ΔK_{t-1}	0.121	0.551		-0.152	-0.060^b	-0.049	-0.040
ΔK_{t-2}	-0.087	-0.054		0.096	-0.003	-0.035	-0.013
ΔL_t	0.231	-1.598		-0.204	0.336^a	0.280^a	0.316^a
ECT_{t-1}	-0.610^a	-1.016^b		-0.646^a	-0.743^a	-0.673^a	-0.625^a
C	0.032^b	-0.037		0.019	0.002	0.007^c	0.004
$\bar{R}^2$	**0.28**	**0.33**		**0.31**	**0.50**	**0.49**	**0.38**

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

Total energy use in the mining sector shows a significant positive level and short-run relationships with mining GDP when normalised on GDP. However, when various energy types are considered, the bound test fails to reject the hypothesis of no level relationship between GDP and electricity. Liquid petroleum shows significant level and short-run relationship with mining GDP when both GDP and energy are taken turn by turn as the dependent variables. Coal exhibits significant long-run relation with GDP only when normalised on GDP.

Table 3.15: Bivariate Bound Test Results for Mining Capital and Labour

	Normalised on Energy				Normalised on K, L		
	Energy	Coal	El	LP	E	El	LP
Long-run relationship-Capital							
K_t	0.224^a		0.377^a	-0.235^a	1.016^a	1.111^a	0.530^a
C	-29.04^a		-13.46^b	-53.16^a	-2.74^c	-3.389^b	4.224^b
t	0.020^a		0.011^a	0.033^a			
F-stat	**4.28**		**8.05**	**3.49**	**5.39**	**3.98**	**6.03**
ECM-Capital							
ΔK_t	-0.080		0.043	0.155	-0.080	0.616	0.132
ΔK_{t-1}	0.061		0.020	-0.187	0.583^a	0.526^b	0.462^b
ΔK_{t-2}	-0.165		-0.90	0.123	-0.256	-0.289	-0.360^b
ECT_{t-1}	-0.405^b		-0.169^b	-0.255^c	-0.346^b	-0.24	-0.272^a
C	0.034^b		0.025^b	0.024	0.040	0.021	0.046^c
$\bar{R}^2$	**0.16**		**0.16**	**0.14**	**0.37**	**0.28**	**0.42**
Long-run relationship-Labour							
L_t	0.513^a	1.308^b		-0.648^a	1.144^a		
C	-56.42^a	57.50^b		-20.42^a	79.70^a		
t	0.033^a	-0.021^c		0.017^a	-0.044^a		
F-stat	**4.51**	**3.15**		**5.59**	**2.80**		
ECM-Labour							
ΔL_t	0.494^b	1.284		0.180	0.266^b		
ECT_{t-1}	-0.488^a	-0.591^b		-0.498^a	-0.184^b		
C	0.030^b	0.014		0.027^b	-0.017^c		
$\bar{R}^2$	**0.25**	**0.26**		**0.23**	**0.16**		

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively

The bivariate results for capital and labour in Table 3.15 suggest that total energy, electricity and liquid petroleum use in the mining sector show significant positive level relation with capital when normalised both on energy and capital. Total mining energy has positive level relationship with mining labour when normalised on both. Except for electricity with a non-significant ECM term, coal and liquid petroleum show significant positive and negative relationships respectively with labour when normalised on energy.

3.4 Conclusion

The purpose of this chapter was twofold. First, it investigated the causality between GDP (and capital and labour) and disaggregated energy types by means of Toda and Yamamoto (1995) version of Granger causality. Secondly, it investigated level relationships among energy types and the respective variables using the ARDL framework of Pesaran et al (2001) for selected` productive sectors in South Africa. The analyses are done for the whole economy, manufacturing, agriculture and mining in multivariate frameworks (and bivariate for energy types with capital and labour). In line with Wolde-Rufael (2009) who also used the same multivariate causality framework, this work establishes a significant causal relationship, running from total energy to GDP, capital and labour (and labour to total energy) in the entire economy. Causality runs from energy to capital formation and from GDP, capital and labour to total energy in the manufacturing sector. In the agricultural and mining sectors, there is bidirectional causality between total energy and GDP (and labour). Total mining energy causes capital formation without feedback.

The analysis in disaggregation reveals that there are differences in effects. Gasoline, kerosene and coal show long-run GDP slow down effects. Gasoline and coal equally have negative employment effects. Except for kerosene with no effect, these energy types also slow down capital formation in the long-run. Electricity, diesel and gas are associated with increase in employment in South Africa. Any reduction in electricity (and gas) supply will adversely affect capital formation, employment and growth in the long-run and vice versa. In the manufacturing sector, kerosene has a negative short and long-run relationship with manufacturing GDP, but all the others enhance production. Total manufacturing energy, coal, diesel and electricity co-integrate positively with capital. The same is the case between labour and manufacturing energy, coal, diesel and electricity. In the agricultural sector, production co-integrates positively with diesel and electricity. Positive level relationships exist for electricity, diesel and kerosene with capital. Labour negatively co-integrates with total energy, diesel, electricity and kerosene. This implies the energy use is associated with lower employment in agriculture. Liquid petroleum and coal uses in mining sector show significant level and short-run relationship with mining GDP. Total energy, electricity and liquid petroleum use in the mining sector have positive level relation with capital and labour (but negative for coal). These results have to be compared with theory-based analysis, which is the subject of the next two chapters.

4. ENERGY AND GROWTH IN SOUTH AFRICA: FACTOR SUBSTITUTABILITY AND RETURN TO SCALE

4.1 Introduction

In chapter three, the causal and level relationships between various energy types and GDP (and capital and labour) for selected economic sectors were analysed in Lag-augmented causality and bound test frameworks. These approaches do not strictly rely on existing theories. Neoclassical (long-run Solow) growth theory has come to the conclusion that increase in economic growth rate can only come about through technical progress (Solow, 1956). Various works have highlighted the importance of energy in technical progress. The first is that of Schurr and Netschert (1960), which hypothesises that increase in electrification, enhances both labour and total factor productivity. The second is the finding by Jorgenson (1988) that technical progress is energy using. Despite these, energy is still being given a dismal consideration in mainstream production theories (Stern and Cleveland, 2004). The incorporation of energy as an input in production has been done either in a unitary elasticity (Cobb-Douglas) or Constant Elasticity of Substitution production functions. Few works that used the KLEM framework are not recent, and do not consider developing countries.

This Chapter adapts Vinod (1972) type non-homogenous production function to three inputs (capital, energy and labour) and classical energy demand framework in simultaneous equations settings to reconcile growth and energy demand theories. The framework can generate three important parameters of production theory. First are the elasticities of substitution between (total and disaggregated) energy types and other factors of production (capital and labour). Second are the output elasticities of respective inputs. Third are the Returns to Scale (RTS) with and without the energy types. In such framework, these parameters are also allowed to vary with factor proportions and time. The analysis is done first for the whole economy, then manufacturing, agriculture and mining sectors. The rest of the chapter is structured as follow: section (4.2) explains the methodological approach and adapts the framework. Section (4.3) presents the results while section (4.4) concludes the chapter comparing the theory-based outcomes with the lag-augmented causality and bound test results of chapter three.

4.2 Methodology of Analysis

The model used in this chapter is based on a Variable Elasticity of Substitution (VES) production function. As stated in section (2.3) of chapter two, the Cobb-Douglas (C-D) and Constant Elasticity of Substitution (CES) production functions have two main weaknesses. One is that they impose restrictions on the value of elasticity of substitution (σ). The other is that both assume fixed RTS. In practice, there is possibility of variations in σ as argued by Revankar (1971). This variation depends on output and/or combinations of inputs (Hicks, 1932 and Allen, 1956). The VES production function is combined with energy demand framework in simultaneous equations models, which are estimated by Ordinary Least Squares (OLS) or Three-stage least squares (3sls) depending on the outcome of endogeneity tests. The next subsections present the VES production function (adopted within the appropriate structural equations including energy demand), estimation techniques and data issues.

4.2.1 The frameworks

The frameworks are developed in two steps. In the first, the appropriate VES production function that accommodates capital, labour and energy is specified. In the second, energy demand function is proposed and combined with the VES in structural equations for estimation. The structural equations are specified for total and each energy types, in the whole economy, manufacturing, agricultural and mining sectors.

4.2.1.1 VES Production Functional Forms

Revankar (1971) develops a class of VES production functions in which σ varies with input ratio. However, this form is less malleable for empirical purpose than the C-D generalisation with the addition of the product of logs of inputs by Vinod (1972) and Christensen et al (1973). Such functional form is linear in parameters and can be conveniently estimated by OLS. The latter is the basic form considered for this work, and extended to three inputs (capital, labour and energy). The model has fourfold virtue. First is that it allows for variable elasticity of substitution amongst inputs. The second is that it imposes no restrictions in the data. The third is flexibility in specification. Lastly, it can generate other properties of production such as output elasticities of factors and Returns to Scale, with different factor proportions. The model specification is as follows:

Let *Y* denote output, and *K, L, E* denote capital, labour and energy respectively, t and α are time trend and parameters respectively, subscript *i*, a particular energy type. The process of model specification is divided into two stages. In the first stage, a two-input (capital and labour) model is estimated. This derives the capital-labour elasticity of substitution (σ_{kl}). In the second stage, the average value of capital-labour elasticity of substitution helps to determine the way capital and labour are specified in the three-input functional form.

Two Inputs VES

Based on Vinod (1972), the two-inputs non-homogenous production function proposed is as follows:

$$Y = \exp^{\alpha_0 + \alpha_1 t} K^{\alpha_2 + \alpha_4 \ln L} L^{\alpha_3} \qquad (4.01)$$

Whereas Vinod's specification does not include time trend, equation (4.01) accommodates time trend exogenously in order to depict exogenous time dependent technological progress by way of α_1. Since (4.01) is multiplicative, it can be written in double logarithmic format, with ε as error term and *ln* denoting natural log:

$$\ln Y_t = \alpha_0 + \alpha_1 t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + \alpha_4 \ln K_t . \ln L_t + \varepsilon \qquad (4.02)$$

The output elasticity of capital ($\in_k$) and labour ($\in_l$) are defined as partial derivatives of output with respect to inputs. Formally, they are represented as:

$$\in_k = \partial \ln Y / \partial \ln K = \alpha_2 + \alpha_4 \ln L \qquad (4.03a)$$

$$\in_l = \partial \ln Y / \partial \ln L = \alpha_3 + \alpha_4 \ln K \tag{4.03b}$$

The capital-labour elasticity of substitution is defined as the percentage change in capital labour ratio (*K/L*) divided by the percentage change in marginal rate of technical substitution (MRTS):

$$\sigma_{kl} = \frac{\Delta(K/L)/(K/L)}{\Delta MRTS_{kl} / MRTS_{kl}} \tag{4.04a}$$

In (4.04a), Δ is a difference operator and MRTS is marginal rate of technical substitution between capital and labour. MRTS is the ratio of prices and also the ratio of marginal productivities of both factors, which is $K.\in_l / L.\in_k$. From the definition of elasticity of substitution[42], equation (4.04a) is equivalent to:

$$\sigma_{kl} = \frac{\in_l + \in_k}{\in_l + \in_l + 2\alpha_4} \tag{4.04b}$$

This is VES because σ depends on $\in$, which varies with the levels of *K* and *L*. Though there may be five possible domain of interpretation of σ (Henderson and Quandt, 1980), for empirical convenience, analyses of production functions emphasise three. The first case is when $\sigma_{kl} = 0$ where substitution between inputs is impossible and the production process is characterised by fixed factor proportions in an L-shape isoquants (Leontief) function. Because this is inconsistent with first and second order partial derivatives, economists avoid it. The second case is when $0 < \sigma_{kl} < 1$, where substitution is possible but limited, with negatively sloping isoquants and positive marginal productivities[43]. The last case is when $\sigma_{kl} = 1$, implying perfect substitutability with non-intersecting isoquants. The last two cases are of interest for the specification of three inputs VES production function.

Three Inputs VES

The general form of a three-input multiplicative VES production function with capital, labour and energy is as follows:

$$Y = \exp^{\alpha_0 + \alpha_1 t} K^{\alpha_2 + \alpha_5 \ln E_i + \alpha_7 \ln L} L^{\alpha_3 + \alpha_6 \ln E_i} E^{\alpha_4} \tag{4.05a}$$

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[42] See Hicks, 1932 and McFadden, 1963.

[43] This suggests efficiency in factor utilisation.

In double log form, (4.05a) becomes:

$$\begin{aligned}\ln Y &= \alpha_0 + \alpha_1 t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + \alpha_4 \ln E_t + \alpha_5 \ln K_t . \ln E_t + \\ &\alpha_6 \ln L_t . \ln E_t + \alpha_7 \ln K_t . \ln L_t + \varepsilon_{yt}\end{aligned} \tag{4.05b}$$

The output elasticities of capital ($\in_k$), labour ($\in_l$) and energy ($\in_e$) are as follows:

$$\in_k = \partial \ln Y / \partial \ln K = \alpha_2 + \alpha_5 \ln E + \alpha_7 \ln L \tag{4.06a}$$

$$\in_l = \partial \ln Y / \partial \ln L = \alpha_3 + \alpha_6 \ln \ln E + \alpha_7 \ln \ln K \tag{4.06b}$$

$$\in_e = \partial \ln Y / \partial \ln E = \alpha_4 + \alpha_5 \ln K + \alpha_6 \ln L \tag{4.06c}$$

If from (4.04b), σ_{kl} is (on average) closed to, equal to or above unity, then $\alpha_7 = 0$ and capital and labour are perfect substitutes in (4.05b), otherwise $\alpha_7 \neq 0$. The scale elasticity or Returns to Scale (RTS) is:

$$RTS = \in_k + \in_l + \in_e \tag{4.06d}$$

The elasticities of substitution are evaluated only for energy and capital, and energy and labour respectively. It is defined as in (4.04a):

$$\sigma_{ex_i} = \frac{\Delta(E/X_i)/(E/X_i)}{\Delta MRTS_{e,x_i} / MRTS_{e,x_i}} \tag{4.07}$$

In (4.07), X is input and i is subscript for capital and labour, taken turn by turn.

4.2.1.2 Energy Demand and Structural Model

Energy demand equations are constructed following classical demand theory. Considerable attention has been paid to energy demand, focusing on gasoline in both developed and developing countries (Akinboade, Ziramba and Kumo, 2008; Drollas, 1984; Graham and Glaister, 2002). The simplest form of energy demand models in empirical literature specifies demand as a function of real income and prices (Akinboade et al, 2008; Eltony and Al-Mutairi, 1995; Birol and Guerer, 1993; Ramanathan, 1999). Other works have included automobile stock (Bentzen, 1994; Eltony, 1993; Polemis, 2006) and /or real alcohol prices (Alves and Bueno, 2003). However, for the purpose of gaining degrees of freedom in limited observations dataset, the parsimonious specification adopted includes only natural logs of income (*Y*), population (*POP*), own energy prices, prices of other energy types (*PE*) and error term (ε_{et}) at time *t*, and parameters β .

$$\ln E_{it} = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln POP_t + \sum_{j=1} \beta_{3i} \ln PE_{it} + \varepsilon_{et} \tag{4.08}$$

In (4.08), *i* is the energy type in consideration (total energy[44], coal, gasoline, diesel, electricity, gas and kerosene). The framework is based on a standard aggregate demand theory, in which individual demand for a good (derived from objective utility maximisation subject to budget constraint) are summed over identical consumers. One can arguably state that energy is more a choice variable than capital and labour. This is bases on the supposition that unlike energy, the process of capital accumulation and rigidities in the labour market institutions can render capital and labour exogenous. Therefore, the final functional form in structural specification is the combination of equations (4.05b) and (4.08), which gives:

$$\begin{cases} \ln Y_t = \alpha_0 + \alpha_1 t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + \alpha_4 \ln E_{it} + \alpha_5 \ln K_t . \ln E_{it} \\ + \alpha_6 \ln L_t . \ln E_{it} + \alpha_7 \ln K_t \ln L_t + \varepsilon_{yt} \\ \ln E_{it} = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln POP_t + \sum_{j=1} \beta_{3i} \ln PE_{it} + \varepsilon_{et} \end{cases} \tag{4.09}$$

Theoretically, capital and labour are expected to have positive output elasticities. After disaggregation of energy types, their individual impacts may not be easily predictable. However, efficient energy types like electricity are expected to have positive effect on production. Energy types such as liquid fuel for luxury cars[45] and those mainly used by the poor[46] may have

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[44] In the model for total energy, only the energy price index is used as price variable.

[45] This may be the case at least in the short run. In the long run, it may be argued that luxury goods bring about knowledge spill-over, resulting in more growth (see Matsuyama, 2002; Kuwahara, 2006)

[46] This applies for fuel like kerosene, mainly used by the poor in the residential sector. Its negative effect may indicate the fact that their user participate less in productive activities and also that it affects human capital of the poor negatively. However, some kerosene is used as jet fuel in the transport sector. This may attenuate the negative effect of kerosene.

insignificant and/or negative effect on production. For energy demand, the effect of income also depends on energy type types. According to classical demand theory, energy prices are expected to have negative impact on energy use, the sign of the coefficient of cross prices depend on whether the energy types are substitutes or complements. Population is expected to have positive effect on demand.

4.2.2 Estimation Techniques

The main concern with the application of Ordinary Least Square (OLS) to the single equations of model (4.09) is endogeneity between GDP and energy demand. It is important to decide whether or not OLS will be consistent. Davidson and Mackinnon (1993) propose an augmented regression or Durbin-Wu-Hausman (DWH) test. This test consists of applying OLS to generate the residual of the endogenous right hand side variables, then including the residual as a function of all the exogenous. In other words to test for the endogeneity of GDP in energy demand equation, one would regress the following:

$$\ln E_{it} = \beta_0 + \beta_1 \ln(Y_t) + \beta_2 \ln(P_{it}) + \beta_3 \ln(POP_t) + \beta_5 \varepsilon_{yt} + \varepsilon_{et} \qquad (4.10)$$

In equation (4.10), ε_{yt} is the residual of production equation. The next is to conduct a Wald test for the significance of β_5. If it is significantly different from zero, then energy and production are endogenous and OLS is inconsistent. In such case, a simultaneous equation estimation method of (4.09) would be necessary, with the application of 3sls. The final specification of model (4.09) is done after Wald test of coefficients. It is likely that the coefficients of some energy types or interactive terms are insignificant. This may also be the case with some cross price coefficients. In such cases the insignificant coefficients are excluded from the model in order to improve the performance of the model.

4.2.3 Variables, Data and Summary Statistics

The data used in this chapter span 1971 to 2006. Annual energy data obtained from the International Energy Agency spans 1971 to 2005. Complementary energy data for 2006 are from the South African Department of Minerals and Energy. Energy types available are total energy, electricity, kerosene, diesel, gasoline, gas and coal for the whole economy; total manufacturing energy, kerosene, diesel, gas and coal; aggregate agricultural energy, electricity, coal, diesel and kerosene; and mining energy, coal, electricity and liquid petroleum. Their units of measurement are harmonised[47] to Tera Joules (TJ). Energy types are considered in net of uses in the energy sector[48].

GDP and capital formation (both in million ZAR at constant 2000) are from the South African Reserve Bank (SARB) dataset. Data from STATSSA (2007b) are combined with SARB employments indices to generate real private sector, manufacturing and mining employment data (in thousand persons)[49]. For the whole economy, labour force series is from the World Development Indicators (WDI, 2008).

Agricultural employment data is from the Abstract of Agricultural statistics, published by the department of agriculture[50]. Population data is from the WDI (2008). Aggregate energy price series is measured by Consumer Price Index (CPI) for energy, taken from STATSSA, electricity prices are from Eskom Tariffs (in South African cents/kWh), while prices for the other energy types are from the Department of Minerals and Energy and are expressed in indices.

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[47] Coal is sum of bituminous coal (comprising hard coal) and coke oven coal and lignite coal. Hard coal is made of three components with net calorific value (NCV) as follows: *Anthracite:* 28.95 - 30.35; *Coking coals:* 26.60 - 29.80; *Bituminous:* 22.60 - 25.50 Averages of NCV were taken for each sub category of coal and the average of the averages calculated and used to convert units of coal from kilo tonnes (kt) to Tera Joules (TJ). Gasoline: NCV is average for aviation gasoline and motor gasoline. Gas is sum of LPG, gas works gas and coke oven gas. LPG unit of measurement was changed from kt to TJ using NCV of 46.15 GJ/t and density of 522.2 kg/m^3, assuming a mixture of 70% propane and 30% butane by mass. 1GJ = (x 1000tonnesc46.15GJ/t)/1000. Electricity consumption was multiplied by its 3.6 conversion equivalent to convert from GWh to TJ. (see IEA, 2005, Energy Statistic manual)

[48] For example, coal is taken net that used in electricity and petroleum sectors

[49] Assuming that the SARB private sector employment data depicts the actual variations in the series.

[50] Missing values are interpolated with the assumption of linear evolution of the series.

No price data was available for gas, so aggregate energy price index was used. Table 4.1 gives the summary statistics of natural log of variables.

Table 4.1: Summary Statistics of Log of Variables

Log of Variable	Obs	Mean	Std. Dev.	Min	Max
Whole Economy					
GDP	36	13.521	0.220	13.115	13.977
Capital	36	11.746	0.197	11.450	12.305
Labour	36	9.439	0.087	9.269	9.572
Total energy	36	14.499	0.178	14.138	14.815
Electricity	36	12.909	0.411	12.030	13.563
Kerosene	36	10.966	0.408	10.498	11.579
Gasoline	36	12.437	0.300	11.961	12.866
Diesel	36	12.154	0.221	11.620	12.677
Gas	36	11.455	0.121	11.159	11.810
Coal	36	13.345	0.087	13.168	13.500
Manufacturing Sector					
GDP	36	11.774	0.216	11.277	12.163
Capital	36	10.065	0.328	9.324	10.712
Labour	36	7.486	0.096	7.285	7.626
Energy	36	13.639	0.126	13.305	13.886
Electricity	36	12.435	0.361	11.671	12.948
Kerosene	36	7.793	0.771	6.395	9.312
Diesel	36	10.193	0.219	9.761	10.492
Gas	36	11.368	0.138	11.083	11.703
Coal	36	12.832	0.210	12.372	13.207
Agricultural Sector					
Value Added	36	8.078	0.184	7.741	8.346
Capital	36	8.634	0.300	8.117	9.348
Labour	36	7.004	0.228	6.443	7.402
Energy	36	10.920	0.264	10.495	11.357
Electricity	36	9.118	0.751	7.729	10.007
Kerosene	36	7.006	0.800	5.862	8.031
Diesel	36	10.584	0.134	10.400	10.906
Coal	36	7.671	0.925	4.405	9.007
Mining Sector					
GDP	36	11.108	0.040	11.027	11.220
Capital	36	9.332	0.371	8.286	9.787
Labour	36	6.720	0.299	5.988	7.047
Energy	36	11.879	0.285	11.304	12.295
Electricity	36	11.448	0.269	10.817	11.739
Liquid petroleum	36	9.637	0.320	9.323	10.386
Coal	36	10.041	0.552	8.284	10.962

Others variables					
Population	36	17.371	0.233	16.956	17.693
Energy price	36	3.390	1.151	1.344	4.955
Coal price	36	4.987	0.241	4.359	5.397
Gasoline price	36	4.211	0.625	3.528	5.673
Diesel price	36	4.169	0.683	3.360	5.924
Electricity price	36	2.773	0.184	2.535	3.058

4.3 Empirical Results

In this section, the results of the analysis are outlined following the economic sectors considered – whole economy, manufacturing, agriculture and mining. For each sector, the two-input production function with capital and labour is presented first. From this, the capital-labour elasticity of substitution is calculated. This enables the formulation of appropriate three-input functional form. This is followed by the presentation of the estimates of the structural equations with endogenous test results which helps to decide whether to use Ordinary Least Squares (OLS) or three-stage least squares (3sls) techniques.

4.3.1 Whole Economy

4.3.1.1 No-Energy Scenario

The results of the estimates of the two-input model (capital, labour) equation (4.02) (with t-values in parentheses) are as follows[51]:

$$y = \underset{(-2.82)}{-85.034^{b}} + \underset{(32.80)}{0.017^{a}}\,t + \underset{(2.03)}{5.370^{c}}\,k + \underset{(2.01)}{6.559^{c}}\,l - \underset{(-1.94)}{0.541^{c}}\,kl$$

$R^2 = 0.92$: $AR^2 = 0.92$: F-stat=1378.95; N = 36

The adjusted R-square of 0.92 suggest a high explanatory power[52] of the model and a significant F-statistic of 1378.95 further supports the validity of

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[51] Figures in bracket are t-statistics. ^{a}, ^{b}, ^{c} denote that coefficient is significantly different from zero at 1%, 5% and 10% significance levels respectively.

[52] It is noteworthy that the variables have not been corrected for unit root. Though it may be important, however, the usual methodology involving differencing till the achievement of stationarity is done at the expense of information about the long-run, with consequent loss of degrees of freedom. Besides, the interactive terms make differencing complicated. Chapter three applies the unit roots corrections.

the regression model. The values of the t-statistics show that the individual variables are statistically significant, at 10% level of significance. The time trend, which captures the effect of technology, is also statistically significant at 1% level. The output elasticities, scale elasticity and capital labour elasticity of substitution – evaluated at mean values of the variables – are presented in Table 4.2, along with their domains of variation.

Table 4.2: Capital-Labour VES Parameters – Whole Economy

	Mean	Std. Dev.	Min	Max
$\in_k$	0.259	0.047	0.189	0.353
$\in_l$	0.190	0.107	-0.101	0.361
RTS	0.449	0.141	-0.017	0.694
σ_{kl}	0.804	0.351	0.160	1.937

The output elasticities of capital (E_k) and labour (E_l) evaluated at the mean values of the data are respectively 0.259 and 0.190. While the output elasticity of capital varies less (within 0.189 and 0.353), with standard deviation of 0.047, that of labour has relatively higher variation (within -0.101 and 0.361), with standard deviation of 0.107. The average value of RTS is 0.449. This implies that (without the consideration of energy) when capital and labour both increase by one percent, output increases on average by 0.449. A magnitude less than unity imply diminishing return in South African Economy. However, the RTS varies over time, starting from a high of 0.714 and undulating downward to a local minimum of 0.210 in 1981 before increasing to 0.514 in 1993. From then, it has steadily dropped to -0.017. The RTS appears to closely mimic variations in output elasticity of labour (Figure 4.1). Finally, the capital-labour elasticity of substitution (Eskl) is 0.804 at average evaluation. However, this parameter varies quite significantly over time, starting at 1.937 in 1971, and decreasing to 0.438 in 1981, then rises and fluctuates around 0.7 till 2001, when it gradually falls to 0.160 in 2006.

The capita-labour elasticity of substitution also varies with the ratio of the inputs as suggested by theory. This variation is shown in figure 4.2. The pattern makes economic sense in that coefficients of labour productivity, RTS and K-L elasticity of substitution evolve in phase. The more capital can substitute for labour, the higher the productivity of labour[53] and hence RTS.

Figure 4.1: Evolution of Elasticities over Time – Whole Economy

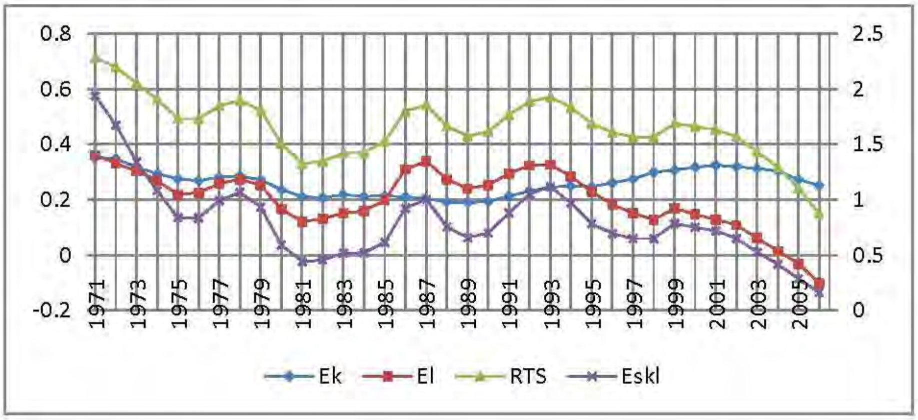
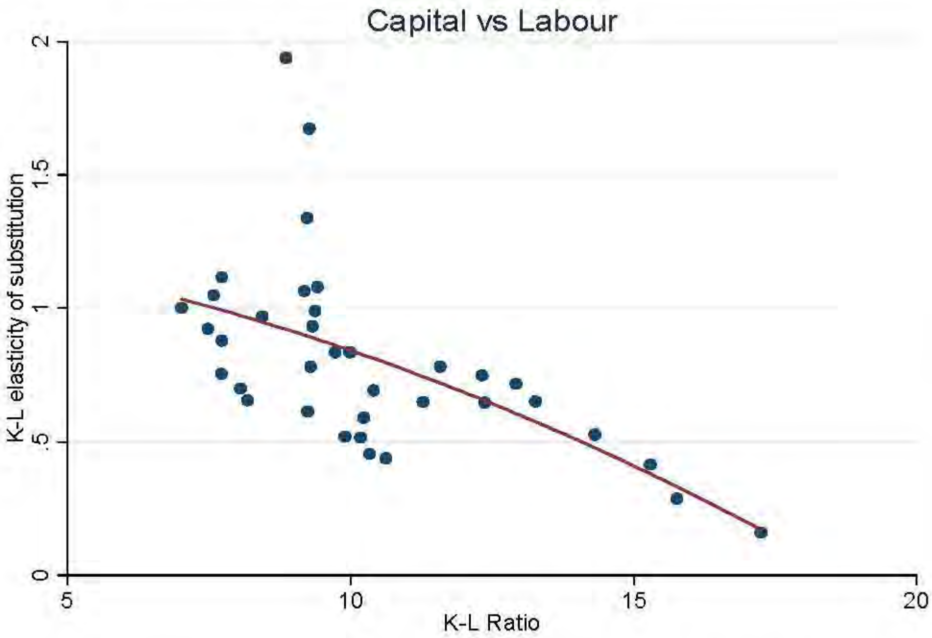


Figure 4.2: K-L Elasticity of Substitution and K-L Ratio – Whole Economy



The mean value of the K-L elasticity of substitution of 0.804, with subsequent fluctuations above 0.5 gives a strong basis for assuming that α_7 in Equation (4.09) is not statistically different from zero. This assumption is supported by

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[53] Capital intensive processes require more skilled labour with higher productivity.

Wald test on α_7. Based on this, (4.09) is estimated without capital-labour interactive term for total energy and all energy types.

4.3.1.2 Estimation with Total Energy

The 3sls estimation results for aggregate energy, capital and labour are presented below. The DWH test result is significant, suggesting that the residuals of energy demand equation are significant in the production equation. This implies that OLS is not consistent for single equations of model (4.09). Both energy demand and production equations have high explanatory power with R-squares of 0.97 for both, and significant chi2. Based on the t-values in parentheses, all the individual coefficients are significant[54]. Wald test on the coefficient of capital-labour interactive term shows that it is not statistically different from zero, confirming the assumption of unitary capital-labour elasticity of substitution based on the evaluation of (4.04b). So the term was excluded from the empirical specification.

$$\begin{cases} y = -\underset{(-2.88)}{78.828^{b}} + \underset{(13.13)}{0.016^{a}}\, t - \underset{(-4.13)}{7.157^{a}}\, k + \underset{(2.01)}{15.207^{a}}\, l + \underset{(1.73)}{3.817^{c}}\, e + \underset{(4.27)}{0.505^{a}}\, ke - \underset{(-3.20)}{1.029^{a}}\, le \\ e = -\underset{(-2.00)}{13.988^{b}} + \underset{(4.86)}{0.494^{a}}\, y + \underset{(2.97)}{1.296^{a}}\, pop - \underset{(-2.42)}{0.204^{b}}\, pe \end{cases}$$

$$R_y^2 = 0.97;\ Chi2_y = 6429.5;\ R_e^2 = 0.97;\ Chi2_e = 1072.64;\ DWHstat = 765.88(0.000)$$

$$N = 36$$

The energy demand equation obeys the classical demand theory with energy demand elasticity of income being 0.494, suggesting energy as essential good in the South African economy. Equally, the price elasticity of energy demand of -0.204 suggest that energy demand is inelastic. The coefficient of population show that one percent rise in population brings about 1.3 percent increase in energy demand.

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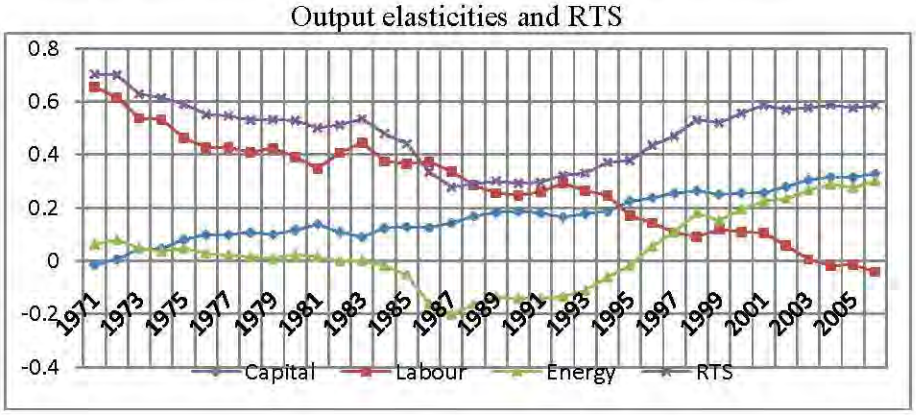
[54] Figures in bracket are t-statistics. ^{a}, ^{b}, ^{c} denote that coefficient is significantly different from zero at 1, 5 and 10% significance levels respectively.

Table 4.3: VES Parameters with Total Energy – Whole Economy

	Mean	Std. Dev.	Min	Max
$\in_k$	0.168	0.090	-0.014	0.328
$\in_l$	0.283	0.183	-0.042	0.655
$\in_e$	0.036	0.141	-0.201	0.300
RTS	0.488	0.121	0.278	0.703
σ_{ke}	0.195	0.121	0.054	0.534
σ_{le}	0.153	0.120	0.003	0.383

Table 4.3 gives the results of output elasticities of capital, labour, energy, RTS, capital-energy and labour-energy elasticities of substitution evaluated at mean values of variables for VES model with total energy. The productivity of capital drops while that of labour rises slightly after introduction of energy. The RTS increases by about the value of output elasticity of energy (0.039)[55]. Since the scale elasticity determines the economy's expansion path, one can conclude that this is aggregate energy's contribution to economic growth. Figure 4.3 shows that RTS and output elasticity of energy evolve in phase. This may suggests that though energy's share in RTS is small, it is the most important limiting factor for growth.

Figure 4.3: Elasticities of Energy with Time – Whole Economy



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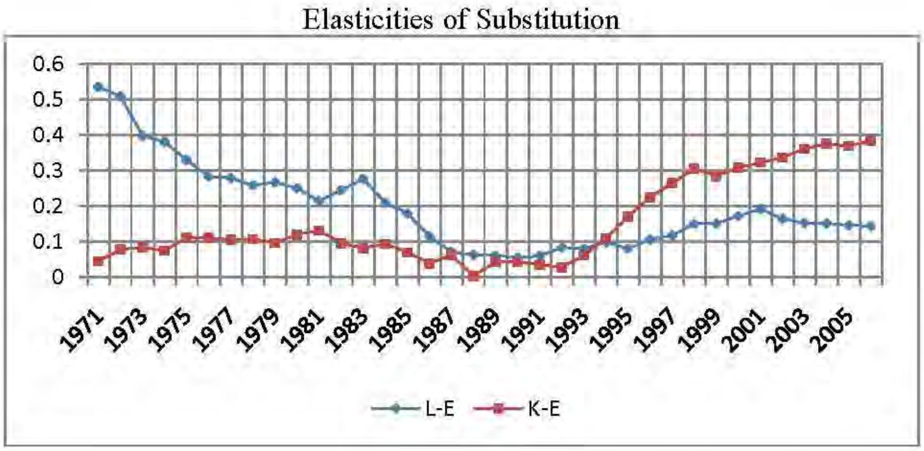
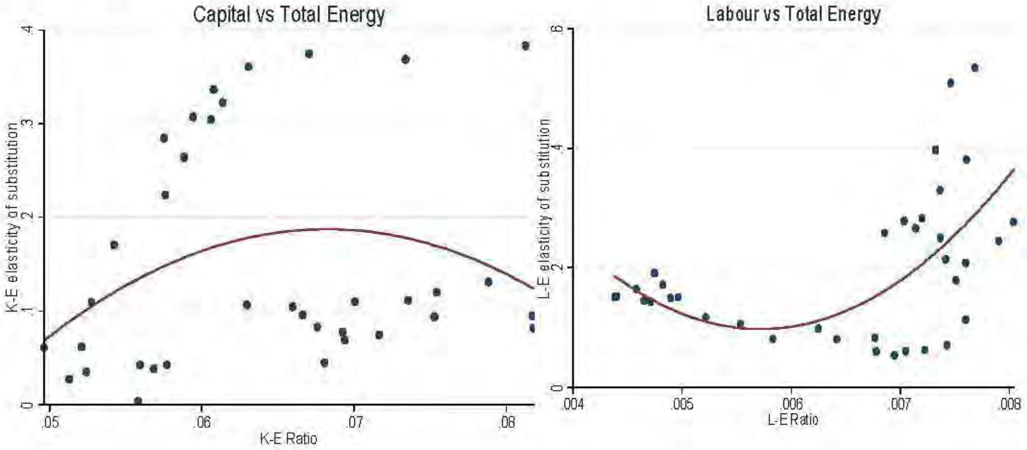
[55] The output elasticity of energy is close to that obtained for the US by Hannon and Joyce (1981)



The average values of capital-energy and labour-energy elasticities of substitution (0.195 and 0.153) seem to suggest that both capital and labour are not substitutes with energy, but this may be misleading because both series vary significantly (Figure 4.3). From 1971 to 1994, energy and capital seem to complement each other, but the elasticity of substitution increases to about 0.4 in 2006. However, the reverse holds for labour, which seems to be substitute with energy from 1971, and the substitution elasticity decreasing (from 0.6) to about 0.1 in 1988. From then to 2006, labour and energy have been more of complements. The evolution of capital-labour elasticity seems to corroborate this, where capital seems to complement labour towards 2006. This evolution could be explained by gradual skills development within South African labour force.

Figure 4.4: Energy Elasticities of Substitution and Factor Ratios - Whole Economy



The evolution of capital – energy (*K-E*) and labour-energy (*L-E*) elasticities of substitution with capital-energy (*K/E*) and labour-energy (*L/E*) ratios in figure (4.4) cannot give any meaningful information. However, it seems to suggest that in times of high labour availability relative to energy, energy and labour tend to be less complements while capital and energy tend to be more complements at low and high capital-energy ratios. However, aggregate measure of energy may mask differences in effects of various energy types.

4.3.1.3 Estimations with Disaggregated Energy

The results of estimates of model (4.09) for electricity, diesel, gasoline, gas, kerosene and coal are presented in Table 4.4. The t-values of coefficients are in parentheses.

Table 4.4: VES Estimates with Energy types – Whole Economy

	Electricity	*Diesel*	*Gasoline*	*Gas*	*Kerosene*	*Coal*
R^2_y	**0.96**	**0.95**	**0.95**	**0.95**	**0.94**	**0.95**
$Chi2_y$	**3.69E7**	**7309.38**	**13186**	**7001**	**12569**	**833.42**
R^2_e	**0.96**	**0.95**	**0.92**	**0.68**	**0.96**	**0.61**
$Chi2_e$	**12108**	**646.52**	**1474**	**80.20**	**767.19**	**12.26**
DWH[56]. **(P-VAL)**	**830.27** **(0.000)**	**474.42** **(0.000)**	**166.65** **(0.000)**	**2.62** **(0.115)**	**103.49** **(0.000)**	**0.01** **(0.929)**
Parameters						
α_0	-55.945 (-1.61)	-91.764^b (-2.27)	-34.029^a (-18.98)	87.101^a (3.34)	-28.922^a (-19.25)	46.531 (0.52)
α_1	0.014^a (3.49)	0.015^a (19.72)	0.022^a (22.47)	0.018^a (0.56)	0.019^a (21.07)	0.018^a (34.13)
α_2	-4.451^a (-3.82)	-3.197^b (-2.52)	-2.567^a (-3.21)	1.779^c (1.67)	-1.655^a (-3.56)	-0.051^c (-1.70)
α_3	9.829^b (2.26)	11.803^b (2.10)	3.854^a (3.91)	-24.712^a (-3.80)	2.572^a (4.42)	-7.346^c (-1.88)
α_4	2.995^c (0.081)	5.881^c (1.80)	-	-18.710^a (-3.80)	-	-5.533^c (-1.83)
α_5	0.354^a (4.05)	0.275^b (2.64)	0.220^a (3.46)	-0.136^c (-1.68)	0.170^a (4.07)	0.020^b (1.97)
α_6	-0.739^b (-2.23)	-0.956^b (-2.06)	-0.288^a (-3.70)	2.173^a (3.83)	-0.218^a (-4.29)	0.569^c (1.84)
β_0	-18.236^a (-48.39)	0.821 (0.92)	-9.155^a (-11.20)	11.106^a (8.92)	-11.247^a (-6.66)	18.463^a (18.86)
β_1	1.092^a (11.15)	1.583^a (6.87)	0.134^b (0.028)	1.368^a (4.07)	-0.970^b (-2.23)	0.524^b (2.49)
β_2	0.937^a (12.35)	0.582^a (3.23)	1.431^a (8.69)	-1.098^a (-4.38)	2.106^a (6.24)	-0.745^a (-4.24)
β_{31}	0.162^a (5.23)	0.021 (0.30)	-0.338^a (-5.07)	0.157 (1.52)	-0.632^a (-4.57)	-0.163^b (-2.69)
β_{32}	0.039 (0.78)	-0.029 (0.08)	0.364^a (3.28)	0.235 (1.44)	-0.674 (-1.31)	-
β_{33}	-0.119^b (-2.04)	0.027 (0.20)	-0.483^a (-3.82)	-0.347^c (-1.86)	-0.163 (-0.62)	-
β_{34}	-	-	-		0.946^c (1.85)	-
β_{35}	-	-	-	0.195^b (2.51)		-0.238^a (-3.65)

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively. Parentheses contain t-values. β_{3i} are the coefficients of energy prices: I = 1 for electricity; 2 for diesel; 3 for gasoline; 4 for kerosene and 5 for coal. Gas prices are not available. Sample size is 36 observations.

The model statistics for production and energy demand equations for all sub models are satisfactory. The goodness of fit for production equation (R^2_y)

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[56] Insignificant DWH test implies that OLS is consistent; model (9) is estimated with the OLS option and the model F-values. Otherwise, 3sls is used and model chi2 values reported.

ranges from 94 to 96 percent. That of energy demand equation is 0.96 for electricity and kerosene, 0.95 for diesel, 0.92 for gasoline, 0.68 for gas and 0.61 for coal. The DWH test shows that OLS is applicable only for gas and coal models. Wald test on α_4 indicates that it is not statistically different from zero for gasoline and kerosene and were excluded. This means that gasoline and kerosene impact GDP through their effect on capital and labour productivities. All the individual variables in the production functions have significant t-statistics.

Income is significant in all energy equations. Electricity, diesel and gas behave more like luxury goods (with elasticity greater than one). This is conceivable because these energy types are likely to complement most luxury goods in South Africa. Gasoline and coal have essential goods characteristics (elasticity less than one but greater than zero) while kerosene proves to be an inferior good (with negative income elasticity). Most of kerosene demand (on average 30% over the data span) is from the residential sector and mainly by the poor for cooking, heating and lighting. As income increases, people move away from kerosene to more modern forms of energy such as electricity.

The coefficients of own prices for the different energy types are significant. Diesel, gasoline and coal all face relatively inelastic demand (prices elasticity of -0.029, -0.483 and -0.238 respectively). Electricity price has a positive coefficient. This should be the consequence of various government subsidies on electricity to the poor such as the free basic electricity (FBE) programme and or long time low electricity prices. Kerosene price exhibits the same effect, but is significant only at 10%. Cross price elasticities seem to suggest that electricity complements gasoline, kerosene and coal. Gas and gasoline seem to also complement each other, but this could not be verified in the gasoline equation for lack of data on gas prices.

Population has significant effect on all the energy types, but is negative on gas and coal. One percent increase in population results in 2.11%, 1.43%, 0.94% and 0.58% increase in demand for kerosene, gasoline, electricity and diesel respectively.

From the VES production function for the respective energy types, the output elasticities of capital, labour and energy, return to scale and capital-energy and labour-energy elasticities of substitution have been calculated at mean levels of variables. These parameters are presented in Table 4.5. In general, compared to Table 4.2, the output elasticity of capital has fallen across all energy types, with the most significant fall in the presence of electricity, followed by diesel, while the output elasticity of labour has slightly improved. On average, the scale elasticity is higher for electricity, gas and coal, relative to the no energy scenario. This suggests that the marginal productivities of these energy types were accorded to capital. Gasoline and kerosene have negative average output elasticities, resulting in lower RTS. From their VES specification, and from the sign of α_6 (-0.288 and -0.218 respectively), it is evident that they reduce labour productivity[57].

Table 4.5: VES Parameters with Energy types – Whole Economy

Model	parameter Mean	Std. Dev.	Min	Max
Output Elasticity of Capital (N=36)				
Electricity	0.120	0.146	-0.191	0.352
Diesel	0.146	0.061	-0.001	0.290
gasoline	0.164	0.066	0.060	0.258
Gas	0.219	0.016	0.171	0.259
Kerosene	0.208	0.069	0.128	0.312
Coal	0.214	0.002	0.211	0.217
Output Elasticity of Labour				
Electricity	0.288	0.304	-0.195	0.938
Diesel	0.186	0.211	-0.314	0.696
Gasoline	0.276	0.086	0.153	0.413
Gas	0.175	0.263	-0.470	0.945
Kerosene	0.186	0.089	0.053	0.288
Coal	0.246	0.049	0.146	0.335
output Elasticity of Energy				
Electricity	0.178	0.100	0.010	0.363
Diesel	0.089	0.104	-0.082	0.257
Gasoline	-0.136	0.052	-0.222	-0.018
Gas	0.196	0.193	-0.133	0.495
Kerosene	-0.059	0.040	-0.125	0.032

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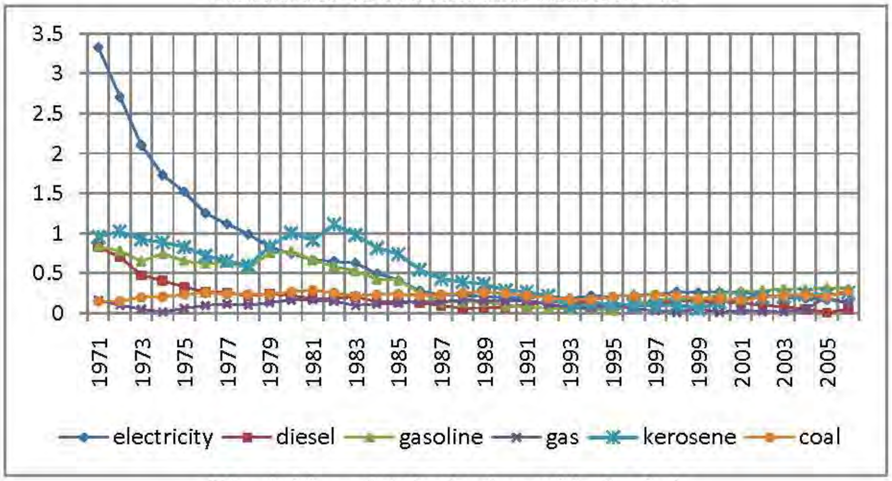
[57] Kerosene's association with ill health and poverty is a possible channel by which it reduces labour productivity, i.e. through low human capital.

Coal	0.070	0.049	-0.032	0.145
Scale elasticity				
Electricity	0.587	0.155	0.403	0.946
Diesel	0.451	0.144	0.201	0.866
gasoline	0.305	0.047	0.223	0.393
Gas	0.589	0.382	-0.343	1.206
Kerosene	0.334	0.031	0.278	0.397
Coal	0.531	0.065	0.408	0.673
Energy-Labour elasticity of Substitution				
Electricity	0.656	0.760	0.128	3.327
Diesel	0.190	0.172	0.003	0.829
Gasoline	0.368	0.257	0.030	0.832
Gas	0.095	0.054	0.008	0.192
Kerosene	0.487	0.349	0.052	1.109
Coal	0.216	0.035	0.146	0.286
Energy-Capital Elasticity of Substitution				
Electricity	0.271	0.134	0.011	0.502
Diesel	0.280	0.117	0.079	0.484
Gasoline	0.160	0.100	0.010	0.353
Gas	3.804	4.271	0.867	23.350
Kerosene	0.278	0.132	0.077	0.501
Coal	0.875	0.020	0.820	0.900

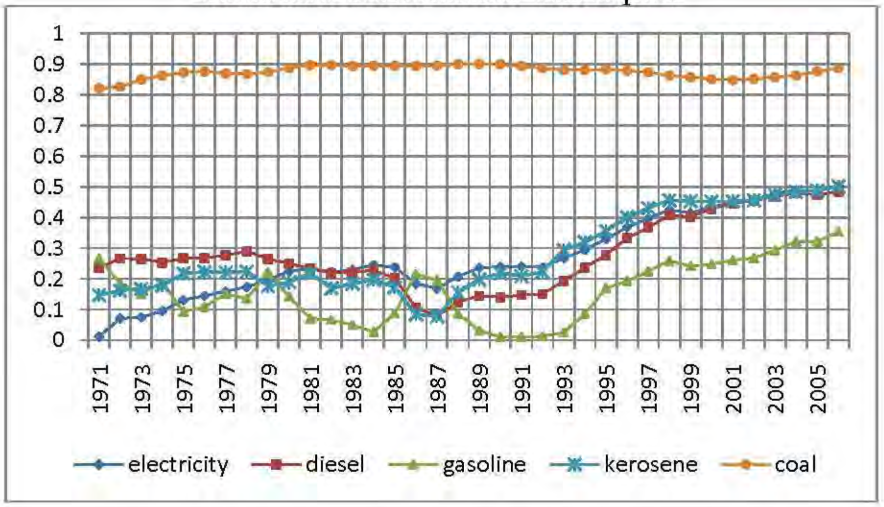
Apart from gas and coal (which seem to be strong substitutes with capital), all the other energy types complement capital. The energy-labour elasticity of substitution show that on average, electricity is more a substitute to labour while the other energy types seem to complement labour. All these quantities prove to vary significantly over time. Figures 4.5 shows the variations in RTS, energy-labour and energy-capital substitutability.

Figure 4.5: Elasticities of Energy types with Time – Whole Economy

Elasticities of Substitution with Labour

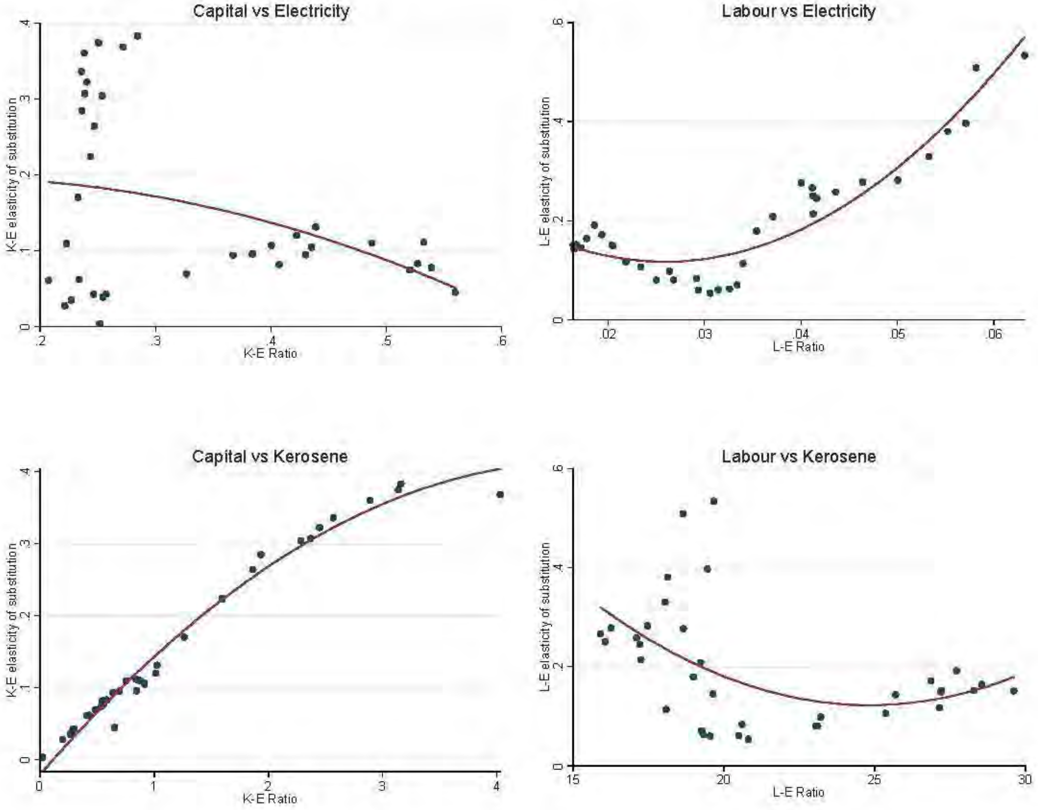


Elasticities of Substitution with Capital



The figure suggests that in the early years of the series (1971 to about 1987), electricity, gasoline and kerosene are more substitutes to labour than the rest of the data span. Except for gas with high variations in energy-capital elasticity of substitution, showing more substitutability around 1973-1978, 1997-1999 and 2005, all the energy types are less substitutable with capital over the years. Figure 4.6 suggests that though electricity complements capital, high capital-electricity ratio reinforces the complementarity. On the contrary, electricity tends to substitute labour more at high labour-electricity ratio. This implies that less electricity relative to labour will lead to high unemployment. This tendency holds for diesel (Table C1 in appendix). However, kerosene and coal (Table C1) show opposite effect from electricity. Kerosene in particular is associated with the activities of the poor who are less endowed with capital, and therefore in high labour intensities, labour complements kerosene.

Figure 4.6: Energy Elasticity of Substitution and Factor Ratios – Whole Economy



4.3.2 Manufacturing Sector

4.3.2.1 No-Energy Scenario

The estimates of manufacturing sector without energy types - two-input model (capital, labour) - are presented below[58]:

$$y = \underset{(-7.00)}{-164.466^{a}} + \underset{(7.48)}{0.010^{a}}\,t + \underset{(5.99)}{15.248^{a}}\,k + \underset{(6.09)}{20.554^{a}}\,l - \underset{(-5.94)}{2.008^{a}}\,kl$$

---

[58] Figures in bracket are t-statistics. ^{a}, ^{b}, ^{c} denote that coefficient is significantly different from zero at 1, 5 and 10% significance levels respectively.

$R^2 = 0.97$: $AR^2=0.97$: F-stat=242.62; $N = 36$

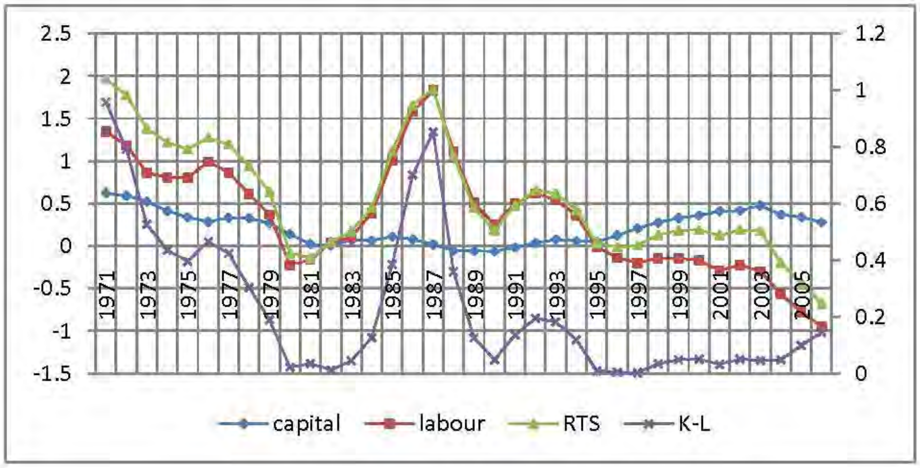
The overall model statistics shows a satisfactory model performance, with adjusted R-square of 0.97 and F-statistics of 242.62. The individual variables are equally statistically significant as indicated by the t-values (in parentheses). The coefficient of time trend is significant at 1% level, with magnitude of 0.01, depicting the effect of technology in the manufacturing sector over time. The various elasticities evaluated at mean values of variables (with standard deviations and range of variability) are presented in Table 4.6.

Table 4.6: Capital-labour VES Parameters – Manufacturing Sector

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	0.216	0.193	-0.064	0.620
$\in_l$	0.343	0.658	-0.955	1.832
RTS	0.559	0.673	-0.679	1.964
σ_{kl}	0.233	0.263	0.002	0.957

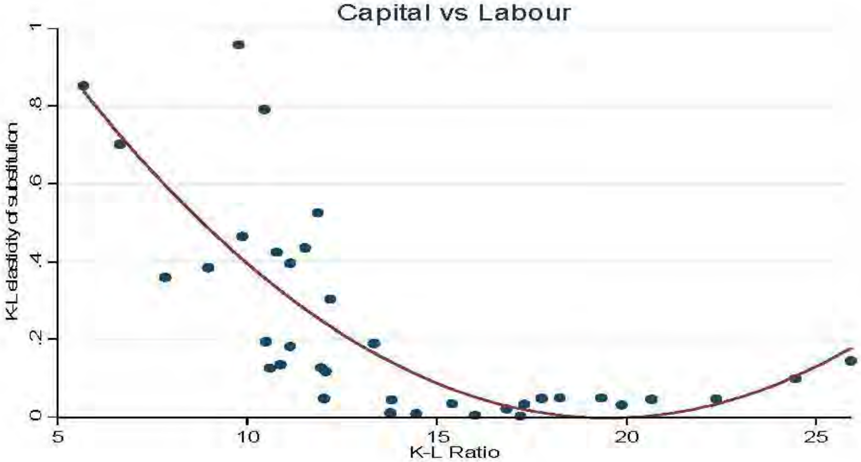
The output elasticities of capital and labour suggest that without the inclusion of energy types, output responds by 0.216% and 0.343% following one percent increase in capital and labour respectively. As is the case with whole economy, capital elasticity varies less, with standard deviation of 0.193, but that of labour has a greater variability with a wider range of variation and standard deviation of 0.658. Scale elasticity (RTS) shows that one percent increase in capital and labour results in 0.559 percent increase in manufacturing output. Because this quantity is less than unity, there is diminishing return in the manufacturing sector, though with less magnitude than the case of the whole economy. The evolution of RTS appear in phase with marginal productivity of labour, which agrees with some elements of South African history, notably the significant fall (-32%) in male labour participation in the last part of the 20th century compared to the 1960s (Feinstein, 2007). This fall is the consequence of increasing unemployment due to widespread rise in black wages during the same period. The period also corresponds to falling marginal productivity of labour (from about 1989 to the close of the century).

Figure 4.7: Evolution of K-L Elasticities and RTS over Time – Manufacturing



Contrary to the result of the whole economy, manufacturing capital-labour (K-L) elasticity of substitution is 0.233. In the major span of the series, variation is below 0.5, with standard deviation of 0.263 and range of (0.002 and 0.957). This suggests that capital and labour are more of complements than substitutes in the manufacturing sector α_7 in Equation (4.09) is expected to be statistically significant in the framework with energy types. The evolution with capital-labour ratio shows that in situations of capital intensity, labour complements capital.

Figure 4.8: K-L Elasticity of Substitution and K-L Ratio – Manufacturing



4.3.2.2 Estimation with Total Energy

The estimates for model with aggregate energy, capital and labour in manufacturing sector are presented below. The DWH statistic suggests endogeneity between total energy and GDP in manufacturing, which serves as the basis for application of 3sls. Both equations have acceptable explanatory power (as shown by the R-squares), with significant model Chi2.

$$\begin{cases} y = \underset{(0.94)}{97.920} + \underset{(17.16)}{0.011^{a}}\, t + \underset{(3.09)}{17.264^{a}}\, k - \underset{(-1.71)}{14.148^{c}}\, l - \underset{(-1.87)}{21.357^{c}}\, e \\ - \underset{-2..91}{2.363^{a}}\, kl + \underset{(0.78)}{0.048}\, ke + \underset{(1.91)}{2.812^{c}}\, le \\ e = - \underset{(-1.42)}{2.777} + \underset{(8.30)}{1.453^{a}}\, y - \underset{(-6.28)}{0.204^{a}}\, pe \end{cases}$$

$R_y^2 = 0.95$; $Chi2_y = 2006.71$; $R_e^2 = 0.69$; $Chi2_e = 94.96$; $DWHstat = 31.21(0.000)$

$N = 36$

Except for all the constant terms and the capital-energy interaction term, all coefficients are significant as suggested by the t-values in parentheses. The capital-labour interaction term is significant, confirming the result of capital-labour elasticity of substitution above. The estimates of the energy demand equation fits the classical demand theory. Manufacturing GDP is the major determinant of manufacturing energy demand, with elasticity of 1.5% implying that as income increases, energy demand increases more than proportionately. The coefficient of energy price suggests inelastic manufacturing energy demand, with magnitude of -0.204.

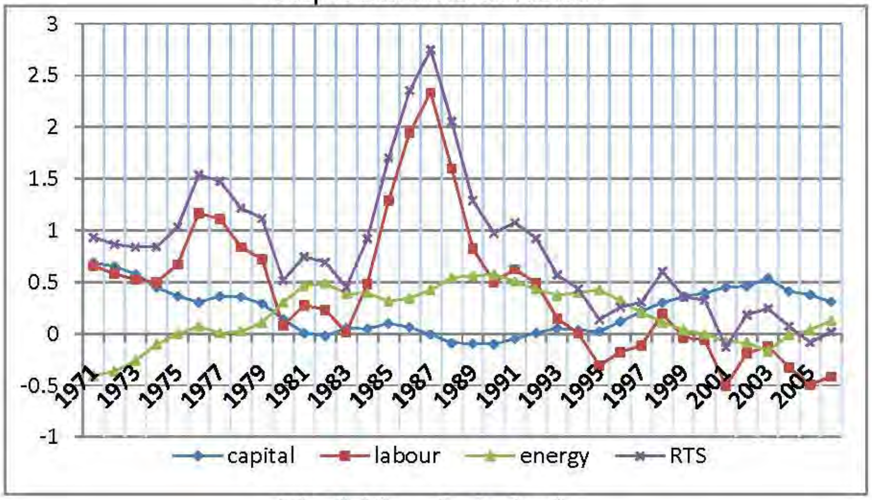
Table 4.7: VES Parameters with Total Energy – Manufacturing Sector

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	0.225	0.225	-0.102	0.684
$\in_l$	0.417	0.669	-0.504	2.333
$\in_e$	0.179	0.270	-0.411	0.574
RTS	0.821	0.668	-0.132	2.748
σ_{ke}	0.806	0.021	0.740	0.831
σ_{le}	0.108	0.081	0.001	0.329
σ_{kl}	0.199	0.221	0.007	0.968

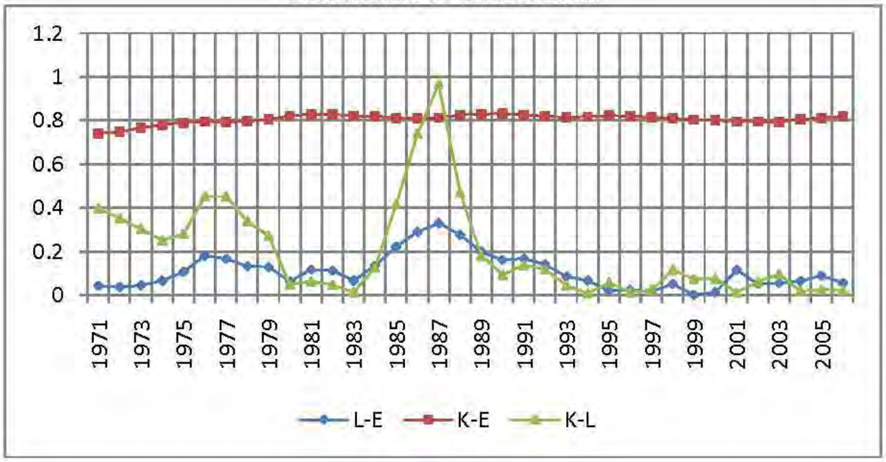
Table 4.7 has the results of output elasticities of capital, labour, energy, RTS, capital-energy and labour-energy elasticities of substitution evaluated at mean values of variables. The average elasticity of capital remains relatively constant after the introduction of energy, while that of labour increased slightly. The marginal productivity of energy is higher in the manufacturing sector (0.179%) than the whole economy. The scale elasticity is far higher (0.82%) for manufacturing sector compared to the whole economy. Total energy appears to be substitute for capital and complement for labour, however this may not say much given that capital-energy interaction coefficient is insignificant. Meaningful information can only be achieved at the disaggregated energy level. The capital labour elasticity of substitution (0.199) agrees with that obtained from no-energy scenario model, suggesting that they are more of complements than substitutes. The variability over time of capital, labour and scale elasticities are similar to the case without energy, with manufacturing RTS evolving in phase with labour elasticity. The elasticities of substitution between labour and energy and labour and capital seem to also evolve in phase. However, it is not possible to say much from this, including capital-energy elasticity of substitution, since capital-energy interaction coefficient is not significant and therefore disaggregating energy would be more meaningful.

Figure 4.9: Evolution of (Energy) Elasticities over Time – Manufacturing

Output and scale elasticities



Elasticities of substitution



The pattern makes economic sense in that coefficients of labour productivity, RTS and K-L elasticity of substitution evolve in phase. The more capital can substitute for labour, the higher the productivity of labour[59] and hence RTS. This explanation is based on the fact that capital intensive processed require more skilled labour, hence higher labour productivity. This co-evolution is more pronounced in manufacturing, but also present in agriculture and mining.

4.3.2.3 Estimations with Disaggregated Energy

The Durbin-Watson-Hausman statistics for endogeneity test suggest that OLS is consistent for models with gas and coal, but inconsistent for the rest of

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[59] Capital intensive processes require more skilled labour with higher productivity.

manufacturing energy types. Therefore 3sls method is applied to models with electricity, diesel and kerosene, while OLS is applied to models with gas and coal. For the OLS, the two Chi2 columns report model F-statistics. The overall model statistics for all the respective production and energy demand equations are satisfactory, with significant Chi2 and F-statistics.

Table 4.8: VES Estimates with Energy types – Manufacturing Sector

	Electricity	*Diesel*	*Gas*	*Kerosene*	*Coal*
R_y^2	**0.97**	**0.96**	**0.94**	**0.95**	**0.94**
$Chi2_y$	**1654.35**	**1984.97**	**2006.71**	**763.48**	**358.02**
R_e^2	**0.95**	**0.84**	**0.69**	**0.43**	**0.43**
$Chi2_e$	**746.45**	**190.18**	**94.96**	**26.85**	**4.52**
DWH[60]. (P-VAL)	**928.33 (0.000)**	**144.38 (0.000)**	**1.90 (0.177)**	**5.65 (0.023)**	**1.80 (0.189)**
Parameters					
α_0	-70.133 (-3.01)	-88.419^c (-1.84)	36.036 (0.77)	-204.94^a (-3.67)	30.763 (0.97)
α_1	-0.000 (-0.05)	0.007^a (6.83)	0.011^a (7.14)	0.013^a (6.94)	0.013^a (8.9)
α_2	6.024^c (1.69)	12.433^a (3.27)	16.467^a (6.94)	13.559^a (3.58)	10.460^a (4.86)
α_3	13.039^a (3.73)	14.347^b (2.25)	-5.286 (-0.69)	23.970^a (3.70)	-5.047 (-1.08)
α_4	-0.159 (-0.06)	-6.702 (-0.87)	-19.649^a (-4.84)	7.998^c (1.68)	-12.744^a (-5.29)
α_5	-1.079^a (-2.50)	-1.991^a (-4.04)	-2.296^a (-5.40)	-1.646^a (-3.63)	-1.509^a (-4.54)
α_6	0.176^b (1.97)	0.260^b (1.99)	0.083 (0.50)	-0.135 (-1.12)	0.077 (0.76)
α_7	-0.159^b (-0.38)	0.585 (0.58)	2.530^a (4.60)	-0.890^b (-1.81)	1.607^a (5.61)
β_0	-8.680^a (-8.55)	-2.218^c (-1.90)	9.255^a (6.65)	5.418 (0.69)	16.337^a (7.18)
β_1	1.879^a (17.20)	1.069^a (8.31)	0.037 (0.24)	1.053 (1.21)	-0.656^b (-2.61)

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[60] Insignificant DWH test implies that OLS is consistent; model (9) is estimated with the OLS option and the model F-values. Otherwise, 3sls is used and model chi2 values reported.

β_{31}	-0.008 (-0.08)	0.276^{b} (2.29)	0.469^{a} (3.09)	-2.108^{a} (-2.54)	0.501^{b} (2.03)
β_{32}	-0.050 (-0.30)	-0.125 (-0.28)	0.031 (0.55)	-8.243^{b} (-2.70)	-1.014 (1.12)
β_{33}	-	0.165 (0.37)	-	-7.349^{b} (-2.37)	1.100 (1.19)
β_{34}	-0.168^{b} (-2.02)	-0.224^{a} (-2.32)	0.225^{c} (1.90)	-0.168 (-0.26)	-0.483^{b} (-2.52)

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively. Parentheses contain t-values. β_{3i} are the coefficients of energy prices: $i = 1$ for electricity; 2 for diesel; 3 for kerosene and 4 for coal. Gas prices are not available. Sample size is 36 observations.

The main variables of interest to evaluate the parameters of the production function are significant for most of the energy types. The estimates of energy demand suggest that except for gas and coal, output has significant and high positive effect on the demand for energy types. The magnitudes of the coefficients of income imply that electricity, diesel and kerosene are superior goods, with income elasticities of 1.88, 1.07 and 1.05 respectively. Coal is an inferior good in manufacturing production, since a percentage increase in income results in 0.66% fall in the demand for coal. The coefficient in gas demand equation is weakly positive but insignificant. The coefficients of own prices for the various energy types have the expected negative sign in accordance with the classical demand theory. However, these coefficients are not significant for electricity and diesel. Manufacturing kerosene demand is very elastic (with elasticity of -7.35%), while that of coal is relatively inelastic. Cross elasticities indicate that electricity and coal are substitutes; diesel complements electricity but is a substitute for coal. Gas complements electricity and coal, while kerosene is substitute with all energy types.

Table 4.9 presents the output elasticities of capital, labour and energy, scale elasticity and the capital-energy and energy-labour elasticities of substitution. These parameters are calculated at the mean values of the variables.

Table 4.9: VES Parameters with Energy types – Manufacturing Sector

Model	parameter Mean	Std. Dev.	Min	Max
Output Elasticity of Capital (N =36)				
Electricity	0.133	0.103	-0.008	0.347
Diesel	0.175	0.178	-0.070	0.499
Gas	0.226	0.215	-0.089	0.664
Kerosene	0.191	0.202	-0.107	0.579
Coal	0.154	0.145	-0.054	0.447
Output Elasticity of Labour				
Electricity	0.193	0.393	-0.586	0.979
Diesel	0.269	0.583	-0.843	1.773
Gas	0.367	0.789	-0.887	2.212
Kerosene	0.473	0.773	-1.279	1.957
Coal	0.391	0.632	-0.586	1.675
output Elasticity of Energy				
Electricity	0.420	0.061	0.274	0.539
Diesel	0.288	0.099	0.041	0.439
Gas	0.132	0.243	-0.418	0.489
Kerosene	-0.017	0.094	-0.147	0.229
Coal	0.066	0.155	-0.295	0.294
Scale elasticity				
Electricity	0.681	0.063	0.472	0.706
Diesel	0.455	0.096	0.217	0.605
Gas	0.601	0.027	0.596	0.716
Kerosene	0.350	2.500	0.017	3.005
Coal	0.585	0.034	0.496	0.652
Energy-Labour elasticity of Substitution				
Electricity	2.922	12.763	0.129	59.113
Diesel	0.313	0.162	0.030	0.622
Gas	0.142	0.078	0.008	0.334
Kerosene	2.151	6.304	0.041	37.143
Coal	0.166	0.091	0.009	0.365
Energy-Capital Elasticity of Substitution				
Electricity	0.601	0.063	0.472	0.706
Diesel	0.455	0.096	0.217	0.605
Gas	0.680	0.027	0.596	0.716
Kerosene	3.517	11.585	0.017	70.005
Coal	0.585	0.034	0.496	0.652

In general, compared to the no-energy scenario, the output elasticities of capital have dropped slightly (except with gas) while those of labour increased slightly (except with electricity and diesel) across most of the energy types. The output elasticities of energy types are highest for electricity (0.420), followed by diesel (0.288) and gas (0.132). It is least for coal (0.066) and negative for kerosene (-0.017). This trend also reflects in the scale elasticities with the respective energy types.

Figure C3 in Appendix suggests that electricity complements capital in manufacturing, but the complementarity is stronger at low and high capital-electricity ratio, and relatively weaker on average. This may imply that as capital intensifies, skilled labour is required which tend to ease the complementarity. However, this cannot be verified since there are no data of skilled labour in manufacturing. Labour is shown to be strong substitute of electricity at all levels of labour-electricity ratio. The variation of capital-coal elasticity of substitution shows the same tendency as with electricity. However, at higher labour-coal ratios, labour tends to be a stronger substitute for coal. Manufacturing kerosene is less of substitute for labour than it is for capital. However, at high capital-kerosene ratios, the substitutatibility with capital decrease, but increases with labour. This could be explained in terms of the fact that when capital increases relative to kerosene, producers move to better forms of energy whereas with relatively higher labour (unemployment), the poor may rely on less capital intensive activities using lesser quality energy.

4.3.3 Agricultural Sector

4.3.3.1 No-Energy Scenario

The Ordinary Least Square (OLS) estimates of two inputs (capital and labour) VES production function are shown below[61]. The R-square and adjusted R-square of 79% and 76% respectively, with model F-statistics of 29.26 indicate a good model performance.

$$y = \underset{(-3.39)}{-59.990^{a}} + \underset{(3.50)}{0.016^{a}}\,t + \underset{(2.04)}{4.238^{b}}\,k + \underset{(2.08)}{5.175^{b}}\,l - \underset{(-2.03)}{0.599^{b}}\,kl$$

$R^2 = 0.79$: $AR^2=0.76$: F-stat=29.26: $N = 36$

The t-values in parentheses show that the constant term, time trend and all the variables and interactive term are significant at five percent level and less. The significance of time trend (0.016) may be attributed to technology in agriculture. The coefficients of capital and labour are positive while that of the

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[61] Figures in bracket are t-statistics. ^{a}, ^{b}, ^{c} denote that coefficient is significantly different from zero at 1, 5 and 10% significance levels respectively.

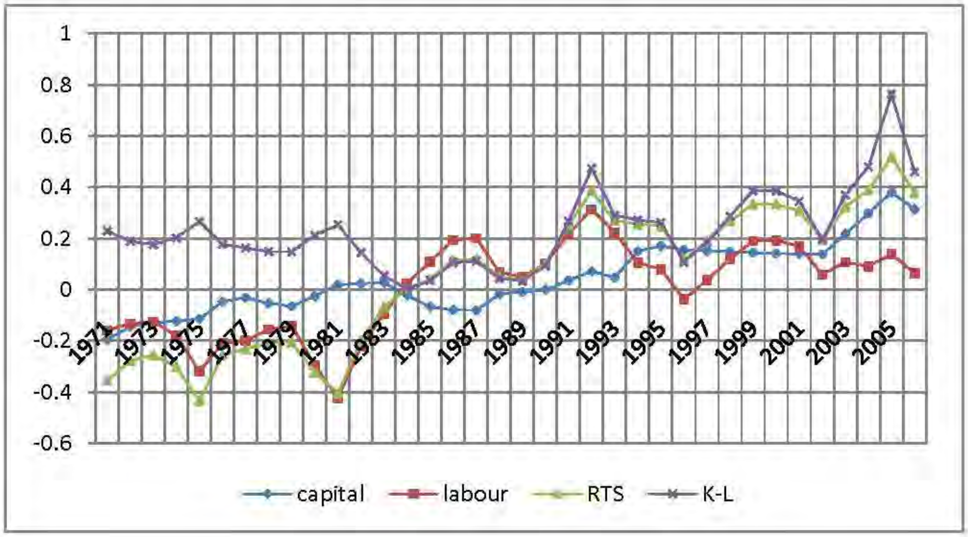
interaction term is negative. The output, scale and substitution elasticities are presented in Table 4.10.

Table 4.10: Capital-labour VES Parameters - Agriculture

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	0.043	0.137	-0.195	0.379
$\in_l$	0.004	0.180	-0.424	0.313
RTS	0.047	0.272	-0.434	0.518
σ_{kl}	0.231	0.156	0.001	0.762

Agricultural output elasticities of capital and labour, calculated at mean values of data show that in the absence of energy, one percent increase in capital and labour results in 0.043% and 0.004% increase in output respectively. This places the scale elasticity at 0.047 on average, implying that a percentage increase in both capital and labour (in the absence of energy) brings about 0.047% increase in agricultural output. The capital-labour elasticity of substitution is on average 0.231, implying a strong degree of complementarity between both inputs. There is a great deal of variation within the span of the parameters as indicated in Figure 4.10. The output elasticities of inputs scale and substitution elasticities trend upward.

Figure 4.10: Evolution of (K-L) Elasticities and RTS over Time – Agriculture



4.3.3.2 Estimation with Total Energy

The specification of VES production function with energy includes the capital-labour interaction term since from the no-energy case, capital and labour appear to complement each other. Results of the joint estimates of production and energy demand in agriculture are shown below. With a DWH statistic of 120.18, there is evidence of endogeneity and therefore the estimates reported are for 3sls regression. The R-square for production function does not change significantly (76%) after the inclusion of energy and that of energy demand function is at 84%. With Chi2 of 133.72 and 194.85 for the respective equations, the model performance is not questionable.

$$\begin{cases} y = \underset{(0.91)}{243.528} + \underset{(3.95)}{0.028^{a}}\, t - \underset{(-1.66)}{25.997^{c}}\, k - \underset{(-1.91)}{23.246^{c}}\, l - \underset{(1.93)}{18.487^{c}}\, e + \underset{(1.59)}{1.578^{c}}\, kl + \\ \underset{(2.21)}{1.386^{b}}\, ke + \underset{1.83}{0.935^{c}}\, le \\ e = \underset{(3.96)}{13.067^{a}} + \underset{(0.87)}{0.377}\, y - \underset{(4.28)}{0.264^{a}}\, pe \end{cases}$$

$R_y^2 = 0.76$; $Chi2_y = 133.72$; $R_e^2 = 0.84$; $Chi2_e = 194.85$; $DWHstat = 120.18(0.000)$

$N = 36$

As suggested by the t-values in brackets, apart from the constant term, all other coefficients are significant (mostly at 10% level) for production equation. In the energy demand equation, income is not significant, but all the other coefficients are. The coefficient of agricultural value added (though not significant) suggest that energy is an essential input (coefficient is positive and less than one). The price elasticity of agricultural energy demand (-0.264) confirms this essential input nature of energy, however, detailed interpretation can only be possible in models with disaggregate energy types.

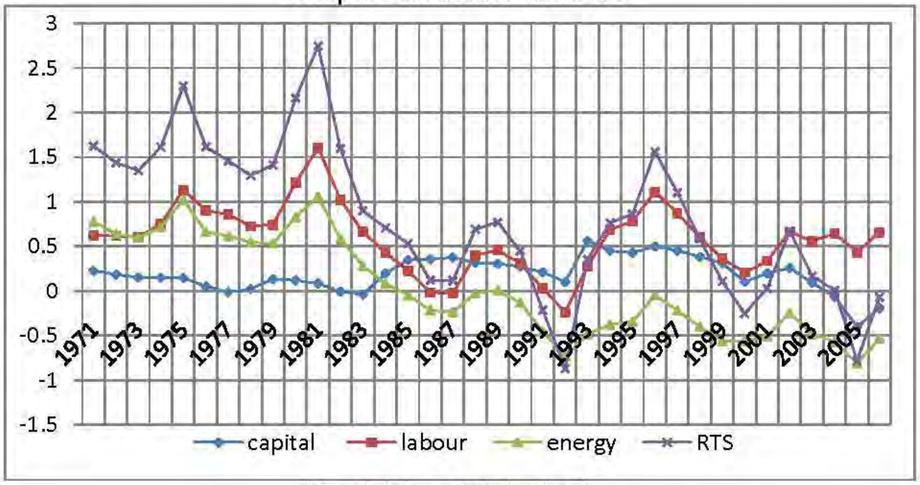
Table 4.11: VES Estimates with Total Energy- Agriculture

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	0.188	0.200	-0.404	0.564
$\in_l$	0.589	0.377	-0.237	1.604
$\in_e$	0.026	0.549	-0.811	1.055
RTS	0.803	0.839	-0.870	2.743
σ_{ke}	0.290	0.207	0.037	1.077
σ_{le}	0.168	0.142	0.004	0.780
σ_{kl}	0.192	0.077	0.009	0.349

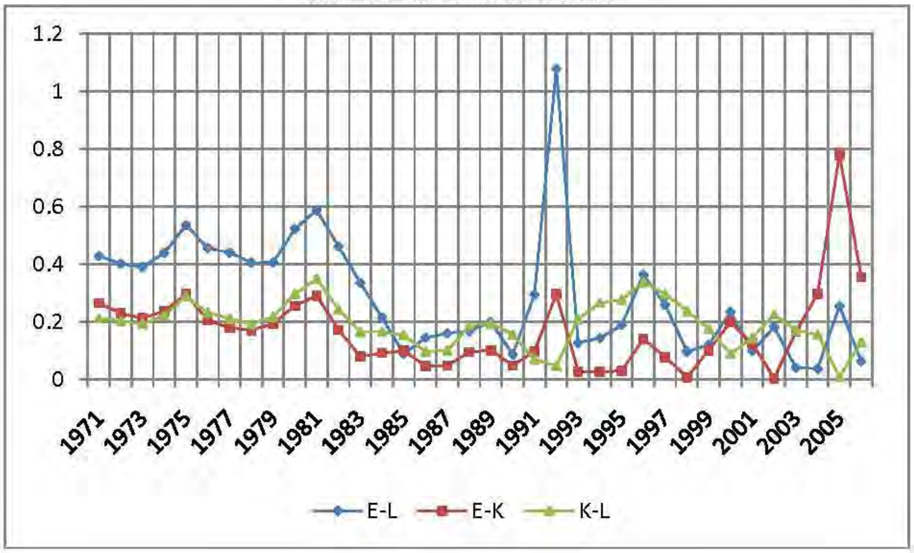
Table 4.11 reports output elasticities, scale and substitution elasticities evaluated and mean values of data. The output elasticities of capital and labour have increased to 0.188 and 0.589 respectively, and that of energy is at 0.026. This suggests that energy is important in enhancing capital and labour productivities. This results in a scale elasticity of 0.803. The elasticities of substitution suggest that all three inputs have high degree of complementarity. However, these results can only make sense when the different effects of various energy types are controlled for.

Figure 4.11: Evolution of (Energy) Elasticities with Time – Agriculture

Output Elasticities and RTS



Elasticities of Substitution



4.3.3.3 Estimations with Disaggregated Energy

While there is evidence of endogeneity between agricultural GDP on one hand and electricity, diesel and kerosene demands on the other, there is no indication of endogenous relationship between the latter and coal demand. Therefore OLS are reported for coal in Table 4.12 and 3sls for other energy types. The goodness of fit measures are alright for production equations, but for energy demand equations it ranges from 84% for diesel to 43% for coal and kerosene. However, the Chi2 for electricity, diesel and kerosene suggest that the models are all trustworthy. Coal model has a low F-statistic (4.52) but acceptable, judging from the model P-values.

Table 4.12: VES Estimates with Energy types - Agriculture

	Electricity	*Diesel*	*Kerosene*	*Coal*
R_y^2	**0.75**	**0.98**	**0.95**	**0.99**
$Chi2_y$	**143.36**	**1984.97**	**763.48**	**358.02**
R_e^2	**0.65**	**0.84**	**0.43**	**0.43**
$Chi2_e$	**90.81**	**190.18**	**26.85**	**4.52**
DWH[62]. (P-VAL)	**264.48 (0.000)**	**32.52 (0.000)**	**11.31 (0.002)**	**1.04 (0.315)**
Parameters				
α_0	60.565 (0.56)	89.960 (0.64)	-155.24^b (-2.80)	-59.092^a (-3.21)
α_1	0.011^b (2.10)	0.020^a (4.80)	0.023^b (2.74)	0.020^a (5.05)
α_2	-8.386^c (-1.79)	-7.953^c (-1.69)	8.150^c (1.65)	1.304 (0.65)
α_3	-7.664^b (-2.73)	-13.109^c (-1.74)	11.817^c (1.67)	2.913^c (1.61)
α_4	-2.568 (-1.06)	-8.721^c (-1.65)	10.981^b (2.06)	2.698^a (4.03)
α_5	0.854^b (1.79)	0.543^c (1.69)	-0.586 (-0.94)	-0.065 (-1.23)
α_6	0.269^b (2.37)	0.405^c (1.91)	-0.581^c (-1.88)	-0.096^c (1.76)
α_7	0.053^b (2.38)	0.835^c (1.74)	-0.862^b (-2.01)	-0.272^a (-3.97)
β_0	-29.095^a (-6.49)	4.107^a (3.38)	7.508^c (1.67)	19.839^b (2.89)
β_1	4.814^a (6.87)	0.882^a (5.24)	0.302 (0.44)	-0.040 (-0.04)
β_{31}	-0.069 (-0.30)	-0.079 (-0.61)	-2.931^a (-4.76)	-4.282^a (-4.15)
β_{32}	0.972 (0.61)	-0.104^b (-2.22)	0.094 (0.04)	7.301^c (1.89)
β_{33}	-1.240 (-0.75)	-	-0.002 (0.01)	-8.597^b (-2.17)
β_{34}	0.140 (0.38)	-	-0.962^b (-2.19)	-1.180^c (-1.60)

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively. Parentheses contain t-values. β_{3i} are the coefficients of energy prices: I = 1 for electricity; 2 for diesel; 3 for kerosene and 4 for coal. Gas prices are not available. The sample size is 36 observations.

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[62] Insignificant DWH test implies that OLS is consistent; model (9) is estimated with the OLS option and the model F-values. Otherwise, 3sls is used and model chi2 values reported.

According to the t-values in parentheses, most of the coefficients, especially those of interest to the VES production function are significant. In the energy demand equations, the intercept is significant for all the energy types. The coefficient of agricultural GDP is significant for electricity and diesel, but not for kerosene and coal. One percent increase in output brings about 4.81% increase in electricity demand (a luxury good nature), and 0.88% increase in diesel demand (an essential input nature). This is not contrary to expectation, given that mechanisation makes diesel an essential input in agriculture. In electricity demand equation, own price coefficients are negative, but not significant. The coefficient of diesel price in diesel demand equation confirms the essential input nature, with one percent increase in price resulting in only 0.102% decrease in diesel demand. Cross price coefficients are not significant. The coefficient of own price of kerosene is negative but not significant. Electricity and coal prove to be strong substitutes for kerosene, with elasticity of -2.931% and -0.932% respectively. In coal demand equation, one percent increase in coal price brings about 1.18% fall in coal demand. The coefficients of cross price elasticities suggest that electricity and kerosene are strong substitutes to coal while diesel is a strong complement, with elasticities of -4.282, -8.597 and 7.301 percent respectively.

Table 4.13: VES Parameters with Energy types - Agriculture

Model	parameter Mean	Std. Dev.	Min	Max
Output Elasticity of Capital (N= 36)				
Electricity	0.048	0.114	-0.221	0.257
Diesel	0.130	0.103	-0.184	0.271
Kerosene	0.230	0.384	-0.552	0.575
Coal	0.111	0.090	-0.005	0.418
Output Elasticity of Labour				
Electricity	0.198	0.229	-0.219	0.789
Diesel	0.416	0.152	0.027	0.820
Kerosene	0.712	0.682	-0.106	1.892
Coal	0.263	0.253	-0.089	1.155
Output Elasticity of Energy				
Electricity	0.128	0.087	-0.014	0.322
Diesel	0.623	0.269	0.063	1.066
Kerosene	-0.079	0.318	-0.620	0.536
Coal	-0.032	0.080	-0.167	0.142
Scale elasticity				
Electricity	0.374	0.276	-0.138	1.095
Diesel	1.169	0.435	0.152	1.926

Kerosene	0.603	1.000	-0.523	2.603
Coal	0.342	0.358	-0.062	1.524
Energy-Labour elasticity of Substitution				
Electricity	0.746	0.392	0.103	2.191
Diesel	0.473	0.085	0.268	0.514
Kerosene	3.402	6.558	0.002	24.005
Coal	1.547	2.353	0.020	10.617
Energy-Capital Elasticity of Substitution				
Electricity	0.258	0.100	0.017	0.521
Diesel	0.257	0.136	0.086	0.423
Kerosene	0.361	0.371	0.010	2.148
Coal	2.173	4.970	0.004	28.636

Figure 4.12: Output Elasticities of Agricultural Energy types

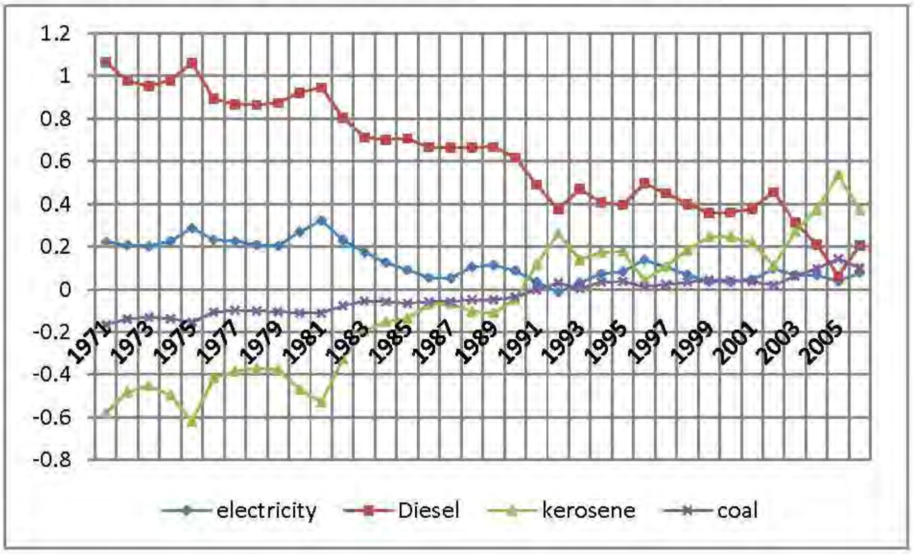

Table 4.13 reports the various elasticities. The output elasticity of capital is lower in the presence of all energy types relative to the total energy model, but higher than for the model without energy. That of labour remained relatively high. This suggest that in the analysis with aggregate energy, average effects are captured, which results in more importance given to capital than energy. The output elasticities of energy types show diesel with the highest coefficient, followed by electricity. These parameters are weak and negative for kerosene and coal. It should be noted that the capital energy interaction terms (α_5) are not significant while those of labour (α_6) are only weakly significant for these two energy types. It is expected therefore that these negative effects are not significant. The scale elasticity is noticeably high for diesel corresponding to

its high output elasticity. The elasticities of substitution indicate that all energy types have strong degree of substitutability for labour and complementarity for capital. However, the substitution elasticities of diesel-labour (and electricity-labour to a lesser extent) seem moderate, showing signs of some complementarity also. This is suggestive of the fact that diesel operated machinery requires some labour (more skilled). In contrast, irrigation schemes that require electricity use far less labour than diesel operation tasks.

The evolution over time of output and scale elasticities for the four energy types (in figure C3 of Appendix) shows a great deal of variation. While output elasticities of electricity and coal have been relatively stable over time, that of diesel has been falling and that of kerosene rising. The evolution in opposing direction of output elasticities of diesel and kerosene suggests that in periods of high diesel prices, some kerosene might be used in place of diesel.

4.3.4 Mining Sector

4.3.4.1 No-Energy Scenario

As with the other sectors, the OLS estimates for two-input VES production function without energy for mining sector are reported below.

$$y = \underset{(-1.82)}{-16.279^{c}} + \underset{(3.04)}{2.825^{a}}\, k + \underset{(3.11)}{4.100^{a}}\, l - \underset{(-3.08)}{0.423^{a}}\, kl$$

$R^2 = 0.56$: F-stat=7.21: $N = 36$

The overall model F-statistic is 7.21 and significant, with R-square of 56%. The coefficients of individual variables are significant, with (negative) constant term at 10% level, capital and labour at 1% level and the input interaction term (negative) significant at 1% level according to the t-values[63] in parentheses. The time trend coefficient is not significant, and it reduced the performance of the model, so it was excluded from the estimation. The non-

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[63] Figures in bracket are t-statistics. ^{a}, ^{b}, ^{c} denote that coefficient is significantly different from zero at 1, 5 and 10% significance levels respectively.

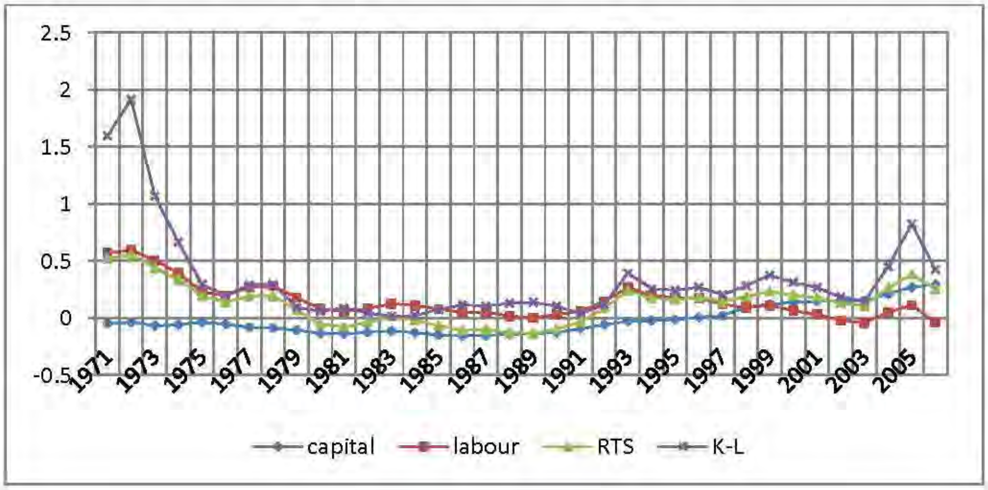
significance suggests that there is no significant technical progress in the mining sector that could lead to rise in production over time.

Table 4.14: Capital-labour VES Parameters – Mining Sector

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	-0.019	0.127	-0.158	0.291
$\in_l$	0.150	0.157	-0.042	0.593
RTS	0.131	0.180	-0.136	0.556
σ_{kl}	0.336	0.416	0.015	1.915

The values of output, scale and substitution elasticities are in Table 4.14. The marginal elasticity of capital is negative, implying that on average, one percent increase in capital results in 0.019% fall in output in the mining sector. This coefficient shows that the mining sector is over capitalised. That of labour is positive, and a percentage increase in labour leads to 0.15% increase in output. One percent increase in both inputs brings 0.131% increase in mining output as suggested by the scale elasticity. The capital-labour elasticity of substitution indicates that mining capital and labour are complements, though not strongly. The variations of these parameters over time are not quite pronounced. However, in the early years (1971 to 1976) of the series, capital and labour are substitutes, and they exhibit more of complementary relationship till the end of the series.

Figure 4.13: Evolution of (K, L) Elasticities and RTS over Time – Mining



4.3.4.2 Estimation with Total Energy

The inclusion of aggregate energy yields a DWH statistic of 4.41, with probability value of 0.043, implying that OLS is inconsistent. The 3sls regression was performed with a hundred iterations, which lead to convergence and better model performance than simple 3sls. The estimation results are presented below. After the inclusion of total energy, the model statistics improved for production equation, with R-square of 61% and Chi2 of 37.33. The statistics for energy demand equation have Chi2 of 333.65 and R-square of 90%.

$$\begin{cases} y = \underset{(-3.28)}{126.85^{a}} + \underset{(0.95)}{1.858}\ k + \underset{(4.04)}{17.947^{a}}\ l + \underset{(3.76)}{11.304^{a}}\ e - \underset{(-0.15)}{0.024^{c}}\ kl - \underset{(-1.73)}{0.150^{c}}\ ke - \underset{(-4.28)}{1.455^{a}}\ le \\ e = -\underset{(-2.06)}{12.805^{b}} + \underset{(3.85)}{2.141^{a}}\ y - \underset{(17.07)}{0.266^{a}}\ pe \end{cases}$$

$$R_y^2 = 0.61;\ Chi2_y = 37.33;\ R_e^2 = 0.90;\ Chi2_e = 333.65;\ DWHstat = 4.41(0.043)$$

$$N = 36$$

Though capital and capital-labour interaction terms are not significant, all other coefficients are. The non-significance of capital is not surprising, because the mining sector (though capital intensive) is a very energy intensive sector. The operation of capital therefore largely depends on energy, and hence the inclusion of energy reduces the significance of capital coefficient. The energy demand equation has the expected classical demand behaviour and all coefficients are significant. A percentage increase in mining production (average price of energy) results in 2.141% (0.266%) rise (fall) in aggregate energy demand. However, these are aggregate effects; more meaningful interpretation can be possible only after disaggregation. The elasticities of inputs, scale and substitution derived at average values of variables are presented in Table 4.15.

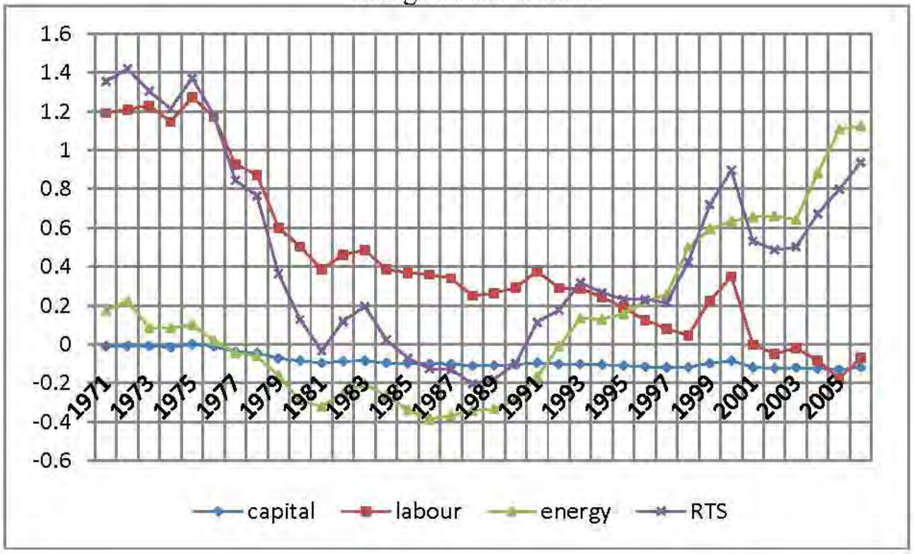
Table 4.15: VES Parameters with Total Energy – Mining Sector

$N = 36$	Mean	Std. Dev.	Min	Max
$\in_k$	-0.086	0.040	-0.132	-0.001
$\in_l$	0.431	0.422	-0.178	1.272
$\in_e$	0.126	0.427	-0.386	1.125
RTS	0.470	0.494	-0.204	1.419
σ_{ke}	0.296	0.289	0.002	0.964
σ_{le}	0.984	1.002	0.027	4.793
σ_{kl}	1.125	0.417	0.193	2.780

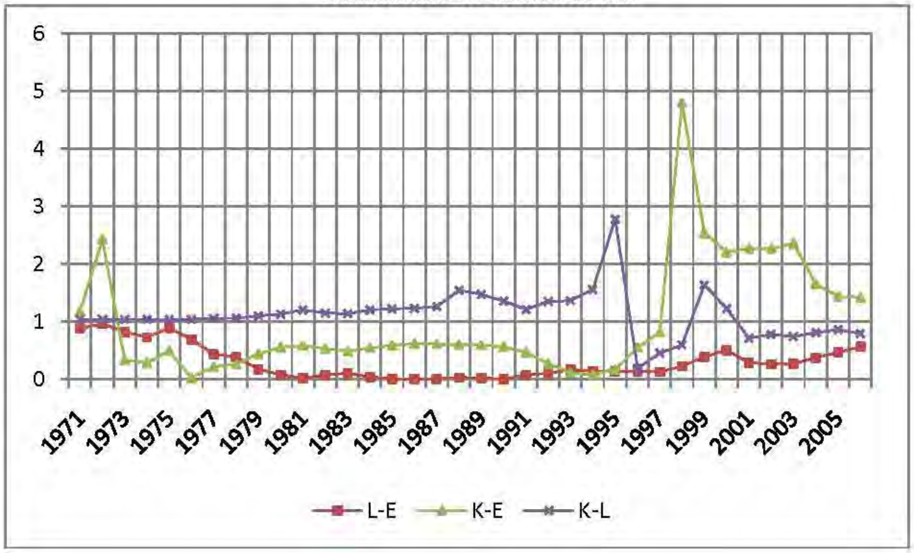
The marginal elasticity of capital remains negative, that of labour increases slightly to 0.0431 and that of energy is at 0.126. The inclusion of energy raises the scale elasticity to from 0.131 to 0.470%. Substitution elasticities suggest that in the presence of energy, labour is easily substituted for by capital and energy, with average coefficients of 1.125 and 0.984% respectively. Capital and energy are complements, with elasticity of 0.296. The evolution of the parameters over time (Figure 4.14) show that while the marginal elasticity of capital is relatively stable, that of labour is constantly dropping, but that of energy is rising. This evolution seems to agree with the nature of extractive industry like mining, where as more resources are exploited, it becomes increasingly difficult to extract more, except with more sophisticated capital technique (requiring more energy), therefore the marginal elasticity and hence productivity of labour drops. However, this is only intuitive and the mechanism could be otherwise. The elasticities of substitution are relatively stable over time, except for the period from 1994 to 2006, corresponding to the period of the post apartheid era, with major policy (especially labour) changes.

Figure 4.14: Evolution of (Energy) Elasticities – Mining

Marginal Elasticities



Elasticities of Substitution



4.3.4.3 Estimations with Disaggregated Energy

The endogeneity test for disaggregated energy types show that OLS is inconsistent in all the sub models, requiring 3sls regression method. The results are reported in Table 4.16. The overall model statistics show significant Chi2, and satisfactory R-squares.

Table 4.16: VES Estimates with Energy types – Mining Sector

	Electricity	*Liquid petroleum*	*Coal*
R_y^2	**0.59**	**0.65**	**0.99**
$Chi2_y$	**0.75**	**71.95**	**358.02**
R_e^2	**0.45**	**0.87**	**0.43**
$Chi2_e$	**48.55**	**241.77**	**4.52**
DWH[64]. (P-VAL)	**22.79 (0.000)**	**3.46 (0.072)**	**14.05 (0.002)**
Parameters			
α_0	-24.880 (-0.73)	-47.219 (-1.60)	-40.575^a (-2.87)
α_1	-0.001 (-0.23)	-0.001 (-0.58)	0.003^b (2.72)
α_2	-2.606 (-0.65)	2.760 (0.96)	4.051^a (3.40)
α_3	8.596^c (1.94)	6.447^a (2.83)	3.886^a (3.18)
α_4	3.615^c (1.79)	5.028^a (2.57)	2.446^a (3.60)
α_5	0.059 (1.31)	-0.171^c (-1.85)	-0.309^b (-2.82)
α_6	0.194^b (2.52)	-0.180^c (-1.60)	-0.198^a (-3.43)
α_7	-0.792^b (-1.71)	-0.474^a (-5.78)	-0.081^b (-2.50)
β_0	48.696^a (4.41)	8.237 (0.95)	-246.39^a (-6.12)
β_1	3.723^a (3.76)	0.017 (0.02)	2.913^a (6.27)
β_{31}	-1.237^a (-4.08)	-0.411^b (-2.06)	3.648^a (3.96)
β_{32}	-0.325^a (-3.50)	-0.302^a (-5.03)	0.769^b (2.81)
β_{34}	0.135 (0.61)	0.294^c (1.97)	-3.053^a (-4.44)

Notes: ^{a}, ^{b}, and ^{c} denote significance at 1%, 5%, and 10% levels respectively. Parentheses contain t-values. β_{3i} are the coefficients of energy prices: I = 1 for electricity; 2 average price for liquid fuel and 4 for coal price. Gas prices are not available. The sample size is 36 observations.

In production functions, all coefficients for coal model are significant. The constant, trend and capital coefficients are not significant for electricity and liquid petroleum. All other variables for the two sub models are significant. In the energy demand equations, the constant term is significant for electricity and coal, but not for liquid petroleum. The sign of the coefficient of mining

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[64] Insignificant DWH test implies that OLS is consistent; model (9) is estimated with the OLS option and the model F-values. Otherwise, 3sls is used and model chi2 values reported.

GDP is positive. Mining GDP has significant impact on mining electricity and coal demands, with a percentage increase in GDP leading to 3.723% and 2.913% increase in the demand for the respective energy types. Mining GDP coefficient is not significant in liquid petroleum demand. Own price elasticities are all significant and negative. One percent increase in prices of electricity, liquid petroleum and coal results in 1.237, 0.302 and 3.053 percent fall in the demands for the respective energy types. Liquid petroleum portrays the nature of essential input in the mining sector. Coefficient of cross prices suggest that liquid petroleum and electricity are complements, with 0.325 and 0.411 percent fall in the demand for electricity and liquid petroleum, resulting from one percent increase in the prices of liquid petroleum and electricity respectively. Liquid petroleum is substitute to coal, with one percent increase in coal and liquid petroleum prices resulting in 0.294 and 0.769 percent increase in the demands for liquid petroleum and coal respectively. Coal and electricity seem to be substitutes, though the coefficient of coal price is not significant in electricity demand equation. When the price of electricity increases by one percent, coal demand responds with 3.648 percent increases.

Table 4.17: VES Parameters with Energy types – Mining Sector

Model	parameter Mean	Std. Dev.	Min	Max
Output Elasticity of Capital (N = 36)				
Electricity	0.019	0.052	-0.100	0.091
Liquid petroleum	-0.130	0.022	-0.162	-0.089
Coal	-0.012	0.112	-0.152	0.450
Output Elasticity of Labour				
Electricity	0.079	0.196	-0.155	0.520
Liquid petroleum	0.284	0.189	-0.147	0.587
Coal	0.189	0.117	-0.017	0.475
Output Elasticity of Energy				
Electricity	0.104	0.262	-0.150	0.771
Liquid petroleum	0.161	0.143	-0.037	0.469
Coal	0.052	0.072	-0.039	0.256
Scale elasticity				
Electricity	0.202	0.236	-0.086	0.738
Liquid petroleum	0.315	0.194	0.047	0.828
Coal	0.230	0.204	-0.066	0.761
Energy-Labour elasticity of Substitution				
Electricity	2.233	5.543	0.283	31.312

Liquid petroleum	0.214	0.221	0.008	0.844
Coal	3.783	4.344	0.009	19.524
Energy-Capital Elasticity of Substitution				
Electricity	0.398	0.400	0.034	1.660
Liquid petroleum	1.253	4.198	0.052	25.342
Coal	0.409	0.851	0.004	5.109

The different elasticities at mean values are reported in Table 4.17. The output elasticity of capital in the presence of electricity is 0.019%. This elasticity is negative in the presence of all other energy types. That of labour is very low (0.079) for electricity, this implies that electricity using machines are less labour requiring, such that an extra unit of labour will result in only a dismal increase in output. This is also confirmed by the positive coefficient of capital elasticity, which also suggests that the mining sector can accommodate more electrical machines, relative to capital using other energy types. The elasticities of energy types show that one percent increase in electricity, liquid petroleum, and coal use brings about 0.104, 0.161 and 0.052 percent increase in mining output respectively, holding all else constant. The scale elasticity is higher for liquid petroleum and coal, mainly due to the contribution of labour, but also energy, for liquid petroleum. The magnitude of labour elasticity implies that there is room for (production enhancing) employment in the mining sector, but this can only come with higher liquid petroleum consumption.

According to the elasticities of substitution, electricity and coal appear to be strong substitutes for labour, while liquid petroleum show some complementary effect with labour. This tendency is reverse for capital-energy substitution elasticity, where electricity and coal show complementarity with capital while liquid petroleum shows some substitutionary effect.

According to the standard deviations and the graphs of figures C4 (in Appendix), the variations in output response to energy types and in scale elasticities are moderate relative to elasticities of substitution. From 1990, the output elasticities of all energy types have been trending upward, with electricity rising the fastest, followed by liquid petroleum, and coal is moderate. This is indicative of increase in energy prices (especially petroleum) but also capacity expansion. This tendency is also suggestive of an extractive industry like mining, where, the more exploitation is done, the less easy it is to exploit further, and growth then comes with higher effort, indicated by greater energy usage. The lesson here is that future growth in the mining sector will come with higher energy requirement, and there will be a tendency to move from electricity and petroleum to coal if increases in electricity tariffs and current tendencies in liquid fossil fuel prices keep on.

4.4 Conclusion

This chapter had as objective, to use a VES production function in three inputs in order to relax the quite often implausible assumptions of unitary (Cobb-Douglas) and constant (CES) elasticity of factor substitution. The work also takes care of endogeneity problems by carrying out a Durbin-Wu-Hausman test for endogeneity and jointly estimating VES production and energy demand functions in cases of OLS inconsistency, using 3sls. The estimates also provide information on determinants of demand for various energy types. The VES production function estimates equally provide useful information on output elasticities of labour, capital and the respective energy types, the Returns to Scale with and without energy (with growth implications) and nature of association between various energy types and capital and labour in the whole economy, manufacturing, agriculture and mining sectors.

The results have various implications. First is that there is endogeneity problem for all energy types in production process except for gas and coal. This suggests that when this problem is not addressed in estimating production functions with energy, bias due to simultaneity might be inherent[65]. The second is that elasticities of substitution among inputs are neither unitary nor constant. There is evidence of significant variation over time and with factor proportion. This implies that it pays to allow the elasticity to vary in the production function.

The third is that various energy types have different effects on output (and also on growth by their contribution to the scale elasticity). Some energy types

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[65] There can be other sources of bias, such as heterogeneity, which is not tackled in this work. However, this does not make the findings less important.

enhance output to various extends (in order of importance are: electricity, gas, coal and diesel), while others hinder production (gasoline and kerosene). Though this may be obvious, the finding however stresses the need to disaggregate energy forms. The fourth is that some energy types have stronger impact in certain productive sectors than others. For instance electricity shows stronger effect in manufacturing than agriculture and mining, while diesel shows stronger effect in agriculture than any other sector. The growth reducing impact of kerosene is stronger in agriculture than manufacturing, while coal has weak positive impact in mining and manufacturing but negative in agriculture. This implies that it is important to disaggregate both energy into its constituent fuels and the economy into various sectors.

The fifth is that though the four energy types (electricity, gas, coal and diesel) have lower contribution to scale elasticity (which is the determinant of an economy's growth path) than capital and labour, the graph of the time evolution show that they set the pace for RTS, this implies that if South African Economy is less endowed with these resources, economic growth will be inhibited. Evaluating elasticity of factor substitution at aggregate energy measure, one would conclude that energy is more a complement of labour and capital. Disaggregating energy types indicate that electricity is more a substitute for labour and complement to capital. These results are consistent within the various productive sectors considered, and they imply that benefits of the electrification efforts in South Africa are likely to accrue to the (rich) owners of capital and not the poor labour suppliers.

5. ENERGY AND PRO-POOR GROWTH IN SOUTH AFRICA

5.1 Introduction

The previous two chapters looked at the energy-GDP inter-linkages in both non-theoretical and theoretical frameworks. However, it is not automatic that any contribution to economic growth (such as the role of aggregate energy and various energy types in the different sectors) is translated into poverty effects.

Some consensus has emerged due to the debate about the necessary conditions for economic growth to be considered pro-poor. One is that the poor undoubtedly share in aggregate income growth, but also suffer as a result of economic slow-downs (Dollar and Kraay, 2002). However, different viewpoints exist about pro-poor growth concept and measurement. In general, policy debate has highlighted the *absolute* and *relative* concepts. There are two types of absolute pro-poor concepts. One is the *strong absolute,* in which the absolute income gain of the poor must be more than the average gain or the gain of the rich (Klasen, 2005). The other is the *weak absolute,* in which pro-poor growth means that the aggregate growth rate of the poor's income is greater than zero (White and Anderson, 2000). The relative concept implies that income growth has to favour the poor (relative to the rich), leading to faster poverty reduction (Kakwani and Pernia, 2000). This leads to the second consensus, that fastest poverty reduction occurs in cases where income growth is accompanied by falling inequality (Bourguignon, 2004; Son and Kakwani, 2008).

Bourguignon, 2004 explains that the question of whether or not there is any interrelation between growth and inequality remains a major challenge in establishing development policies. In addition to this challenge, Voitchovsky (2005) suggests that using a single inequality statistic (like the Gini coefficient used in empirical works) in the study of the effect of inequality on growth may be misleading. This is because such measure only reflects an average of the shape of the income distribution curve. The multiracial nature of South Africa may imply that inequality within- and between-groups are likely to affect (or respond from) growth in different ways. As such, average inequality measure may not be able to reveal the effects in and across sub-groups. There are other reason consider South Africa for this study. One is that South Africa has been excluded in most of the past analyses for lack of data. However, with availability of new poverty and inequality data, such research becomes possible for South Africa. Second, Kuznets' development-inequality hypothesis is based on time series data (for England, Germany and United States) rather than cross-section analyses.

For unbiased estimation of the usual pro-poor framework of Kakwani and Pernia (2000) and Son and Kakwani (2008), inequality-growth endogeneity must be taken into account. In this chapter, the question of energy, inequality, growth and poverty relationship is tackled in simultaneous equations (time series) frameworks. Contrary to the production framework in chapter four, the production function adopted here is a simple output per worker (per capita) version of Cobb-Douglas in two inputs (capital per worker and energy per worker). Energy demand is specified in per capita terms, while inequality is specified by augmenting Ahluwalia's (1976) formulation with government expenses (per unit GDP). The framework from which poverty functional form is built is the poverty equivalent growth model due to Son and Kakwani (2008). The equations are then jointly estimated in order to control for possible production-inequality and energy-production endogeneity. These are done for the whole economy, manufacturing, agricultural and mining sectors. The rest of the chapter is structured as follow: In section two, the models are developed and estimation techniques and remainder of data issues explored. Section three presents the results while section four concludes the chapter.

5.2 Methodology

This section explains the methodology used in the analysis of energy, production, inequality and poverty nexus. Though production-energy framework has been developed in section 4.2 of chapter four, this section rather specifies models with variables in per capita terms, which is suitable for poverty analysis. The section starts with the development of the frameworks required. It proceeds to estimation techniques and to description of variables and their sources of data.

5.2.1 The Frameworks

5.2.1.1 Production Framework

Based on the survey of literature, it is assumed that there are two ways through which inequality can enter the production function. The first is through the credit, savings and investment channel (Aghion and Bolton, Banerjee and Newman, 1993; 1997; Bourguignon, 2004; Galor and Zeira, 1993) and the skills, incentive and innovation channel (Hassler and Mora, 2000; Voitchovsky, 2005; Akerlof and Yellen, 1990; Schwabish et al, 2003). These channels suggest that inequality may exert its effects through individual factor (capital and labour) productivities. The second is through its effect on the production process at large. The proposed avenue is the political economy channel[66] (Alesina and Perotti, 1993; Clarke, 1995; Deininger and Squire, 1996b; Persson and Tabelini, 1994; Rodrik, 1998). Schleifer et al (1989) suggest that high inequality may lead to reduction in the demand (and the production) of certain goods. These can be suitably captured by overall and disaggregated (between-group and within-group) inequality measures.

Let Y, K, L, E_j and α denote output, capital, labour, energy type j and parameters respectively and θ_1, θ_2, θ_3 denote average, bottom and top inequalities respectively, and A parameter of technology. The basic Cobb-Douglas production function can be written as follows:

$$Y = exp^{A+\sum_i^3 ln\theta_i^{\alpha_{1i}}} K^{\alpha_2} E_j^{\alpha_3} L^{\alpha_4} \tag{5.01}$$

$$\alpha_2 + \alpha_3 + \alpha_4 = 1 \tag{5.02}$$

From (5.02), equation (5.01) can be expressed as follows:

$$Y = exp^{A+\sum_i^3 ln\theta_i^{\alpha_{1i}}} K^{\alpha_2} L^{1-\alpha_2-\alpha_3} E_j^{\alpha_3} = exp^{A+\sum_i^3 ln\theta_i^{\alpha_{1i}}} L \left(\frac{K}{L}\right)^{\alpha_2} \left(\frac{E_j}{L}\right)^{\alpha_3}.$$

Dividing through by L gives output per worker function as follows:

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[66] Based on the socio-political unrest, hindering both investment and employment of labour.

$$y = exp^{A+\sum_i^3 ln\theta_i^{\alpha_{1i}}} k^{\alpha_2} e_j^{\alpha_3} \tag{5.03}$$

where lower case letters are variables expressed in per worker terms (if population is assumed to be equal to work force, then these are in per capita terms). Expressing equation (5.03) in double log with *t* denoting time gives:

$$lny_t = \alpha_0 + \alpha_{11} ln\theta_{1t} + \alpha_{12} ln\theta_{2t} + \alpha_{13} ln\theta_{3t} + \\ \alpha_2 lnk_t + \alpha_3 lne_{jt} + \varepsilon_{yt} \tag{5.04}$$

5.2.1.2 Per Capita Energy Demand

The energy demand equation in (4.08 of Chapter four) can be expressed in per capita terms by assuming that per capita energy demand is a function of per capita income (y) and energy prices (pe), a measure of inequality *(θ),* an error term (ε_{et}) and β are parameters[67].

$$lne_{jt} = \beta_0 + \beta_1 lny_t + \beta_2 lnpe_{jt} + \varepsilon_{et} \tag{5.05}$$

In (5.05), j is the energy type in consideration. The framework is based on a standard aggregate demand theory, in which individual demand for a good (derived from objective utility maximisation subject to budget constraint) are summed over identical consumers.

5.2.1.3 Inequality Framework

The discussion on the Kuznets' relationship and the works of Ahluwalia (1976) and Anand and Kanbur (1993a and 1993b) suggest that inequality can be a non-linear function of per capita income (y). Literature also suggests that another important determinant of inequality is an indicator of redistribution policies. Government spending as a ratio of GDP (g) can be a proxy for redistribution. This work adopts Ahluwalia's (1976) formulation because of the ease with which in can be incorporated in a system of equations such as the one to be used in this work. To the framework, an indicator of government

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[67] To minimise the lost of degrees of freedom in a more limited observations dataset, cross prices are excluded from the framework in this chapter. Chapter four has explored the role of cross prices in the demand for various energy types.

expenses to indicate redistribution policies is added to yield the following double logarithmic functional form:

$$ln\theta_t = \gamma_0 + \gamma_1 lny_t + \gamma_2(lny_t)^2 + \gamma_3 lng_t + \gamma_4 lne_{jt} + \varepsilon_{\theta t} \qquad (5.06)$$

5.2.1.4 Poverty Frameworks

Based on literature, it has been established that the channels of poverty reduction are economic growth and inequality reduction. Let $P^{\alpha}(\alpha = 0,1,2)$ be any measure of poverty from the Foster-Greer-Thorbecke (FGT) family of indices, δ parameters. A framework for poverty based on the pro-poor growth theory would be as follows:

$$P_t^{\alpha} = \delta_0 y_t^{\delta_1} \theta_t^{\delta_2} \qquad (5.07)$$

For the introduction of energy in (5.07), per capita income is replaced by its function (5.03):

$$P_t^{\alpha} = \delta_0 (exp^{A+\sum_i^3 ln\theta_i^{\alpha_{1i}}} k^{\alpha_2} e_j^{\alpha_3})_t^{\delta_1} \theta_t^{\delta_2} \qquad (5.07')$$

Simplifying and taking the double log of (5.07') and introducing the error term ε_{pt} gives the following functional form

$$lnP_t^{\alpha} = \delta_0 + \delta_1 lnk_t + \delta_2 ln\theta_t + \delta_3 lne_{jt} + \varepsilon_{pt} \qquad (5.08)$$

Similarly, energy types are incorporated turn by turn as factors of production whose returns may reduce or exacerbate poverty, depending on how much access (or lack) the poor have to (of) them.

5.2.1.5 Combined System of Frameworks

The following combined system of equations incorporating production, energy demand, inequality and poverty is considered holistically.

$$\left(\begin{array}{c} lny_t = \alpha_0 + \alpha_{11} ln\theta_{1t} + \alpha_{12} ln\theta_{2t} + \\ \alpha_{13} ln\theta_{3t} + \alpha_2 lnk_t + \alpha_3 lne_{jt} + \varepsilon_{yt}; \\ lne_{jt} = \beta_0 + \beta_1 ln\theta_{1t} + \beta_2 lny_t + \beta_3 lnpe_{jt} + \varepsilon_{et}; \\ ln\theta_t = \gamma_0 + \gamma_1 lny_t + \gamma_2 (lny_t)^2 + \gamma_3 lng_t + \gamma_4 lne_{jt} + \varepsilon_{\theta t}; \\ lnP_t^{\alpha} = \delta_0 + \delta_1 lny_t + \delta_2 ln\theta_t + \delta_3 lne_{jt} + \varepsilon_{pt} \end{array}\right)_s \qquad (5.09)$$

Where s denotes economic sectors (whole economy, manufacturing, agriculture and mining sectors) and each equation in the system is separated by semicolons.

5.2.2 Estimation Technique

The augmented regression test done in chapter four has established at least the existence of simultaneity bias between energy types and production. Theory strongly suggests another simultaneity bias between production and inequality. These constitute the basis of application of simultaneous equations modelling. Because of the limited observations dataset to be used, the variables for inequality at the top and bottom ends of the income distribution curve are dropped and only averaged (total, between-group and within-group) Theil indices are considered. In order to estimate a linear simultaneous equations system, the quadratic term for income in inequality equation is exogenised by lagging it by one period. The following combined frameworks are estimated. First with per capita income excluding energy types:

$$\left\{\begin{array}{c} lny_t = \alpha_0 + \alpha_1 ln\theta_{1t} + \alpha_2 lnk_t + \varepsilon_{yt}; \\ ln\theta_t = \gamma_0 + \gamma_1 lny_t + \gamma_2 (lny_{t-1})^2 + \gamma_3 lng_t + \varepsilon_{\theta t}; \\ lnP_t^{\alpha} = \delta_0 + \delta_1 lny_t + \delta_2 ln\theta_t + \varepsilon_{pt} \end{array}\right\}_s \tag{5.10A}$$

Second, a system in which per capita income is replaced by its function in the poverty equation without energy

$$\left\{\begin{array}{c} lny_t = \alpha_0 + \alpha_1 ln\theta_{1t} + \alpha_2 lnk_t + \varepsilon_{yt}; \\ ln\theta_t = \gamma_0 + \gamma_1 lny_t + \gamma_2 (lny_{t-1})^2 + \gamma_3 lng_t + \varepsilon_{\theta t}; \\ lnP_t^{\alpha} = \delta_0 + \delta_1 lnk_t + \delta_2 ln\theta_t + \varepsilon_{pt} \end{array}\right\}_s \tag{5.10B}$$

Third is the inclusion of energy in (5.10B) as follows:

$$\left\{\begin{array}{c} lny_t = \alpha_0 + \alpha_1 ln\theta_{1t} + \alpha_2 lnk_t + \alpha_3 lne_{jt} + \varepsilon_{yt}; \\ lne_{jt} = \beta_0 + \beta_1 ln\theta_{1t} + \beta_2 lny_t + \beta_3 lnpe_{jt} + \varepsilon_{et}; \\ ln\theta_t = \gamma_0 + \gamma_1 lny_t + \gamma_2 (lny_{t-1})^2 + \gamma_3 lng_t + \gamma_4 lne_{jt} + \varepsilon_{\theta t}; \\ lnP_t^{\alpha} = \delta_0 + \delta_1 lnk_t + \delta_2 ln\theta_t + \delta_3 lne_{jt} + \varepsilon_{pt} \end{array}\right\}_S \tag{5.10C}$$

The most suitable method of estimation of systems (5.10A) to (5.10C) is a three-stage least square (3sls) regression method. The estimation method adopted is that which corrects for small sample size and reports student's t-statistics instead of the normal z-statistics.

5.2.3 Variables and Data issues

The following describe the variables and data sources employed in the models: *Output per capita* (y): this is captured by output (GDP) for a given sector divided by labour force in that sector. GDP for the whole economy, manufacturing and mining sectors and agricultural value added at constant 2000 prices are from the South African Reserve Bank (SARB). The SARB reports indices of total private sector, manufacturing and mining employments (from 1971 to 2008) at 2000 base year. Statistics South Africa (STATSSA)[68] provides total and sector-wise real employment figures only from 2000 to 2006. These values are used together with the SARB indices to generate real private sector, manufacturing and mining employment data (in thousand persons)[69]. Agricultural employment data is taken from the Abstract of Agricultural statistics, published by the department of agriculture[70]. *Capital (k)* is the ratio of gross fix capital formation to labour force for the various sectors. *Government expenses* (g) are measured by total central government expenses as a ratio of GDP. Both government expenses and capital formation data (in million ZAR at constant 2000) are from the South African Reserve Bank (SARB) dataset.

Energy consumption per capita (e_j): is a given energy type in a given sector divided by labour force for that sector. Time series of energy from 1971 to 2005 and 2006 to 2008 are from the International Energy Agency and the South African Department of Minerals and Energy respectively. The same energy types considered in previous chapter are studied here. These are: total energy, coal, electricity, diesel, gasoline, gas and kerosene for whole

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[68] Various Labour Force Surveys http://www.statssa.gov.za/qlfs/index.asp

[69] Assuming that the SARB private sector employment data depicts the actual variations in the series.

[70] Missing values are interpolated with the assumption of linear evolution of the series.

economy; total energy, coal, electricity, diesel, gas and kerosene for manufacturing; total energy, coal, electricity, diesel and kerosene for agriculture; total energy, coal, electricity and liquid petroleum for mining. *Energy Prices* (pe_{jt}): the Consumer Price Index (CPI) for energy, taken from STATSSA, is considered as proxy for aggregate energy price. Electricity prices are from Eskom Tariffs (in South African cents/kWh). Indices of prices for the other energy types are from the Department of Minerals and Energy. Aggregate energy price index is used for gas, due to non availability of gas prices.

Inequality (θ): Due to its advantage of being additive across subgroups, the Theil index is preferred over Gini coefficient for the measurement of overall income distribution. The use of total, between-group and within-group inequalities are done in separate frameworks, such that turn after turn, total, between-group and within-group inequalities are employed for the estimation of models (5.10A) to (5.10C). This decomposition is relevant for a multi-racial society like South Africa where within and between inequalities are likely to affect (and respond to) economic growth differently.

The poverty variable (P^{α}) is captured by the Foster-Greer-Thorbecke (FGT, 1984) family of poverty indices. Poverty incidence, intensity and severity are derived for $\alpha = 0, 1$ and 2 respectively. These three measures are considered turn by turn, together with the three inequality measures considered. Inequality and poverty[71] data are from the South African Development Indicators (2009) published by the Ministry of National Planning at the Presidency of South Africa. The dataset is based on the bi-annual (All Media and Products Survey – AMPS) data, collected by the South African Advertising Research Foundation (SAARF). Although this data is not without controversy (Seekings, 2007), it is most suitable for the analysis in this chapter for various reasons. The first is that it gives a more comprehensive time series for the variables in consideration for this type of work. The second is that the alternative – Income and Expenditure Surveys (IES) of the National Statistics

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[71] The poverty data is generated using poverty line of ZAR 388 per month at constant 2008 ZAR.

– are seemingly also plagued with irregularities[72] (Ardington et al, 2005; Simkins, 2004; van der Berg et al, 2006) that make comparison of inequality and poverty over time quite unsuitable.

The span of the dataset in this chapter is limited by poverty and inequality series, with only 16 observations each (from 1993 to 2008). In order to improve the degrees of freedom, the assumption is made that serious structural changes to these variables only started occurring with the phasing out of apartheid. This allowed the generation of other observations by replacing the values pre-1993 with the mean of the observations between 1993 and 1996. With this adjustment, the span of the data is from 1988 to 2008. The summary statistics are presented in Table 5.1.

Table 5.1: Summary Statistics in Per Capita Terms

Variable	Obs	Mean	Std. Dev.	Min	Max
Total Inequality (Theil)	20	0.94	0.05	0.88	1.03
Between-group inequality	20	0.49	0.06	0.34	0.55
Within-group inequality	20	0.45	0.10	0.35	0.61
Poverty incidence (%)	20	49.06	3.43	41.00	53.00
Poverty intensity(%)	20	23.79	2.29	19.00	27.00
Poverty severity(%)	20	14.61	1.78	11.00	17.00
Government expenses/GDP	20	0.32	0.12	0.15	0.56
Whole Economy					
Output per worker	20	76.93	13.00	56.15	91.81
Capital per worker	20	12.23	3.00	7.58	17.25
Coal per worker(TJ)	20	50.90	6.48	40.33	60.09
Gas per worker (TJ)	20	7.89	1.29	6.76	10.94
Gasoline per worker(TJ)	20	28.44	2.71	21.93	31.37
Diesel per worker(TJ)	20	19.47	3.90	13.15	25.03
Kerosene per worker(TJ)	20	7.66	1.43	4.33	9.24
Electricity per worker(TJ)	20	49.69	9.13	34.28	61.07
Total energy per worker(TJ)	20	196.68	25.82	147.79	228.19
Manufacturing					
Output per worker	20	90.33	16.56	66.08	110.67
Capital per worker	20	18.23	4.71	10.49	25.91
Coal per worker(TJ)	20	186.85	40.93	123.37	288.75

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[72] Some of these deficiencies include high number of ‘zero income households, missing income data. Statistics South Africa also admits that the IES1995 and IES2000 are not directly comparable (van der Berg et al, 2006). There is also evidence of underrepresentation of white and overrepresentation of black populations in IES2000 (Hoogeveen and Ozler, 2004).

Gas per worker(TJ)	20	49.19	10.12	40.69	72.00
Diesel per worker(TJ)	20	17.58	3.24	11.72	22.00
Kerosene per worker(TJ)	20	2.04	1.94	0.35	6.39
Electricity per worker(TJ)	20	199.90	40.15	134.18	244.73
Total energy per worker(TJ)	20	498.39	82.98	366.19	619.41
Agriculture					
Output per worker	20	4.44	1.14	2.67	6.71
Capital per worker	20	5.48	1.27	3.19	7.27
Coal per worker(TJ)	20	4.27	2.72	0.61	9.07
Diesel per worker(TJ)	20	50.94	7.66	32.98	61.42
Kerosene per worker(TJ)	20	3.09	0.93	0.42	4.34
Electricity per worker(TJ)	20	21.66	6.55	10.23	31.64
Total energy per worker(TJ)	20	85.52	16.37	52.01	108.87
Mining					
Output per worker(TJ)	20	111.71	33.30	71.24	172.46
Capital per worker(TJ)	20	22.83	9.61	10.08	44.30
Coal per worker(TJ)	20	59.20	46.10	6.90	137.77
Liquid petroleum per worker(TJ)	20	39.56	20.06	12.30	81.27
Electricity per worker(TJ)	20	183.56	44.26	134.34	284.60
Total energy per worker(TJ)	20	319.67	120.30	174.55	522.57

5.3 Results and Interpretation

The results of the analyses are presented and interpreted according to the economic sectors considered. It starts with the whole economy, followed by manufacturing, agriculture and mining. For each sector, results without energy are presented and analysed, followed by results including total energy and respective energy types.

5.3.1 Whole Economy`

The pair-wise correlation coefficients and probabilities of non-significance for the main variables of concern are presented in Table 5.2 for Production, energy, inequality and poverty. Total inequality appears to correlate negatively with poverty, but decomposing into between- and within-groups components show that respective components are positively and negatively associated with all poverty measures. This agrees with the theory of pro-poor growth, in which inequality exacerbates poverty. However, in this case, only between-group inequality seems to hamper poverty reduction efforts. Production correlates positively with total and within-group inequality, but negatively with between-group inequality and all measures of poverty.

Table 5.2: Correlation Coefficients for Whole Economy

Poverty	inequality			Poverty			Output/ worker
	T	T_B	T_W	P^0	P^1	P^2	
P^1	-0.532^{b} (0.034)	0.883^{a} (0.000)	-0.810^{a} (0.000)	-	-	-	-
P^2	-0.495^{c} (0.051)	0.776^{a} (0.000)	-0.722^{a} (0.002)	-	-	-	-
P^3	-0.506^{b} (0.046)	0.812^{a} (0.000)	-0.746^{a} (0.001)	-	-	-	-
output per worker	0.758^{a} (0.001)	-0.799^{a} (0.000)	0.933^{a} (0.000)	-0.624^{b} (0.010)	-0.546^{b} (0.029)	-0.524^{b} (0.037)	-
Total Energy	0.706^{a} (0.002)	-0.665^{b} (0.005)	0.829^{a} (0.000)	-0.453^{c} (0.078)	-0.362 (0.169)	-0.368 (0.161)	0.965^{a} (0.000)
Coal	0.658^{b} (0.006)	-0.402 (0.123)	0.638^{b} (0.008)	-0.226 (0.400)	-0.158 (0.560)	-0.164 (0.545)	0.816^{a} (0.000)
electricity	0.780^{a} (0.000)	-0.766^{a} (0.001)	0.922^{a} (0.000)	-0.608^{b} (0.013)	-0.531^{b} (0.034)	-0.516^{b} (0.041)	0.994^{a} (0.000)
Diesel	0.780^{a} (0.000)	-0.815^{a} (0.000)	0.947^{a} (0.000)	-0.667^{b} (0.005)	-0.587^{b} (0.017)	-0.560^{b} (0.024)	0.994^{a} (0.000)
Gasoline	0.595^{b} (0.015)	-0.475^{c} (0.063)	0.652^{b} (0.006)	-0.252 (0.347)	-0.137 (0.614)	-0.136 (0.615)	0.847^{a} (0.000)
Gas	0.513^{b} (0.042)	-0.858^{a} (0.000)	0.800^{a} (0.000)	-0.837^{a} (0.000)	-0.785^{a} (0.000)	-0.726^{a} (0.002)	0.676^{a} (0.004)
Kerosene	0.585^{b} (0.017)	-0.479^{c} (0.060)	0.648^{b} (0.007)	-0.256 (0.338)	-0.168 (0.534)	-0.163 (0.547)	0.855^{a} (0.000)
Government expenses/GDP	0.712^{a} (0.002)	-0.859^{a} (0.000)	0.932^{a} (0.000)	-0.748^{a} (0.001)	-0.670^{b} (0.005)	-0.643^{b} (0.007)	0.964^{a} (0.000)

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively. T, T_B and T_W denote total, between-group and within-group Theil inequality measures.

All energy types have positive correlation with total and within-group inequality and level of output, and negative correlation with between-group inequality. Electricity, diesel and gas are negatively correlated with all poverty measures, while total energy is significant only on poverty incidence. Government expenses correlate positively with total income, total and within-group inequality, but negatively with between-group inequality and all three poverty measures.

Estimation without Energy

Table 5.3 presents the estimation results of production-inequality-poverty for total, between-group and within-group inequalities with poverty incidence. The overall model statistics seem satisfactory, with R-squares above 50 percent in most cases.

Table 5.3: 3sls for GDP-Inequality-Poverty Intensity – Whole Economy

Variable	Total inequality[73]				Between-Group		Within-Group	
	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
Production equation (dependent variable: per capita income)								
$ln\theta_{1t}$	0.296	0.96	0.305	0.98	-0.081^c	-1.76	0.303^b	2.54
lnk_t	0.625^a	10.75	0.623^a	10.64	0.631^a	10.83	0.421^a	4.12
α_0	2.803^a	17.51	2.807^a	17.41	2.709^a	28.06	3.537^a	10.22
$\mathbf{R_y^2}$	**0.95**	**162.22**	**0.95**	**161.07**	**0.95**	**168.32**	**0.95**	**139.38**
Inequality equation (dependent variable: Inequality)								
lny_t	-5.942^b	-2.26	-5.368^c	-2.00	24.233^a	5.45	-20.966^a	-5.17
$(lny_{t-1})^2$	0.734^b	2.38	0.670^b	2.14	-2.789^a	-5.38	2.525^a	5.30
lng_t	-0.069	-1.05	-0.081	-1.21	-0.447^a	-4.22	0.196^b	2.74
γ_0	11.799^b	2.10	10.500^c	1.84	-53.812^a	-5.63	42.783^a	4.99
$\mathbf{R_\theta^2}$	**0.60**	**11.46**	**0.60**	**11.21**	**0.84**	**37.77**	**0.96**	**126.03**
Poverty Equation (Poverty)								
lnk_t	-0.232^c	-1.90	-0.166^c	-1.95	0.071	1.46	0.426^a	3.19
lnk_{t-1}	-	-	-	-	-	-	-0.308^a	-3.82
$ln\theta_{1t}$	-0.240	-0.53	-0.170	-0.37	0.604^a	6.94	-0.417^a	-3.17
δ_0	4.877^a	8.86	4.290^a	18.22	4.156^a	48.70	3.245^a	8.53
$\mathbf{R_P^2}$	**0.39**	**6.22**	**0.45**	**6.68**	**0.76**	**38.52**	**0.74**	**18.84**
Breusch-Pagan	**4.45**	**0.217**	**3.30**	**0.348**	**11.77**	**0.008**	**9.76**	**0.021**
Obs.	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**
Joint test on lny_t and $(lny_t)^2$			**5.19**	**0.010**	**15.55**	**0.000**	**24.58**	**0.000**

Notes: ^{a}, ^{b} and^c denote significance at 1%, 5%, and 10% levels respectively. The Breusch-Pagan Statistics is for the test of independence of residuals of the equations. F-statistics (under coef. Columns) and P-VAL (under t-stat columns) for joint Wald test on lny_t and $(lny_t)^2$ are presented on the last row. The use of lag value of capital in poverty equation is to test the trickle-down hypothesis within-group.

Capital per unit labour is significant across all the sub-models. While the positive effect of total inequality on per capita income is not significant, between-group inequality has negative and significant coefficient. Within-

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[73] The first two columns of the table give results that contain per capita income in poverty equation. The rest of the columns have capital per worker in place of per capita income in poverty equation.

group inequality significantly enhances output per worker. It may be asked if there is a good dimension of inequality in a multiracial society like South Africa. The significant negative effect of between-group inequality on production may be explained in theory by credit constrains, political economy (i.e. distortionary policies and socio-political instability) channels, but also criminality and between race tensions. Therefore the interracial tensions and inequality in access to capital (mostly inherited from the apartheid era) still generate significant adverse effects that stifle economic growth.

However, within-group inequality is shown to impact production positively. This does not mean that inequality should be actively promoted within-groups, but simply that it should not be a policy concern. The positive effect could be capturing the trickle-down effect of the fruits of growth via social capital within-group especially in African households where significant remittances may go to poorer individuals from the richer and well endowed ones, which could serve as capital for productive ventures by the hitherto poorer members of the group. However, it is important to note that with the active black economic empowerment, increase in within-group inequality does not necessarily mean that the poor within-group are getting poorer[74] but rather that the effect of income at the top tail of within-group inequality is weighing positively in the national income.

Per capita output has significant negative sign on total and within-group inequality. Its square has positive sign on these respective measures of inequality. The signs are reversed in between-group inequality equation. These suggest that there is an inverted U-shape inequality-per capita income relationship for between-group inequality, but a U-shaped one for total and within-group inequality. A Wald (significance) test of per capita income and its square indicates that they are jointly significant in all the inequality equations. Given the short span of the data in question, it may be difficult for one to claim that this result is picking the Kuznets U-shaped development-inequality hypothesis. Ahluwalia (1976, p.335) calculates that for an economy growing at a per capita (GNP) rate of 2.5 percent, it will take about 100 years

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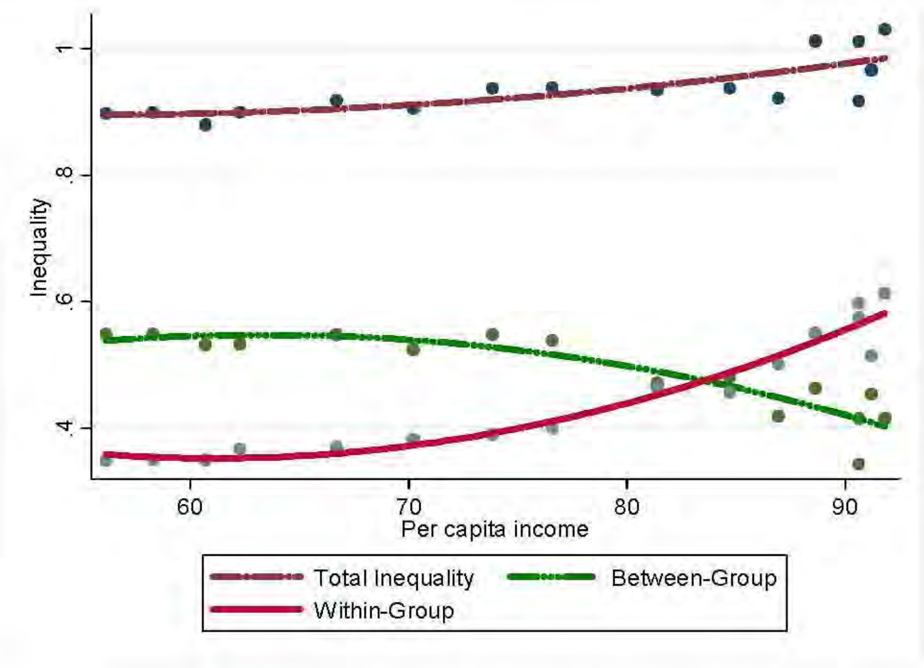
[74] The blacks constitute 80 percent of the population

to transit from worsening inequality phase to the falling one. However, the magnitude of the curvature suggests that the U-shape is a broader one (lower magnitude) than that of Ahluwalia (1996) for a panel data. It is a little more pronounced when inequality is disaggregated into sub-groups. The graphs, plotting the relationship between per capita income and total, between-group and within-group inequalities in Figure 5.1 may seems to indicate that South Africa is at the declining phase of the inverted-U for between-group, but at the inclining phase of the U for within-group.

Figure 5.1: Inequality-Development Graph – Whole Economy



However, these results seem to agree more with the active post-apartheid policies of Black Economic Empowerment, which, while yielding fruits in the reduction of between-group inequality, actually increases within-group inequality. This is supported by the coefficients of Government expenses with significant negative and positive impacts on between-group and within-group inequality components respectively. None of the lag values of inequality was significant, so is has been excluded from the equations.

According to the results of impact on poverty, the coefficient of per capita income is negative and significant (at 10% level). One percent increase in per capita income reduces poverty by 0.232 percent. Regression with income substituted by production function shows that capital per worker also has anti-poverty effects (significant at 10% level). However, this effect disappears between-group and turns positive within-group. Between-group inequality (in line with theory that inequality exacerbates poverty) has poverty increasing effect. A percentage increase in between-group inequality is associated with 0.60 percent higher poverty incidence. But the same increase in within-group leads to 0.542 percent fall in poverty incidence. Table 5.3 indicates similar impacts on poverty intensity and severity. Output per worker and capital both lost their significance on poverty reduction in total and between-group inequality sub-models. However, capital's poverty enhancing effect remains significant within-group. One percent increase in between-group inequality leads to 0.853 and 1.093 rise in poverty intensity and severity respectively, suggesting that the abjectly poor suffer more from inequality than others. This effect is reversed within-group, the same increase is associated with 0.632 and 0.916 percent fall in the respective poverty measures.

The fact that within-group inequality has positive effect on output and negative effect on poverty (with strongest effect on poverty severity), can only make sense in terms of within-group solidarity, where growth at first widens inequality within-group when the relatively well-endowed individuals access some of the fruits of economic growth. The well-endowed individuals then remit some of the growth returns to their poorer family members. These remittances may then serve as productive capital thereafter. This intuition is supported by the fact that regression with the first lag of capital is poverty reducing in within-group inequality (Table 5.3 and 5.4). The fact that within-group inequality has strongest effect on poverty severity implies that within-group remittances may happen for altruistic motives, with the very poor receiving more attention. STATSSA (2002) reports that the most important source of income for unemployed South Africans is financial support from their working relatives

By deduction (from the fact that government expenses reduce total and between-group inequalities) and in line with the correlation coefficients of government expenses (negative and significant) on all poverty measures, one would conclude that government efforts are yielding some anti-poverty fruits. However, as the coefficients indicate, these efforts are a little biased towards the just poor than the very poor.

Table 5.4: 3sls Results for Poverty Intensity and Severity - Whole Economy

Variable	Total inequality		Between-Group		Within-Group				
					With capital		With income		
	P^1	P^2	P^1	P^2	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.305	0.309	-0.080^{c}	-0.078^{c}	0.304^{b}	0.311^{b}	0.306^{b}	0.311^{b}	0.318^{b}
lnk_t	0.623^{a}	0.623^{a}	0.632^{a}	0.632^{a}	0.421^{a}	0.416^{a}	0.418^{a}	0.413^{a}	0.408^{a}
α_0	2.807^{a}	2.809^{a}	2.708^{a}	2.707^{a}	3.537^{a}	3.557^{a}	3.547^{a}	3.563^{a}	3.582^{a}
lny_t	-5.297^{c}	-4.912^{c}	23.379^{a}	21.858^{a}	-20.972^{a}	-20.231^{a}	-19.170^{a}	-19.883^{a}	-19.92^{a}
$(lny_{t-1})^2$	0.662^{b}	0.618^{c}	-2.691^{a}	-2.509^{a}	2.532^{a}	2.450^{a}	2.315^{a}	2.400^{a}	2.412^{a}
lng_t	-0.083	-0.085	-0.441^{a}	-0.462^{a}	0.171^{b}	0.154^{c}	0.209^{b}	0.198^{b}	0.167^{c}
γ_0	10.337^{c}	9.499	-51.954^{a}	-48.812^{a}	42.655^{a}	40.966^{a}	38.975^{a}	40.450^{a}	40.363^{a}
lnk_t	-0.166	-0.167	0.139	0.201^{c}	0.544^{b}	0.714^{b}	1.011^{b}	0.768	0.820
lnk_{t-1}	-	-	-	-	-0.317^{c}	-0.310	-0.731	-0.154	0.172
$ln\theta_{1t}$	-0.452	-0.746	0.853^{a}	1.093^{a}	-0.632^{a}	-0.916^{a}	-0.469^{a}	-0.864^{a}	-1.266^{a}
δ_0	3.545^{a}	3.039^{a}	3.444^{a}	2.975^{a}	2.078^{a}	0.913	2.271^{a}	-0.198	-2.645
$\mathbf{R^2_y}$	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**
$\mathbf{R^2_\theta}$	**0.60**	**0.60**	**0.85**	**0.85**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**
$\mathbf{R^2_P}$	**0.35**	**0.31**	**0.63**	**0.57**	**0.66**	**0.62**	**0.83**	**0.74**	**0.68**

Note: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively. Within-group inequality model is estimated with lag-values of capital and income in poverty equations, which is not significant in other inequality models. The last three columns have results with rows k_t and k_{t-1} bearing the coefficients of income and its one period lag respectively. The sub-column titled *with capital*, under within-group column has income replaced by its function in poverty equation, such that k_t and k_{t-1} are coefficients of capital per worker and its first period lag respectively.

Estimation with Energy

In Table 5.5, the results of system (5.10C) estimated with total energy are reported. The overall model statistics seem satisfactory, with R-squares ranging from 0.96 to 0.98 for production functions, 0.93 to 0.97 for energy demand, 0.60 for total inequality, 0.87 and 0.96 for between-group and within-group inequalities respectively, and 0.51 to 0.90 for poverty equations.

Table 5.5: 3sls for Energy-GDP-Inequality-Poverty - Whole Economy

Variable	Total inequality	Between-Group	Within-Group

	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.539^b	0.547^b	0.542^b	-0.346^a	-0.347^a	-0.345^a	0.250^a	0.256^a	0.250^a
lnk_t	0.143^b	0.139^b	0.142^b	0.029	0.028	0.031	0.001	-0.009	0.001
lne_t	0.857^a	0.861^a	0.858^a	0.971^a	0.972^a	0.969^a	0.999^a	1.009^a	0.999^a
α_0	-0.510^a	-0.519^a	-0.512^a	-1.116^a	-1.120^a	-1.110^a	-0.739^a	-0.761^a	-0.74^a
$ln\theta_{1t}$	-0.517^b	-0.526^b	-0.520^b	0.384^a	0.386^a	0.384^a	-0.349^a	-0.353^a	-0.34^a
lny_t	1.181^a	1.164^a	1.175^a	0.973^a	0.972^a	0.983^a	1.029^a	1.018^a	1.057^a
$lnpe_t$	-0.156	-0.145	-0.152	-0.018	-0.019	-0.011	-0.046	-0.055	-0.028
β_0	0.832^b	0.857^b	0.842^b	1.261^a	1.262^a	1.246^a	0.323^c	0.327^c	0.294
lny_t	-6.151	-5.924	-5.175	12.768^b	10.921^c	10.222^c	-11.53^a	-11.877^a	-10.64^b
$(lny_{t-1})^2$	0.745	0.721	0.639	-1.549^b	-1.349^b	-1.271^c	1.488^a	1.533^a	1.407^a
lng_t	-0.022	-0.025	-0.031	-0.343^a	-0.321^a	-0.320^a	0.239^a	0.218^a	0.184^b
lne_t	0.013	0.000	-0.043	0.787^c	0.895^b	0.931^b	-0.881^a	-0.868^a	-0.986^a
γ_0	12.473	12.018	10.535	-31.486^b	-27.804^b	-26.429^b	26.09^a	26.67^a	24.24^a
lnk_t	-0.549^a	-0.699^a	-0.714^b	-0.285^a	-0.379^b	-0.273	-0.208^c	-0.279	-0.127
$ln\theta_{1t}$	-0.153	-0.444	-0.778	0.427^a	0.585^a	0.816^a	-0.422^a	-0.602^a	-0.865^a
lne_t	0.761^a	1.066^a	1.106^b	0.551^a	0.792^a	0.691^c	0.648^a	0.967^a	0.973^b
δ_0	1.226^c	-0.757	-1.444	2.003^a	0.357	0.302	0.644	-1.735^c	-2.848^c
$\mathbf{R_y^2}$	**0.96**	**0.96**	**0.96**	**0.98**	**0.98**	**0.98**	**0.98**	**0.98**	**0.98**
$\mathbf{R_e^2}$	**0.93**	**0.93**	**0.93**	**0.96**	**0.96**	**0.96**	**0.97**	**0.97**	**0.97**
$\mathbf{R_\theta^2}$	**0.60**	**0.60**	**0.60**	**0.87**	**0.87**	**0.87**	**0.96**	**0.96**	**0.96**
$\mathbf{R_P^2}$	**0.73**	**0.65**	**0.51**	**0.90**	**0.81**	**0.69**	**0.84**	**0.79**	**0.70**
Breusch-Pagan	**19.21**^{a}	**17.56**^{b}	**15.75**^{b}	**23.62**^{a}	**21.88**^{a}	**20.47**^{a}	**24.37**^{a}	**23.97**^{a}	**23.66**^{a}

Notes: ^{a}, ^{b} and^c denote significance at 1%, 5%, and 10% levels respectively. Breusch-Pagan values are statistics for the test of independence of residuals.

Compared to Table 5.3 and 5.4, the introduction of total energy reduces the coefficients of capital per unit labour in the production equation. Though still significant, the coefficient drops from 0.625 to 0.143 for the poverty incidence sub-model of total inequality. In the models with between-group and within-group inequalities, the coefficient becomes insignificant, and drops from 0.631 to 0.029 and 0.421 to 0.001 respectively for poverty incidence sub-model. This implies that in traditional production functions, the high coefficients of capital productivities in the absence of energy are often biased, rather picking the effect of energy. The coefficient of energy is high and significant, ranging from 0.857 to 0.861 for total inequality, 0.969 to 0.972 for between-group inequality and 0.999 to 1.009 for within-group inequality.

The per capita energy demand equations also follow the classical demand theory as in chapter four, in which the coefficients of prices appear negative, but insignificant. All inequality indices show significant impact on total per capita energy demand. One percent increase in total (within-group) inequality results in 0.517 (0.349) percent fall in total per capita energy demand. The same increase in between-group inequality brings about 0.384 percent increase in per capita energy demand in the poverty incidence sub-model. The effect of income remains strongly positive and significant, with coefficient of 1.181, 0.973 and 1.029 for total, between-group and within-group inequality in poverty incidence sub-model.

A possible reason why higher (between-group) inequality may be associated with increased energy consumption is that while energy consumption does not decrease with relatively poorer people, it may increase faster with the richer group as inequality widens. This reason is suggested by the coefficients of price and income elasticities of demand in chapter four and here. The price elasticity suggests that energy is a necessity. This implies that the consumption of the various energy types and aggregate energy falls far slower than their respective prices increase (inelastic). On the other hand, income elasticity shows that one percent increase in income results in more than proportionate increase in the demand for energy. This implies that energy consumption would increase faster at the top end of income distribution curve, where a greater share of the fruits of economic growth goes to.

In the inequality equations, energy use has inequality enhancing (reducing) effects for between-group (within-group) inequality, but the effect on total inequality is insignificant. One percent increase in total energy use results in 0.787 percent rise (0.881percent fall) in between-group (within-group) inequality. This suggests that the fruits of energy's contribution to economic growth are still being appropriated relatively more by the richer groups of the society. The effect of capital on poverty (particularly poverty intensity) remains negative and significant in all inequality sub-models. The coefficients of energy show that total energy is associated with higher poverty, with greater enhancing effects on poverty severity. The opposing effects of capital and energy on poverty may imply that access to productive energy without corresponding access to capital would not result in poverty reducing effects.

Table 5.6 presents the results for the effect of disaggregated energy types on per capita income, total, between-group and within-group inequalities, poverty incidence, intensity and severity with feedbacks from per capita income and the three measures of inequality. The energy types for which regression analyses are performed are electricity, diesel, gasoline, gas, kerosene and coal. Table 5.6 is only a synthesis of the overall results. The detailed results can be found in Tables D1.1 to D1.6 of Appendix. The overall model statistics are satisfactory and the Breusch-Pagan test show that the residual are not independent in most cases.

Table 5.6: Disaggregated Energy-GDP-Inequality-Poverty - Whole Economy

	Effect of Energy types					
	Electricity	Diesel	Gasoline	Gas	Kerosene	Coal
Per capita income	1.002^{a}	0.922^{a}	0.459^{a}	0.315^{a}	0.318^{b}	0.523^{a}
Total inequality	0.865^{a}	1.175^{a}	-0.180	-0.052	0.259	0.291^{b}
Between-group	1.587^{a}	0.309	0.971^{a}	-0.405^{b}	0.685^{a}	0.401^{a}
Within-Group	-0.069	0.939^{b}	-0.684^{a}	0.236^{b}	-0.424^{b}	-0.081
Poverty incidence	0.439^{b}	-0.483^{a}	0.548^{a}	-0.405^{a}	0.403^{a}	0.577^{a}
Intensity	0.602^{b}	-0.534^{b}	0.944^{a}	-0.553^{a}	0.568^{a}	0.808^{a}
Severity	0.414	-0.434	0.849^{b}	-0.687^{a}	0.603^{a}	0.889^{a}
	Effect on Energy Demand					
Per capita income	1.007^{a}	1.042^{a}	1.216^{a}	-0.973	2.149^{a}	0.700^{a}
Total inequality	0.394^{a}	0.413^{b}	-0.197	-0.091	-0.537	0.142
Between-group	0.109^{b}	-0.138^{c}	0.337^{a}	-1.021^{a}	0.595^{b}	0.774^{a}
Within-Group	-0.103^{b}	0.174^{c}	-0.403^{a}	1.079^{b}	-1.162^{a}	-0.586^{b}

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

Except for sub-models with electricity and diesel, the coefficients of capital per unit labour in the per capita income equations are all high and significant in the presence of all the other energy types. This means that only electricity (most importantly) and diesel are the energy types whose effects may be captured by capital in production functions where energy is not controlled for. All the energy types have positive effect on per capita income. One percent increase in electricity, diesel, coal, gasoline, kerosene and gas use leads to 1.002%, 0.922%, 0.459%, 0.523%, 0.318% and 0.315 increase in per worker output respectively.

In chapter four, gasoline and kerosene have negative effects on GDP. While the share of residential kerosene (second after transport) has been falling since the post apartheid era, that of the transport sector has been rising from that period (Figure 5.2). Kerosene in transport is mainly used in the aviation industry, which contributes significantly to transport GDP. Given that the transport sector takes all the gasoline, and more than 50 percent of the kerosene, their positive effects on per capita income in this chapter[75] can be explained by the increasing weight of the transport sector in national income (Figure 5.3).

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[75] The dataset used for this chapter starts from 1993, while that of chapter four starts from 1971

Figure 5.2: Shares of Kerosene in Productive Sectors

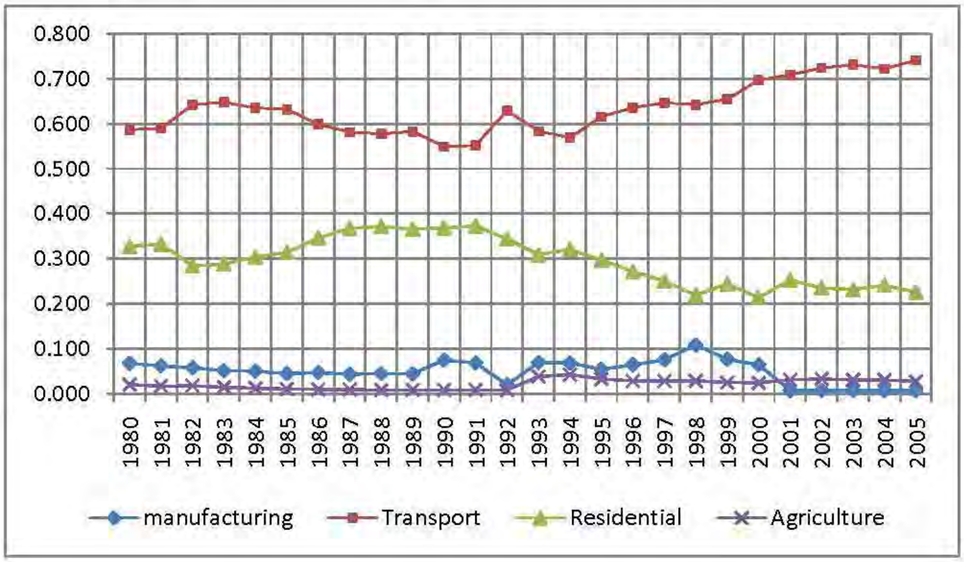
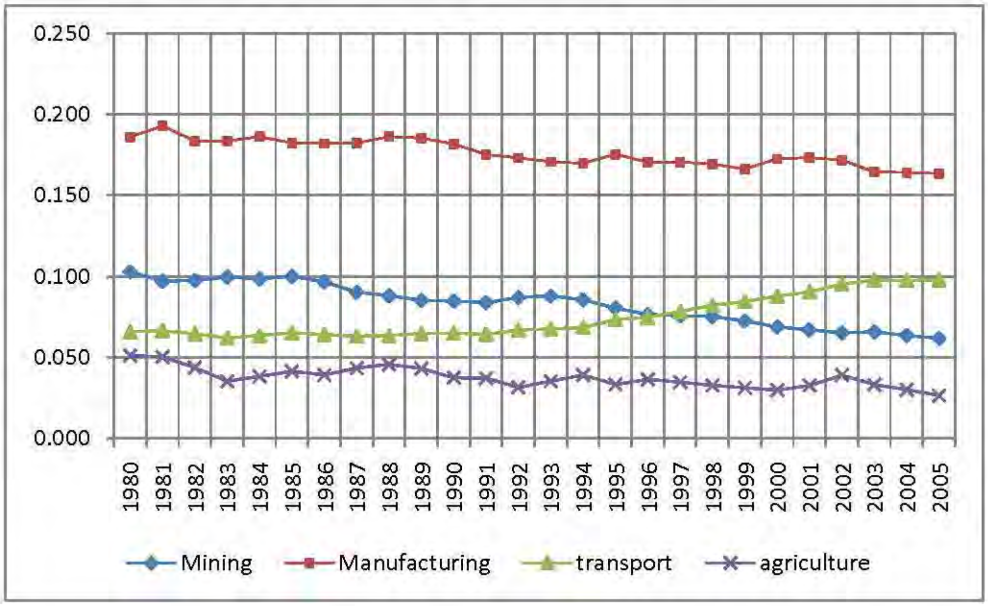


Figure 5.3: Sector-wise GDP Shares in National Income



Income shows significant demand enhancement effects on all energy types except gas. Gasoline and kerosene have strong luxury good behaviour. Between-group inequality impacts all energy types, with negative effects on diesel and gas, and positive effects on electricity, gasoline, kerosene and coal. The positive effect of between-group inequality on energy consumption may be explained by the fact that energy use tends to increase faster among the rich but tends not to decrease among the relatively poorer people as inequality rises. Income and price elasticities confirm this fact.

Except for gasoline and gas, all the energy types show positive effect on total inequality, but only diesel, electricity and coal are significant. Except gas, all energy types have positive effect on the poverty increasing type of inequality (between-group). The impact is highest for electricity (1.587), followed by gasoline and kerosene, and lowest but insignificant for diesel. Gas use is associated with negative and significant between-group inequality (-0.405). The effect of electricity on within-group inequality is weak and insignificant. It is significant and positive for diesel (0.939), and gas (0.236), but negative for gasoline, kerosene and coal, with coefficients of -0.684, and -0.424 respectively.

The combination of high positive impact on per capita income and low and insignificant effect on the poverty increasing type of inequality makes diesel use in the South African economy a good candidate for poverty reduction. One percent increase in diesel use results in 0.483%, and 0.534% fall in poverty incidence and intensity respectively. The effect is not significant on poverty severity. Gas equally has negative and significant effect on poverty, one percent increase in its use resulting in 0.403%, 0.568% and 0.603% fall in the poverty incidence, intensity and severity respectively. Though electricity has the highest impact on labour productivity, it has poverty increasing effect (only on poverty incidence and intensity) due to its relatively higher effect on inequality than productivity. This implies that its contribution to production goes almost exclusively to the rich owners of capital (and skilled labour). Coal, gasoline and kerosene also show significant poverty enhancement effects, equally due to their relatively higher impact on between-group inequality than on output per worker. The effects of coal and kerosene are not surprising, given that the poor rely on kerosene and coal for heating, cooking and (to a lesser extent) lighting. These are also lower forms of energy on the energy ladder and are theoretically associated with lower income. For gasoline, though it has positive effect on per capita income, in chapter four, its effect on production is negative. It has been shown in chapters three and four that gasoline has long-run negative co-integration with labour, and reduces labour productivity. Given that per capita income is the ratio of income and labour (or population), its positive effect may be better explained by its negative impact on labour. This also explains its positive effect on poverty.

5.3.2 Manufacturing Sector

The correlation coefficients in Table 5.7 suggest that total and within-group inequalities are positive and significantly correlated with manufacturing GDP per worker, while between-group inequality is negatively related to manufacturing GDP per worker. Manufacturing GDP negatively relates to all three measures of poverty. Except for manufacturing kerosene with negative correlation coefficient with manufacturing output per worker, total energy and all other energy types show positive correlation. Government expenses have positive correlation with manufacturing output per worker.

Table 5.7: Correlation Coefficients - Manufacturing Sector

	inequality			Poverty			Output/ worker
	T	T_B	T_W	P^0	P^1	P^2	
output per worker	0.763^{a} (0.001)	-0.824^{a} (0.000)	0.950^{a} (0.000)	-0.650^{b} (0.007)	-0.565^{b} (0.023)	-0.535^{b} (0.033)	-
Total Energy	0.792^{a} (0.000)	-0.692^{a} (0.003)	0.867^{a} (0.000)	-0.603^{b} (0.013)	-0.546^{b} (0.029)	-0.517^{b} (0.041)	0.927^{a} (0.000)
Coal	0.794^{a} (0.000)	-0.586^{b} (0.017)	0.789^{a} (0.000)	-0.582^{b} (0.018)	-0.538^{b} (0.032)	-0.489^{c} (0.055)	0.825^{a} (0.000)
electricity	0.771^{a} (0.001)	-0.705^{a} (0.002)	0.876^{a} (0.000)	-0.554^{b} (0.026)	-0.486^{c} (0.056)	-0.473^{c} (0.064)	0.960^{a} (0.000)
Diesel	0.757^{a} (0.001)	-0.752^{a} (0.001)	0.900^{a} (0.000)	-0.583^{b} (0.018)	-0.510^{b} (0.043)	-0.498^{c} (0.050)	0.968^{a} (0.000)
Gas	0.602^{b} (0.014)	-0.834^{a} (0.000)	0.816^{a} (0.000)	-0.895^{a} (0.000)	-0.855^{a} (0.000)	-0.792^{a} (0.000)	0.674^{a} (0.004)
Kerosene	-0.511^{b} (0.043)	0.722^{a} (0.002)	-0.728^{a} (0.001)	0.701^{a} (0.003)	0.661^{b} (0.005)	0.616^{b} (0.011)	-0.621^{b} (0.010)
Government expenses/GDP	0.712^{a} (0.002)	-0.859^{a} (0.000)	0.932^{a} (0.000)	-0.748^{a} (0.001)	-0.670^{b} (0.005)	-0.643^{b} (0.007)	0.958^{a} (0.000)

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

Estimation without Energy

The results of the regression analysis for manufacturing GDP, inequality and poverty without energy types are reported in Table 5.8. They are for total inequality, between-group and within-group inequalities with poverty incidence. Overall, the R-squares vary from 91 to 95 percent for production functions, 56 to 98 percent for inequality and 42 to 77 percent for poverty equations.

Table 5.8: 3sls for GDP-Inequality-Poverty Intensity – Manufacturing Sector

Variable	Total inequality[76]				Between-Group		Within-Group	
	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
$ln\theta_{1t}$	0.923^{b}	2.33	0.929^{b}	2.34	-0.299^{b}	-2.11	0.509^{a}	3.99
lnk_t	0.542^{a}	7.62	0.541^{a}	7.59	0.540^{a}	7.48	0.311^{a}	2.99
α_0	2.992^{a}	13.34	2.995^{a}	13.33	2.720^{a}	19.14	4.009^{a}	10.10
lny_t	-4.575^{c}	-1.86	-4.282^{c}	-1.73	22.488^{a}	5.38	-17.215^{a}	-6.50
$(lny_{t-1})^2$	0.551^{c}	1.99	0.519^{c}	1.86	-2.528^{a}	-5.40	2.015^{a}	6.70
lng_t	-0.067	-1.10	-0.072	-1.18	-0.300^{a}	-3.24	0.161^{a}	3.49
γ_0	9.275^{c}	1.69	8.595	1.55	-51.004^{a}	-5.46	35.989^{a}	6.21
lnk_t	-0.217^{c}	-1.93	-0.127	-1.66	0.072	1.55	0.412^{a}	3.16
lnk_{t-1}	-	-	-	-	-	-	-0.312^{a}	-4.00
$ln\theta_{1t}$	-0.221	-0.49	-0.360	-0.81	0.608^{a}	6.82	-0.393^{a}	-3.06
δ_0	4.849^{a}	9.22	4.232	17.41	4.129^{a}	43.64	3.266^{a}	8.12
$\mathbf{R_y^2}$	**0.91**	**97.09**	**0.91**	**96.94**	**0.93**	**109.36**	**0.94**	**130.50**
$\mathbf{R_\theta^2}$	**0.58**	**11.75**	**0.58**	**11.66**	**0.86**	**39.71**	**0.97**	**206.92**
$\mathbf{R_P^2}$	**0.42**	**6.43**	**0.42**	**6.42**	**0.77**	**37.60**	**0.72**	**18.14**
Breusch-Pagan	**3.98**	**0.264**	**4.20**	**0.241**	**7.32**	**0.062**	**11.09**	**0.011**
Joint test on lny_t and $(lny_t)^2$			**5.62**	**0.007**	**14.65**	**0.000**	**50.23**	**0.000**

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively. The Breusch-Pagan Statistics is for the test of independence of residuals of the equations. F-statistics (under coef. Columns) and P-VAL (under t-stat columns) for joint Wald test on lny_t and $(lny_t)^2$ are presented on the last row.

Manufacturing capital per unit labour is significant across all sub-models, with coefficient a little lower than those of the whole economy. The results largely agree with the suggestion of the correlation coefficients. Unlike the case of the whole economy, total inequality is significant in the per capita income equation, with positive coefficient. The coefficient of within-group inequality is equally positive and significant, but that of between-group is negative and significant on per capita income. In general, the coefficients of the different

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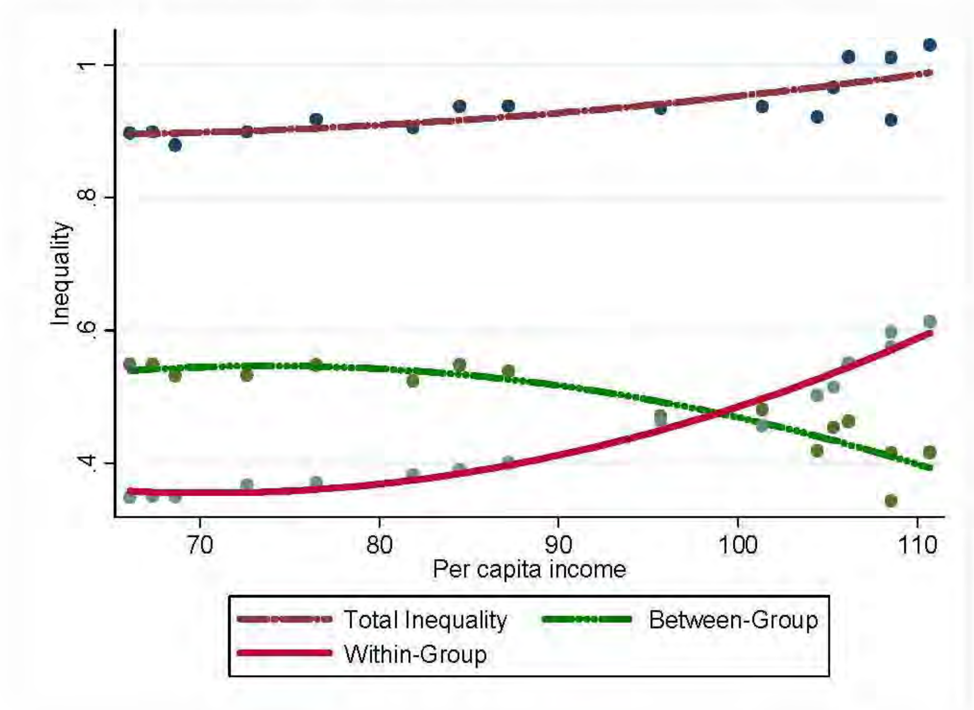
[76] The first two columns of the table give results that contain per capita income in poverty equation. The rest of the columns have capital per worker in place of per capita income in poverty equation.

inequality measures are higher for manufacturing production than for the whole economy. In the same way, it can be suggested that growth stifling factors seem to act through between-group inequality which may be explained in terms of the credit constrains, political economy channels and criminality and interracial tensions. The positive effect of within-group inequality could equally be capturing a trickle-down effect of the fruits of growth via social capital within-group especially in African households where significant remittances may go to poorer individuals from the richer ones.

As with the whole economy, manufacturing per capita output and its square have the respective significant negative and positive signs on total and within-group inequality. The signs are reversed on between-group inequality equation. Both per capita income and its square are jointly significant in all the inequality equations. an inverted U-shaped relationship for between-group, but a U-shaped one for total and within-group inequality with per capita income are suggested. The magnitude of the quadratic term suggests a broader U-shape and more pronounced when inequality is disaggregated into sub-groups. Figure 5.4 plots the relationship and seem to suggest a latter phase of the Kuznets process in the manufacturing sector. However, this result may rather corroborate the policies of the post-apartheid government of South Africa. Policies such as the Black Economic Empowerment measures have enabled the hitherto disadvantaged (black) group to access shares in manufacturing and other sectors but also at the same time leaving other blacks behind, thereby widening the income gap within-group. These may underlie the observed inequality-income relationship in South Africa rather than a Kuznets process.

Figure 5.4: Inequality-Per Capita Income - Manufacturing



Manufacturing output per worker shows negative effect on all poverty measures, but the effect is significant only on poverty incidence (Table 5.8) and not on poverty intensity and severity (Table 5.9). One percent increase in manufacturing output per worker leads to 0.217 percent reduction in poverty incidence, but the abjectly poor do not benefit from manufacturing production.

Table 5.9: Impact on Poverty Intensity and Severity– Manufacturing Sector

Variable	Total inequality		Between-Group		Within-Group				
					With capital		With income		
	P1	P2	P1	P2	P1	P2	P0	P1	P2
$ln\theta_{1t}$	0.931^b	0.936^b	-0.300^b	-0.303^b	0.513^a	0.523^a	0.484^a	0.497^a	0.504^a
lnk_t	0.541^a	0.540^a	0.539^a	0.538^a	0.307^b	0.298^b	0.331^a	0.320^a	0.314^a
α_0	2.997^a	2.999^a	2.721^a	2.723^a	4.024^a	4.060^a	3.932^a	3.975^a	3.997^a
lny_t	-4.142	-3.917	21.995^a	20.986^a	-16.904^a	-16.063^a	-16.006^a	-16.031^a	-16.466^a
$(lny_{t-1})^2$	0.503^c	0.479^c	-2.471^a	-2.355^a	1.981^a	1.893^a	1.891^a	1.898^a	1.954^a
lng_t	-0.073	-0.074	-0.309^a	-0.325^a	0.156^a	0.131^b	0.108	0.090	0.055
γ_0	8.280	7.772	-49.953^a	-47.792^a	35.269^a	33.246^a	32.987^a	32.950^a	33.738^a
lnk_t	-0.110	-0.101	0.155^b	0.230^b	0.716^a	0.984^a	0.918^a	1.629^a	2.484^a
lnk_{t-1}	-	-	-	-	-0.509^a	-0.622^b	-0.595^a	-1.102^a	-1.763^a
$ln\theta_{1t}$	-0.727	-1.067	0.885^a	1.149^a	-0.585^a	-0.828^a	-0.550^a	-0.786^a	-0.994^a

δ_0	3.433[a]	2.894[a]	3.366[a]	2.853[a]	2.066[a]	0.927	1.976[a]	0.124	-1.431
$\mathbf{R^2_y}$	**0.91**	**0.91**	**0.93**	**0.93**	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**
$\mathbf{R^2_\theta}$	**0.58**	**0.58**	**0.86**	**0.86**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**
$\mathbf{R^2_P}$	**0.32**	**0.28**	**0.65**	**0.59**	**0.67**	**0.65**	**0.87**	**0.87**	**0.87**

Note: [a], [b] and[c] denote significance at 1%, 5%, and 10% levels respectively. Within-group inequality model is estimated with lag-values of capital and income in poverty equations, which is not significant in other inequality models. The last three columns have results with rows k_t and k_{t-1} bearing the coefficients of income and its one period lag respectively. The sub-column titled *with capital*, under within-group column has income replaced by its function in poverty equation, such that k_t and k_{t-1} are coefficients of capital per worker and its first period lag respectively.

Regression with income substituted by production function shows that manufacturing capital per worker has no significant anti-poverty effects for poverty incidence. However, it enhances poverty intensity and severity in the presence of within- and between-group inequality components, with coefficients of 0.155 and 0.277 (significant at 10% and 5% respectively) for poverty intensity, and 0.230 and 0.391 (both significant at 5%) for poverty severity. Introducing the lag value of capital in within-group inequality sub-model increases the coefficient of capital to 0.716 and 0.984 for poverty intensity and severity respectively. However, one percent increase in the lag value of capital reduces both poverty measures by 0.508 and 0.622 percents respectively. The same behaviour is observed by the lag value of income. This strongly supports the suggestion that remittances from wealthier individual within-group may be causing within-group inequality to have poverty reducing effects.

Estimation with Energy

The results with total energy in the manufacturing model are shown in Table 5.10. The model statistics for all three inequality sub-models are reliable. The goodness of fit measures are from 0.90 for per capita output equations, 0.86 to 0.88 for per capita energy demand equations, 0.71 to 0.98 for inequality and 0.27 to 0.77 for poverty equations.

Table 5.10: 3sls for GDP, Energy, Inequality and Poverty– Manufacturing Sector

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.232	-0.227	-0.220	-0.263[b]	-0.261[b]	-0.256[b]	0.096	0.098	0.103
lnk_t	0.234[b]	0.230[b]	0.226[b]	-0.001	0.001	0.008	0.099	0.095	0.084
lne_t	0.766[a]	0.770[a]	0.774[a]	1.001[a]	0.999[a]	0.992[a]	0.901[a]	0.905[a]	0.916[a]
α_0	-0.948[a]	-0.960[a]	-0.974[a]	-1.906[a]	-1.899[a]	-1.871[a]	-1.303[a]	-1.315[a]	-1.348[a]
$ln\theta_{1t}$	0.854[b]	0.846[b]	0.846[b]	0.408[a]	0.403[a]	0.398[a]	-0.057	-0.055	-0.060
lny_t	0.923[a]	0.903[a]	0.886[a]	0.801[a]	0.801[a]	0.791[a]	0.964[a]	0.928[a]	0.874[a]
$lnpe_t$	-0.104	-0.091	-0.080	0.171	0.169	0.173	-0.035	-0.015	0.020
β_0	2.584[a]	2.612[a]	2.640	2.126[a]	2.131[a]	2.157[a]	1.985[b]	2.057[b]	2.134[b]
lny_t	-7.179[a]	-7.132[a]	-6.680[a]	16.506[a]	16.734[a]	15.804[a]	-23.188[a]	-23.277[a]	-22.624[a]
$(lny_{t-1})^2$	0.801[a]	0.796[a]	0.747[a]	-1.865[a]	-1.889[a]	-1.785[a]	2.665[a]	2.674[a]	2.606[a]
lng_t	-0.045	-0.045	-0.047	-0.393[a]	-0.397[a]	-0.415[a]	0.146[b]	0.147[b]	0.136[b]
lne_t	0.361[a]	0.360[a]	0.351[a]	0.308[c]	0.308[c]	0.344[c]	0.215[c]	0.218[c]	0.196
γ_0	13.691[a]	13.589[a]	12.613[a]	-39.565[a]	-40.098[a]	-38.276[a]	48.329[a]	48.523[a]	47.095[a]
lnk_t	-0.167	-0.111	-0.063	0.067	0.231	0.406[b]	0.033	0.181	0.326
$ln\theta_{1t}$	-0.592	-0.992	-1.279	0.617[a]	0.906[a]	1.187[a]	-0.556[a]	-0.831[a]	-1.080[a]
lne_t	0.115	0.056	-0.020	0.022	-0.104	-0.265	0.302[b]	0.324	0.312
δ_0	3.620[a]	3.072[c]	2.897	4.014[a]	3.811[a]	4.021[a]	1.471[c]	-0.039	-1.072
$\mathbf{R_y^2}$	**0.90**	**0.90**	**0.90**	**0.89**	**0.89**	**0.89**	**0.89**	**0.89**	**0.89**
$\mathbf{R_e^2}$	**0.87**	**0.87**	**0.87**	**0.88**	**0.88**	**0.88**	**0.86**	**0.86**	**0.86**
$\mathbf{R_\theta^2}$	**0.71**	**0.71**	**0.72**	**0.88**	**0.88**	**0.88**	**0.98**	**0.98**	**0.98**
$\mathbf{R_P^2}$	**0.40**	**0.30**	**0.27**	**0.76**	**0.66**	**0.62**	**0.66**	**0.59**	**0.59**

Notes: [a], [b] and[c] denote significance at 1%, 5%, and 10% levels respectively. (-1) denotes that the variable is lagged by one period and cons. is constant term.

As with the whole economy, the inclusion of energy causes the coefficients of capital per unit labour to drop in all sub-models and to become insignificant in between and within-group inequality sub-models. Equally, the coefficients of total energy in all sub-models are high and significant, implying that the bias in attributing the impact of energy in production to capital is also prominent in the manufacturing sector. In per capita energy demand equations, total and between-group inequality significantly enhances energy demand, while within-group inequality is insignificantly negative. The effects of per capita income remain significant, but the magnitudes are not as high as in the national economy. Manufacturing energy use per capita has enhancing effects on all inequality measures, with one percent increase resulting in 0.361% and 0.308% and 0.215% increase in total, between-group and within-group inequalities. Total manufacturing energy use show positive and significant impact on poverty incidence within-group, but is insignificant for the other sub-models.

Table 5.11 reports the summary statistics for the impacts of (disaggregated manufacturing) energy sources on manufacturing output per worker, inequality and poverty, with the feedback effect from per capita income and all three inequality measures. The energy types considered for the manufacturing sector are total energy, electricity, diesel, gas, kerosene and coal. The detailed regression tables are shown in Tables D2.1 to D2.5 of Appendix. The overall model statistics are good and the Breusch-Pagan tests suggest that the residuals are largely interdependent.

Table 5.11: Disaggregated Energy types– Manufacturing Sector

	Effect of Energy types				
	Electricity	Diesel	Gas	Kerosene	Coal
Per capita income	0.856^{a}	0.941^{a}	0.364^{a}	0.020	0.534^{a}
Total inequality	0.525^{a}	0.317^{c}	0.090	-0.025	0.188^{a}
Between-group	0.481^{a}	0.199^{c}	-0.259^{b}	0.055^{b}	0.112
Within-Group	0.189	0.178	0.242^{a}	-0.030^{c}	-0.081
Poverty incidence	0.425^{b}	0.290	-0.386^{a}	0.040^{a}	0.009
Intensity	0.563^{b}	0.355	-0.568^{a}	0.055^{a}	-0.021
Severity	0.568	0.253	-0.699^{a}	0.063^{a}	0.008
	Effect on Energy Demand				
Per capita income	0.388^{b}	1.112^{a}	-0.011	3.946	-4.871^{b}
Total inequality	1.131^{c}	0.358	1.543	1.288	2.473^{a}
Between-group	0.193^{a}	0.110	-1.256^{a}	2.825	0.410
Within-Group	0.092	-0.033	1.765^{a}	-7.564^{c}	0.285

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively

Except for manufacturing electricity and diesel, the coefficients of capital per worker are all high and significant in the presence of the other energy types. Because of their close complementarity with capital, these energy types are those whose effects can likely be erroneously captured by capital in the estimation of manufacturing production function. However, the coefficients in the models with diesel are far lower than those in the models with electricity. The same energy types equally have the strongest impact on manufacturing output per worker. One percent increase in manufacturing diesel and electricity use per capita results in 0.941% and 0.856% rise in manufacturing output per worker respectively. The rest of the energy types also have positive effects on manufacturing output, but kerosene coefficient is near zero and insignificant.

One percent increase in coal and gas uses result in 0.534% and 0.364% increase in manufacturing output per capita respectively.

Except for gas and kerosene with insignificant coefficients, all the energy types have total inequality enhancing effects. While gas has negative and significant coefficient (-0.259), and coal positive but insignificant, all the energy types significantly enhance between-group inequality. One percent rise in manufacturing electricity, diesel, and kerosene uses bring about 0.481%, 0.199%, and 0.055% rise in between-group inequality. However, only gas and kerosene have significant effect on within-group inequality, with coefficients of 0.242 and -0.030 respectively. Consequently, manufacturing gas consumption shows negative and significant impact on poverty, with one percent increase resulting in 0.386, 0.568 and 0.699 percent fall in poverty incidence, intensity and severity respectively. Coal also shows negative impact, but it is not significant. The other resources have positive effect on poverty, but only electricity and kerosene are significant. The elasticities of substitution in chapter four demonstrate that energy types with poverty reducing effects are equally strong complements with labour, while those with positive effects on poverty rather substitute labour in production. Therefore the findings of chapter four corroborate the poverty effects in this section. The poverty enhancing effect of manufacturing electricity is likely due to its strong inequality enhancing effects, while that of kerosene is rather due to its weak and insignificant contribution to productivity and hence growth.

Feedback effects show that per capita income is a strong positive determinant of manufacturing diesel and electricity demands. A percentage increase in manufacturing output per worker brings about 1.112 and 0.388 percent rise in manufacturing diesel and electricity demands, but rather a 4.871% fall in coal demand. The effect of income on gas demand is also negative but insignificant. The suggestion here is that both gas and coal are likely used by the poor for low income businesses such as the case of Small and Medium-Size enterprises (SME). Such SMEs are mostly small scale motorcar repairs and art and craft sectors. It is worth noting that the manufacturing sector also includes the informal sector, where most of the small businesses may be located. This may better explain the association of gas with poverty reduction, because it may have much to do with livelihood business activities of the poor. Total inequality has positive effects on all energy types, but is significant only for electricity and coal. Between-group inequality significantly boosts electricity demand, but it strongly reduces gas demand. Within-group inequality is significant only on gas and kerosene, with coefficients of 1.765 and -7.564 respectively. It is possible that gas use is encouraged by individuals of poorer groups because it is more productive than kerosene.

5.3.3 Agricultural Sector

The correlation coefficients of agricultural energy per capita, GDP per worker, inequality (total, between- and within-group) and poverty are in Table 5.12. Total and within-group inequality both associate positively with agricultural production, but between-group inequality show significantly negative association. Agricultural production negatively correlates with all poverty measures. Except coal, all agricultural energy types have positive and significant correlation with agricultural value-added per worker. Coal and agricultural value added are negatively correlated. All energy types except coal correlate positively with total and within-group inequality and negatively with between-group inequality. The correlation coefficients are not statistically significant for diesel and kerosene. Coal correlates significantly and negatively (positively) with total and within-group (between-group) inequality. Apart from coal with positive and significant coefficient, all the energy types in agriculture show negative and significant association with all poverty measures. Government expenses show a positive and significant relationship with agricultural value added per worker.

Table 5.12: Correlation Coefficients for – Agricultural Sector

	inequality			Poverty			Output/ worker
	T	T_B	T_W	P^0	P^1	P^2	
output per worker	0.626[b] (0.009)	-0.830[a] (0.000)	0.858[a] (0.000)	-0.751[a] (0.001)	-0.722[a] (0.002)	-0.718[a] (0.002)	-
Total Energy	0.424 (0.102)	-0.487[c] (0.056)	0.513[b] (0.042)	-0.512[b] (0.043)	-0.474[c] (0.063)	-0.481[c] (0.059)	0.790[a] (0.000)
Coal	-0.565[b]	0.842[a]	-0.817[a]	0.814[a]	0.756[a]	0.670[b]	-0.722[a]

	(0.023)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)	(0.002)
electricity	0.574^{b} (0.020)	-0.588^{b} (0.017)	0.659^{b} (0.006)	-0.621^{b} (0.010)	-0.578^{b} (0.019)	-0.571^{b} (0.021)	0.818^{a} (0.000)
Diesel	0.256 (0.339)	-0.353 (0.180)	0.337 (0.202)	-0.367 (0.162)	-0.336 (0.204)	-0.345 (0.190)	0.680^{a} (0.004)
Kerosene	0.400 (0.125)	-0.472 (0.065)	0.526^{b} (0.036)	-0.331 (0.210)	-0.268 (0.316)	-0.286 (0.283)	0.739^{a} (0.001)
Government expenses/GDP	0.712^{a} (0.002)	-0.859^{a} (0.000)	0.932^{a} (0.000)	-0.748^{a} (0.001)	-0.670^{b} (0.005)	-0.643^{b} (0.007)	0.922^{a} (0.000)

Notes: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively

Estimation without Energy

Table 5.13 shows the regression results of the framework without energy types for agriculture. The overall model statistics are equally satisfactory, with R-square for agricultural production function ranging from 0.72 to 0.85, while the others range from 0.48 to 0.88 for inequality equations and 0.36 to 0.77 for poverty equations.

Table 5.13: 3sls Results for GDP-Inequality-Poverty Incidence – Agricultural Sector

Variable	Total inequality[77]				Between-Group		Within-Group	
	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
$ln\theta_{1t}$	2.407^a	3.34	2.409^a	3.35	-1.169^a	-6.01	0.810^a	5.85
lnk_t	0.578^a	4.09	0.577^a	4.08	0.394^a	3.64	0.369^a	3.27
α_0	0.651^b	2.46	0.653^b	2.47	-0.051	-0.32	1.505^a	5.47
lny_t	-0.210	-0.64	-0.246	-0.76	1.330^b	2.56	-1.286^c	-1.99
$(lny_{t-1})^2$	0.071	0.72	0.082	0.83	-0.518^a	-3.32	0.479^b	2.47
lng_t	0.105^c	1.93	0.107^c	1.97	-0.216^b	-2.57	0.443^a	4.04
γ_0	0.212	0.67	0.244	0.77	-1.796^a	-3.54	0.541	0.85
lnk_t	-0.171^b	-2.78	-0.077	-1.17	0.017	0.40	0.007	0.12
$ln\theta_{1t}$	-0.325	-1.00	-0.843^b	-2.49	0.506^a	6.72	-0.308^a	-4.54
δ_0	4.120^a	39.14	3.964^a	32.15	4.232^a	71.64	3.628^a	26.44
$\mathbf{R_y^2}$	**0.72**	**27.00**	**0.72**	**26.93**	**0.84**	**53.70**	**0.85**	**55.41**
$\mathbf{R_\theta^2}$	**0.48**	**8.11**	**0.48**	**8.22**	**0.82**	**32.17**	**0.88**	**48.28**
$\mathbf{R_P^2}$	**0.56**	**9.99**	**0.36**	**7.04**	**0.77**	**32.71**	**0.65**	**17.15**
Breusch-Pagan	**3.46**	**0.326**	**9.56**	**0.023**	**6.82**	**0.078**	**5.60**	**0.133**
Joint test on lny_t and $(lny_t)^2$			**0.36**	**0.697**	**9.74**	**0.001**	**4.49**	**0.018**

Notes: ^{a}, ^{b} and^c denote significance at 1%, 5%, and 10% levels respectively. The Breusch-Pagan Statistics is for the test of independence of residuals of the equations. F-statistics (under coef. Columns) and P-VAL (under t-stat columns) for joint Wald test on lny_t and $(lny_t)^2$ are presented on the last row.

Agricultural capital per unit labour is as expected, positive and significant. Total and within-group inequalities significantly enhance agricultural value added, while between-group inequality reduces it. Their coefficients are higher than those of whole economy and manufacturing sector. A percentage increase in between-group inequality brings about 1.169 percent drop in agricultural value added. The same increase in within-group inequality causes 0.810 percent rise in agricultural value added per worker. This suggests that both growth lowering effects of between-group tensions, credit (and other factor) constraints and the trickle-down effect of the fruits of growth via social capital within-group are equally at work in the agricultural sector.

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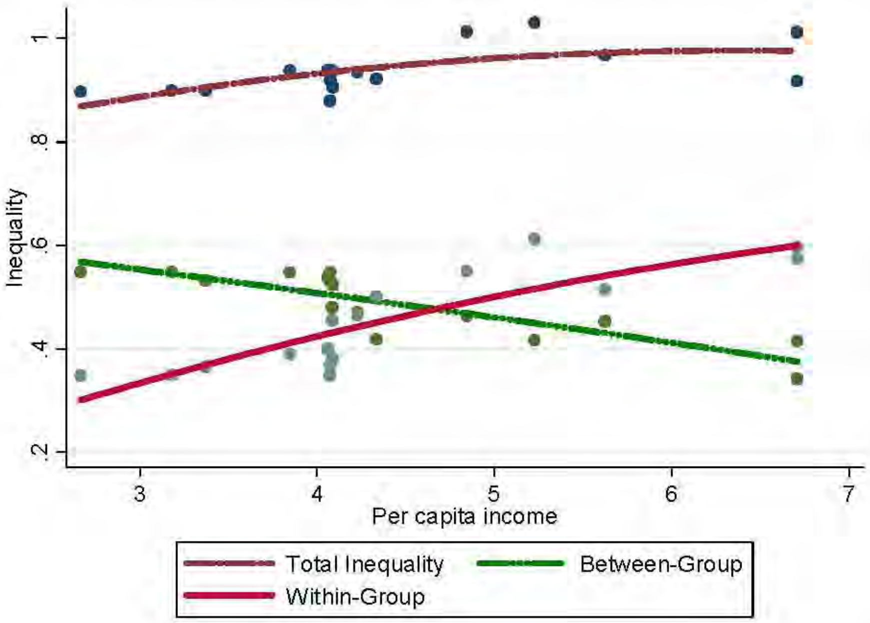
[77] The first two columns of the table give results that contain per capita income in poverty equation. The rest of the columns have capital per worker in place of per capita income in poverty equation.

Unlike the whole economy and the manufacturing sector, agricultural value-added per worker and its square are neither individually, nor jointly significant on total inequality. However, a mild and significant inverted U-shape for between-group inequality with per capita income relationship and U-shape one for within-group inequality seem to exist. Agricultural per capita output and its square have the respective significant negative (-1.286) and positive (0.479) signs on within-group inequality. The signs are reversed in between-group inequality equation (1.330 and -0.518 respectively). Both are jointly significant in between- and within-group inequality equations. Figure 5.5 plots the relationships. This result may be supported by the active support to the agricultural sector, particularly in terms of diesel subsidies, extension services, credit provisions and (less significantly) land redistribution, largely in favour of black farmers.

Figure 5.5: Inequality-Per Capita Income in Agriculture



In the poverty equations, agricultural production has negative impacts on all poverty measures. The impacts on poverty incidence are in Table 5.13 and those on poverty intensity and severity are in Table 5.14. One percent increase in value-added per worker in the agricultural sector results in 0.171, 0.234 and 0.309 percent reduction in poverty incidence, intensity and severity respectively. These coefficients are higher than those of whole economy and manufacturing. The abjectly poor thus benefit more from agricultural production enhancement than the just poor.

Table 5.14: Impact on Poverty Intensity and Severity– Agricultural Sector

Variable	Poverty intensity equation		Poverty Severity equation	
	Coef	t-stat	Coef	t-stat
T-Theil	-0.309	-0.66	-0.276	-0.46
B-Theil	0.647[a]	4.98	0.738[a]	4.11
W-Theil	-0.374[a]	-3.52	-0.423[a]	-3.01
Income	-0.234[b]	-2.65	-0.309[b]	-2.73
Capital/L	-0.100	-1.06	-0.138	-1.13
R_p^2/F-stat	**0.65**	**17.97**	**0.60**	**13.44**

Note: [a], [b] and[c] denote significance at 1%, 5%, and 10% levels respectively. There are three regressions per poverty measure - each for total, between- and within-group inequalities. Income coefficients are for total inequality equation, while capital coefficients are for within-group inequality.

Regression with agricultural income substituted for by its production function shows that agricultural capital per worker has no significant anti-poverty effects on any of the poverty measures. The Introduction of the lag value of capital in within-group inequality sub-model made no difference. The same indifference is observed on the lag value of income. This suggests that the trickle-down effect of income from richer members to poorer ones of the group may not apply for agricultural sector. Agricultural activities reduce poverty directly through the poor's current participation in the sector, either via labour supply or farm ownership. Therefore in the agricultural sector, the weight of income at the top tail of within-group underlies its positive coefficient on agricultural income more than within-group solidarity.

Estimation with Energy

The figures in Table 5.15 are the estimates of per capita agricultural value added, inequality and poverty with energy included. The goodness of fit for production, inequality and poverty remain close to those of the estimation without energy. The R-squares for all energy equations are above 65 percent.

Table 5.15: 3sls for, Energy-Inequality-GDP and Poverty – Agricultural Sector

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	1.938^{a}	1.932^{a}	1.931^{a}	-0.861^{a}	-0.857^{a}	-0.859^{a}	0.592^{a}	0.591^{a}	0.591^{a}
lnk_t	0.092	0.101	0.101	0.034	0.046	0.044	-0.048	-0.044	-0.041
lne_t	0.908^{a}	0.899^{a}	0.899^{a}	0.966^{a}	0.954^{a}	0.956^{a}	1.048^{a}	1.044^{a}	1.041^{a}
α_0	-2.589^{a}	-2.564^{a}	-2.563^{a}	-3.504^{a}	-3.466^{a}	-3.473^{a}	-2.618^{a}	-2.607^{a}	-2.598^{a}
$ln\theta_{1t}$	-0.408	-0.357	-0.342	0.822^{a}	0.805^{a}	0.810^{a}	-0.792^{a}	-0.783^{a}	-0.775^{a}
lny_t	1.008^{a}	1.025^{a}	1.031^{a}	1.011^{a}	1.025^{a}	1.028^{a}	1.025^{a}	1.025^{a}	1.026^{a}
$lnpe_t$	-0.199^{c}	-0.220^{c}	-0.226^{c}	-0.028	-0.049	-0.049	0.111^{b}	0.104^{c}	0.097^{b}
β_0	3.834^{a}	3.905^{a}	3.927^{a}	3.680^{a}	3.738^{a}	3.738^{a}	1.784^{a}	1.821^{a}	1.858^{a}
lny_t	-0.171	-0.135	-0.087	1.150^{c}	1.037^{c}	0.884	-0.386	-0.153	-0.011
$(lny_{t-1})^2$	0.040	0.030	0.016	-0.487^{b}	-0.461^{b}	-0.414^{b}	0.230	0.166	0.121
lng_t	0.124^{b}	0.121^{b}	0.119^{b}	-0.239^{b}	-0.221^{b}	-0.218^{b}	0.426^{a}	0.405^{a}	0.404^{a}
lne_t	0.010	0.006	0.003	0.272^{b}	0.287^{b}	0.299^{b}	-0.289^{a}	-0.314^{a}	-0.323^{a}
γ_0	0.199	0.184	0.158	-2.831^{a}	-2.768^{a}	-2.697^{a}	1.035^{c}	0.920^{c}	0.848
lnk_t	-0.007	0.015	0.051	0.143	0.182	0.254	0.158	0.211	0.309
$ln\theta_{1t}$	-0.784^{b}	-0.921^{c}	-1.078^{c}	0.514^{a}	0.631^{a}	0.732^{a}	-0.309^{a}	-0.373^{a}	-0.440^{a}
lne_t	-0.147	-0.244	-0.362	-0.165	-0.246	-0.379	-0.210	-0.311	-0.467
δ_0	4.503^{a}	4.161^{a}	4.123^{a}	4.756^{a}	4.412^{a}	4.460^{a}	4.304^{a}	3.884^{a}	3.869^{a}
$\mathbf{R_y^2}$	**0.69**	**0.70**	**0.70**	**0.80**	**0.80**	**0.80**	**0.81**	**0.81**	**0.81**
$\mathbf{R_e^2}$	**0.66**	**0.66**	**0.66**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**
$\mathbf{R_\theta^2}$	**0.51**	**0.51**	**0.51**	**0.83**	**0.83**	**0.83**	**0.90**	**0.90**	**0.90**
$\mathbf{R_P^2}$	**0.35**	**0.30**	**0.30**	**0.81**	**0.69**	**0.64**	**0.69**	**0.59**	**0.55**

Note: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

Like in the case of the whole economy and manufacturing, the inclusion of energy causes the coefficient of capital per unit labour to drop and become insignificant. Energy elasticity of agricultural value-added per worker is also high, at 0.908% for total inequality model, 0.966% between-group and 1.048% within-group in poverty incidence sub-model. Per capita agricultural income is a significant determinant of energy demand in agriculture. One percent rise in agricultural income causes 1.008 percent increase in agricultural energy use. Energy price effect is also significant and lies between -0.028 and -0.226 for the different sub-models. This implies that per capita energy demand in agriculture is inelastic with respect to price. Though total inequality show no significant effect on agricultural energy use, both between- and within-group components do. A percentage increase in between-group (within-group) inequality increases (reduces) agricultural energy use by 0.822 (0.792) percent in poverty incidence sub-model. Aggregate energy use in agriculture has significant between-group widening and within-group reducing effects. Energy use in agriculture is poverty reducing, but not significant on poverty severity.

Table 5.16 summarises the results for disaggregated agricultural energy types (details are in Tables C3.1 to C3.4 of Appendix). In terms of R-squares and F-statistics of the models, they are reliable. The capital per worker coefficients are high and significant for coal and kerosene, significant and moderate for electricity, but low and insignificant for diesel. On the contrary, coal does not significantly enhance agricultural production per capita. The effect of kerosene is the lowest among significant coefficients. One percent increase in diesel, electricity and kerosene leads to 0.746, 0.616 and 0.170 percent increase in per capita agricultural value added.

Table 5.16: Disaggregated Energy-GDP-Inequality-Poverty – Agriculture

	Effect of Energy types			
	Electricity	Diesel	Kerosene	Coal
Per capita income	0.616^{a}	0.746^{a}	0.170^{b}	-0.045
Total inequality	0.018	-0.075	-0.018	-0.015
Between-group	0.238^{a}	0.271^{b}	0.028	0.081^{a}
Within-Group	-0.205^{b}	-0.543^{a}	-0.092	-0.081^{b}
Poverty incidence	-0.154^{c}	0.027	0.004	0.060^{a}
Intensity	-0.224^{c}	-0.012	0.009	0.080^{a}
Severity	-0.286^{c}	-0.084	-0.003	0.085^{b}
	Effect on Energy Demand			
Per capita income	0.979^{a}	0.904^{a}	1.963^{a}	-2.095
Total inequality	1.152	-0.876	-0.603	-7.635^{c}
Between-group	0.372	0.851^{a}	2.278^{c}	6.960^{a}
Within-Group	-0.115	-0.814^{a}	-1.374	-5.602^{a}

Note: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

On the feedback effect, per capita agricultural output is a significant determinant of electricity, diesel and kerosene demands. The coefficients indicate that one percent increase in per capita income in agriculture results in more than proportionate (1.963 percent) rise in kerosene demand, and less than proportionate rise in electricity (0.979) and diesel (0.904) demands. Between-group inequality tends to increase energy demand while within-group inequality tends to attenuate it for all energy types, but the coefficients are insignificant for electricity.

Coal use significantly widens between-group inequality and lowers within-group inequality and is associated with increase in poverty. Because coal has insignificant effect on production per capita, this suggests that coal may be used mainly by the low income farmers, and it exacerbates their poverty by reducing productivity. Agricultural electricity use has significant poverty reducing effects on all poverty measures. Though diesel shows poverty reducing tendencies, its coefficients are insignificant. This suggests that the poorer farmers do not use diesel, which is the most productive agricultural energy type. Because of diesel's positive long-run relationship with capital and negative with labour, one suggests that lack of capital is limiting the use of diesel by the poor, and the use of diesel reduces labour employment, leaving diesel with no impact on poverty.

5.3.4 Mining Sector

The pair-wise correlation coefficients of mining energy, GDP per capita, inequality, poverty and government expenses and their significance probabilities are shown in Table 5.17. Mining output per worker correlates positively with total and within-group inequality and all the energy types. It has negative correlation with between-group inequality, and all the poverty measures. All mining energy types have negative correlation with the three poverty measures. Government expenses show significantly positive association with mining GDP.

Table 5.17: Correlation Coefficients - Mining Sector

	inequality			Poverty			Output/ worker
	T	T_B	T_W	P^0	P^1	P^2	
output per worker	0.777[a] (0.000)	-0.866[a] (0.000)	0.958[a] (0.000)	-0.819[a] (0.000)	-0.756[a] (0.001)	-0.707[a] (0.002)	-
Total Energy	0.754[a] (0.001)	-0.869[a] (0.000)	0.950[a] (0.000)	-0.800[a] (0.000)	-0.726[a] (0.002)	-0.662[b] (0.005)	0.983[a] (0.000)
Coal	0.643[b] (0.007)	-0.687[a] (0.003)	0.764[a] (0.001)	-0.702[a] (0.002)	-0.621[b] (0.010)	-0.509[b] (0.044)	0.801[a] (0.000)
Electricity	0.766[a] (0.001)	-0.848[a] (0.000)	0.937[a] (0.000)	-0.811[a] (0.000)	-0.747[a] (0.001)	-0.692[a] (0.003)	0.978[a] (0.000)
Liquid Petroleum	0.779[a] (0.000)	-0.837[a] (0.000)	0.951[a] (0.000)	-0.734[a] (0.001)	-0.662[b] (0.005)	-0.632[b] (0.009)	0.978[a] (0.000)
Government expenses/GDP	0.712[a] (0.002)	-0.859[a] (0.000)	0.932[a] (0.000)	-0.748[a] (0.001)	-0.670[b] (0.005)	-0.643[b] (0.007)	0.965[a] (0.000)

Notes: [a], [b] and[c] denote significance at 1%, 5%, and 10% levels respectively.

Estimation without Energy

The results of the regression output without energy in Table 5.18 show significant model performance and high goodness of fit for all the equations in the various sub-models. Mining production function’s goodness of fit ranges from 83 o 92 percent, that of inequality from 63 to 92 and of poverty from 40 to 76 percent.

Table 5.18: 3sls for GDP-Inequality-Poverty Incidence - Mining Sector

Variable	Total inequality[78]				Between-Group		Within-Group	
	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
$ln\theta_{1t}$	1.949^b	2.20	1.999^b	2.22	-1.141^a	-5.13	1.340^a	9.61
lnk_t	0.439^a	4.55	0.433^a	4.35	0.313^a	4.34	0.028	0.44
α_0	3.467^a	10.15	3.488^a	9.91	2.890^a	19.14	5.684^a	19.49
lny_t	1.323	1.24	0.868	0.79	5.343^b	2.42	0.202	0.18
$(lny_{t-1})^2$	-0.111	-1.05	-0.064	-0.58	-0.585^b	-2.65	0.052	0.45
lng_t	-0.105	-1.33	-0.100	-1.23	-0.221	-1.44	0.016	0.23
γ_0	-3.936	-1.44	-2.844	-1.01	-13.135^b	-2.33	-2.884	-1.00
lnk_t	-0.234^a	-4.39	-0.072	-1.39	0.046	1.59	0.169^a	3.10
$ln\theta_{1t}$	0.336	1.02	-0.423	-0.88	0.612^a	6.82	-0.637^a	-5.45
δ_0	5.009^a	18.76	4.083^a	22.15	4.198^a	71.93	2.859^a	11.14
$\mathbf{R_y^2}$	**0.84**	**50.95**	**0.83**	**50.23**	**0.89**	**83.84**	**0.92**	**153.89**
$\mathbf{R_\theta^2}$	**0.64**	**12.38**	**0.63**	**12.37**	**0.80**	**29.89**	**0.92**	**100.11**
$\mathbf{R_p^2}$	**0.69**	**16.22**	**0.40**	**6.47**	**0.76**	**37.68**	**0.75**	**29.53**
Breusch-Pagan	**4.83**	**0.185**	**12.97**	**0.005**	**14.07**	**0.003**	**20.41**	**0.000**
Joint test on lny_t and $(lny_t)^2$			**3.92**	**0.028**	**8.85**	**0.001**	**41.41**	**0.000**

Notes: ^{a}, ^{b} and^c denote significance at 1%, 5%, and 10% levels respectively. The Breusch-Pagan Statistics is for the test of independence of residuals of the equations. F-statistics (under coef. Columns) and P-VAL (under t-stat columns) for joint Wald test on lny_t and $(lny_t)^2$ are presented on the last row.

Mining capital per worker shows positive effect on per capita mining income but it is significant only in total and between-group inequality models. All inequality measures have significant effect on mining output. Total and within-group inequalities have positive effect, with respective coefficients of 1.99 and 1.34. Between-group inequality is negative on output, with one percent increase leading to 1.141 percent fall in mining output per worker. The magnitudes of the inequality coefficients are higher than for the whole economy and the manufacturing sector, but lower than those of the agricultural sector. There is the same suggestion that growth stifling factors seem to act through between-group inequality via the credit, political economy channels and criminality and interracial tensions. The positive effect of within-group inequality may also be capturing the trickle-down effect of the fruits of growth via social capital within-group especially in African households.

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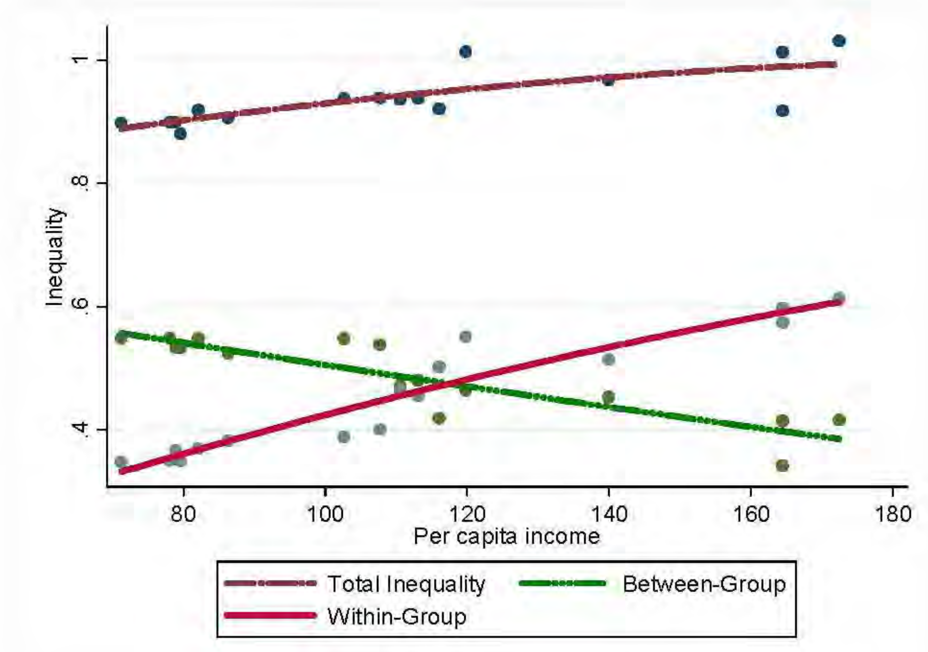
[78] The first two columns of the table give results that contain per capita income in poverty equation. The rest of the columns have capital per worker in place of per capita income in poverty equation.

Contrary to the other sectors, both mining output per worker and its square are insignificant on total and within-group inequality. However, there is evidence of an inverted U-shaped relationship with between-group inequality. This implies that one percent increase in mining output enhances between-group inequality by 5.343 percent, but in times of more enhanced increase in mining activity, inequality increase is attenuated at a rate of 0.585 percent. Figure 5.6 plots the relationship. Equally, the active redistribution policies of the post-apartheid government of South Africa (which has enabled share and stakes to be acquired by black people, through the BEE process in the mining and other sectors) may be at the basis of this relationship.

Figure 5.6: Inequality-Per Capita Income for Mining



The estimates with poverty equations show that like in the agricultural sector, mining production per worker has negative impacts on all poverty measures. The impacts on poverty incidence are in Table 5.18 and those on poverty intensity and severity are in Table 5.19. One percent increase in mining GDP per worker brings about 0.234, 0.267 and 0.310 percent reduction in poverty incidence, intensity and severity, all significant at 5% level and less. Like the agricultural sector, the abjectly poor benefit more from agricultural production enhancement than the just poor.

Table 5.19: Impact on Poverty Intensity and Severity - Mining Sector

Variable	Poverty intensity equation		Poverty Severity equation	
	Coef	t-stat	Coef	t-stat
T-Theil	-0.832	-1.18	-0.969	-1.04
B-Theil	0.833^{a}	5.36	1.002^{a}	4.60
W-Theil	-0.907^{a}	-4.92	-1.124^{a}	-4.41
Income	-0.267^{a}	-3.13	-0.310^{b}	-2.60
Capital/L	-0.060	-0.79	-0.076	-0.76
R_P^2/F-stat	**0.64**	**21.60**	**0.59**	**16.23**

Note: ^{a}, ^{b} and ^{c} denote significance at 1%, 5%, and 10% levels respectively. The output is for three regressions per poverty measure - one for total, between- and within-group inequalities. Income coefficients are for total inequality equation, while capital coefficients are for within-group inequality.

Regression with mining income substituted for by its production function shows that mining capital per worker has no significant anti-poverty effects on any of the poverty measures in total and between-group inequality models. In within-group inequality model, mining capita per worker enhances all measures of poverty. As with the agricultural sector, the introduction of the lag value of capital in within-group inequality sub-model made no difference. The same indifference is observed on the lag value of mining income. This suggests mining activities reduce poverty directly through the poor's current participation in the sector, via labour supply.

Estimation with Energy

Table 5.20: 3sls for Production, Energy, Inequality, GDP and Poverty - Mining Sector

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-1.489^{a}	-1.489^{a}	-1.507^{a}	0.572^{a}	0.577^{a}	0.578^{a}	-0.373^{a}	-0.373^{a}	-0.376^{a}
lnk_t	-0.012	-0.012	0.000	-0.086	-0.077	-0.064	-0.009	-0.008	0.002
lne_t	1.012^{a}	1.012^{a}	1.000^{a}	1.086^{a}	1.077^{a}	1.064^{a}	1.009^{a}	1.008^{a}	0.998^{a}
α_0	-1.156^{a}	-1.156^{a}	-1.126^{a}	-0.837^{a}	-0.812^{a}	-0.774^{a}	-1.355^{a}	-1.352^{a}	-1.328^{a}
$ln\theta_{1t}$	0.005	0.005	0.006	-0.357^{b}	-0.357^{b}	-0.353^{b}	0.256	0.259	0.276
lny_t	1.026^{a}	1.029^{a}	1.059^{a}	0.849^{a}	0.873^{a}	0.933^{a}	0.894^{a}	0.899^{a}	0.948^{a}
$lnpe_t$	0.187	0.184	0.157	0.236^{b}	0.215^{b}	0.160	0.174	0.167	0.111
β_0	0.057	0.055	0.038	0.399^{c}	0.386^{c}	0.354	0.943	0.953	0.990
lny_t	0.812	0.797	0.997	6.600^{a}	6.007^{b}	5.964^{b}	-1.379	-1.269	-1.312
$(lny_{t-1})^2$	-0.067	-0.066	-0.087	-0.668^{a}	-0.608^{b}	-0.601^{b}	0.173	0.163	0.166
lng_t	-0.068	-0.069	-0.073	-0.305^{c}	-0.287^{c}	-0.334^{c}	0.083	0.070	0.104

$ln e_t$	0.036	0.035	0.038	-0.271	-0.271	-0.238	0.257	0.260	0.241
γ_0	-2.670	-2.633	-3.128	-15.742^{b}	-14.277^{b}	-14.464^{b}	0.461	0.139	0.431
$ln k_t$	0.091	0.157	0.168	0.069	0.114	0.097	0.157^{b}	0.239^{b}	0.294^{b}
$ln\theta_{1t}$	0.167	0.005	0.035	0.452^{a}	0.597^{a}	0.843^{a}	-0.434^{b}	-0.660^{b}	-1.038^{a}
$ln e_t$	-0.286^{a}	-0.388^{a}	-0.447^{b}	-0.088	-0.131	-0.069	-0.102	-0.114	-0.009
δ_0	5.253^{a}	4.902^{a}	4.713^{a}	4.512^{a}	4.001^{a}	3.387^{a}	3.645^{a}	2.549^{a}	0.983^{a}
$\mathbf{R_y^2}$	**0.91**	**0.91**	**0.91**	**0.93**	**0.93**	**0.93**	**0.94**	**0.94**	**0.94**
$\mathbf{R_e^2}$	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**
$\mathbf{R_\theta^2}$	**0.63**	**0.63**	**0.63**	**0.81**	**0.81**	**0.81**	**0.92**	**0.92**	**0.92**
$\mathbf{R_p^2}$	**0.68**	**0.57**	**0.44**	**0.81**	**0.69**	**0.61**	**0.78**	**0.70**	**0.65**

Note: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

The introduction of aggregate energy to the model equally results in a sharp fall in the coefficients of capital per unit labour (Table 5.20). They are all insignificant in the presence of total mining energy. Mining energy is a strong determinant of mining output per worker. A percentage increase in energy use resulting in 1.012 percent increase in output per worker. Mining output per worker is also a significant determinant of aggregate per capita energy demand in the sector, with coefficient of around 1.026. Mining energy does not appear to have significant effects on any inequality measure, and shows significant poverty reducing effects in total inequality model. One percent increase in energy use results in 0.286, 0.388 and 0.447 percent reduction in poverty incidence, intensity and severity.

Table 5.21: Estimates with disaggregated Energy types - Mining

	Effect of Energy types		
	Electricity	Liquid Petroleum	Coal
Per capita income	0.924^{a}	0.757^{a}	0.041
Total inequality	0.033	0.142^{c}	0.010
Between-group	0.151	-0.055	0.018
Within-Group	-0.025	-0.011	-0.019
Poverty incidence	-0.427^{a}	-0.213^{a}	-0.039^{c}
Intensity	-0.591^{a}	-0.219^{a}	-0.049
Severity	-0.663^{a}	-0.349^{a}	-0.041
	Effect on Energy Demand		
Per capita income	0.911^{a}	1.375^{a}	1.588
Total inequality	-0.219	1.286	0.895
Between-group	0.155	-0.031	0.239
Within-Group	-0.022	0.823^{b}	-1.365

Note: ^{a}, ^{b} and^{c} denote significance at 1%, 5%, and 10% levels respectively.

Disaggregation of energy types (Table 5.21 and Tables D4.1 to D4.3 of Appendix) shows that mining electricity and liquid petroleum both have strong positive effect on output per worker, with coefficients of 0.924 and 0.757 respectively. Output equally strongly enhances the demand for these energy types, with elasticities slightly less than unity for electricity and above unity for liquid petroleum. Coal has no effect on output and inequality. Both output and inequality do not also significantly affect mining coal use.

All energy types in the mining sector show poverty reducing effects but the coefficient of coal is significant only on poverty incidence. One percent increase in electricity use leads to 0.427, 0.591 and 0.663 percent reduction in poverty incidence, intensity and severity. The same increase in liquid petroleum use leads to 0.213, 0.219 and 0.349 percent reduction in the respective poverty indices, while that of coal brings about only 0.039 percent reduction in poverty incidence. A number of factors can explain the performance of the mining sector towards poverty reduction. First, mining sector is a heavy employer of low- and semi-skilled labour after agriculture (see STATSSA Labour Force Survey, 2004). Secondly, with the Black Economic Empowerment (BEE) policies, many black-owned mining firms are emerging, such as African Rainbow Minerals and Mvelaphanda Resources. These imply that factor rewards in the mining sector trickle down to the poor (however, not through capital), either through the sales of labour, or ownership of factors other than crude labour.

5.4 Conclusion

This chapter completes the pro-poor growth analysis with the addition of inequality and poverty into the energy and production framework developed in chapter four. It uses a Cobb-Douglas per worker production function, and develops inequality frameworks based on Ahluwalia (1976) and poverty equations based on pro-poor growth framework (Son and Kakwani, 2008). The frameworks are jointly estimated first without energy types, then including per capita energy demand, with inequality disaggregated into sub-group components. There are some suggestions in the results.

There is significant negative effect of between-group inequality on production (in all the sectors) which may be explained in theory by credit constrains, criminality and between race tensions. Within-group inequality impacts positively on production, which could be capturing the trickle-down effect of the fruits of growth via social capital within-group especially in African households where significant remittances may go to poorer individuals from the richer and well endowed ones. This may apply particularly for the whole economy and manufacturing sector. For agricultural and mining sectors, black economic empowerment effects may cause income at the top tail of within-group inequality to weigh positively in the overall income, causing its positive effect.

There is evidence of an inverted U-shape inequality-per capita income relationship for between-group inequality, but a U-shaped one for within-group inequality. it may be difficult for one to claim that this result is picking the Kuznets U-shaped development-inequality hypothesis since the time period under consideration here is only about 20 years. This may rather agree with the active post-apartheid policies of Black Economic Empowerment, which, while yielding fruits in the reduction of between-group inequality, actually increases within-group inequality. This is supported by the coefficients of Government expenses with significant negative and positive impacts on between-group and within-group inequality components respectively.

Per capita income has poverty reducing effects in the entire economy and in the respective sectors studied. Between-group inequality (in line with pro-poor growth theory) has poverty increasing effect, with the abjectly poor suffering more from inequality than others. The effect of within-group inequality makes sense in terms of within-group solidarity, where growth at first widens inequality within-group when the relatively well-endowed individuals access some of the fruits of economic growth. They then remit some of the growth returns to their poorer family members. This intuition is supported by the fact that first lag of capital is poverty reducing in within-group inequality (holds only for total economy and manufacturing sector). The strong effect on poverty severity implies that such remittances are for altruistic motives, with the very poor receiving more attention. Statistics South Africa (2002) reports that the most important source of income for the unemployed in South Africa is financial support from other working members of their household. By deduction (from the fact that government expenses reduce total and between-group inequalities) and in line with the correlation coefficients of government expenses (negative and significant) on all poverty measures, one would conclude that government efforts are yielding some anti-poverty fruits. However, as the coefficients indicate, these efforts are a little biased towards the just poor than the very poor.

The reduction in the coefficients of capital per unit labour following the introduction of productive energy types into the production equation imply that capital estimates in traditional production functions be biased, picking the effect of omitted energy.

Higher between-group inequality results in higher demand for all energy types (except gasoline and gas in whole economy, gas in manufacturing). The possible reason why higher inequality may be associated with increased energy consumption is that while energy consumption does not decrease with relatively poorer people, it may increase faster with the richer group as inequality widens. This reason is suggested by the coefficients of price (inelastic) and income (luxury good nature).

All the energy types (except diesel in the whole economy) enhance total and between-group inequality. The impact is negative (except for gas) on within-group inequality. All the manufacturing energy types have positive overall total and between-group inequality elasticities, but negative on within-group inequality (except for gas). Diesel though shows a negative effect on total and within-group inequalities, has a positive elasticity on between-group inequality. However, it may be erroneous to interpret that the uses of the above energy types reduce within-group inequality since the other inputs (capital) show the same effect. The possible explanation for negative effects on within-group inequality is that energy's productivity (as well as those of other factors) eventually trickle-down within-group (through remittances for altruistic and other motives).

Total energy, gasoline, kerosene and coal for the whole economy, electricity, diesel and kerosene in manufacturing, and coal in agriculture are associated with higher poverty (for all three measures of poverty). One would say that the fruits of production from these energy types go to the rich. Due to strong complementarity with capital, electrification by itself may not contribute significantly to poverty reduction unless other factors such as capital (both physical, human and social) accompany it.

The poverty elasticities of all mining energy types and electricity in agriculture are negative. This is possibly because both sectors are the main employers of unskilled labour. Capital's weak poverty (incidence) reducing effect and poverty (intensity and severity) enhancing effects in the whole economy and manufacturing sector, and its ineffectiveness on poverty in agriculture and mining sectors suggest that lack of adequate access to capital by the poor is the main hindrance to poverty reduction, and not just energy.

6. GENERAL CONCLUSION

6.1 Introduction

This thesis investigates the impact of energy types on poverty in South Africa. Since poverty reduction comes by growth boosting and inequality attenuating factors, the thesis specifically investigates the relationship between various energy types and economic output in disaggregated forms; investigates the relationship between energy types and other factors of production; examines the production-inequality-poverty nexus and assesses the effect of various energy types on inequality and poverty.

Literature on pro-poor growth in general and the role of energy in particular suggest some unresolved issues that fall within the objective of this thesis. The first is possible simultaneity problems between production/growth and inequality on one hand, and production and energy on the other hand. The second is distinguishing the impacts of different energy types on the whole economy and disaggregated economic sectors. This is needed because various fuels can have different effects, and the effects can vary with economic sectors. Third is the need for a country-specific time series case study for the above growth-inequality link. This thesis directly addresses these concerns.

The methodology used is designed to look at the impact of energy types on other factors of production on the one hand, and production/growth, inequality and poverty on the other. While chapter one introduces the thesis and chapter two explores related literature, chapter three revisits the Vector Autoregressive approach to causality and co-integration with twofold purpose. (1) To determine the degree and direction of causality between various energy types and real GDP (and other factors of production), in the Lag-Augmented Causality (LAC) framework. (2) To assess whether there are any long-run or co-integrating relationships between the energy types and GDP (and other factors of production), using the Auto-Regressive Distributed Lag (ARDL) or bound test approach. In chapter four, a theory-based Variable Elasticity of Substitution (VES) production function is adapted to compare results with the relatively less theoretical ARDL setup. The framework allows for the calculation of three important parameters of production theory - elasticities of substitution, output elasticities and Returns to Scale (RTS). The VES functions are jointly estimated with classical energy demand equations by 3sls. In chapter five, a per capita Cobb-Douglas (C-D) production function is adapted to include inequality and energy. Ahluwalia's (1976) inequality functional form is extended with government expenses and energy. Inequality is decomposed into between- and within-group components. These are jointly estimated with a poverty equation adapted from Son and Kakwani (2008) and per capita energy demand.

Energy types are disaggregated and the whole economy, manufacturing, agriculture and mining are the sectors considered because of availability of suitable data. Energy data are from the International Energy Agency and South African Department of Minerals and Energy (DME). Energy prices from Statistics South Africa (STATSSA), Eskom and DME. GDP, capital formation, employment and government expenses are from South African Reserve Bank (SARB), STATSSA and Department of Agriculture. Population data are from World Development Indicators (2008). Inequality and poverty data are from South African Development Indicators (2009) based on All Media and Products Survey data. The rest of the chapter presents the main findings of the thesis (6.2), implications of the findings for research (6.3), for policy (6.4).

6.2 Main Findings

The main findings of this thesis relate energy to output and output growth, other factors of production (capital and labour), inequality and poverty. Other findings not directly related to energy are also highlighted.

6.2.1 Energy and Income/Income Growth

The findings are arranged in order of methods used. Causal relationships run from total energy to GDP in the entire economy, but from GDP to total energy in the manufacturiHng sector. In the agricultural and mining sectors, there is bidirectional causality between total energy and GDP. There are positive co-integrated relationships between GDP and energy in the whole economy and all the three sectors considered. However, disaggregating energy types and economic sector reveals differences in effects. In the whole economy, electricity and gas co-integrate positively with GDP, while gasoline, kerosene and coal show long-run GDP slow-down effects. Electricity, diesel, coal and gas have long-run GDP enhancement effects, but kerosene slows down GDP in the long-run for manufacturing. Electricity and diesel in agriculture, and liquid petroleum and coal in mining co-integrate positively with GDP of the respective sectors.

The results agree largely with those of the theory-based analysis. Though the marginal productivity of total energy is lower than those of capital and labour, it enhances the Returns to Scale elasticity (RTS). RTS rises from 0.449 without energy to 0.488 with total energy in the whole economy, from 0.559 to 0.821 in manufacturing, 0.047 to 0.803 in agriculture and 0.131 to 0.470 in mining. Differing impacts are shown when energy types are disaggregated. Electricity contributes the highest to RTS (more than capital), followed by gas, coal and diesel in the whole economy, while gasoline and kerosene reduce RTS relative to estimation with no energy. The same order is observed in manufacturing, with the contributions of the respective energy types to RTS enhancement higher than in the whole economy. However, kerosene's RTS slow-down effect is more attenuated in manufacturing than in the whole economy. The difference may be accounted for by the residential sector where kerosene may impair the development of human capital (Muller et al, 2003). In the agricultural sector, diesel contributes the most to RTS enhancement, followed by kerosene and electricity. In the mining sector, all energy types enhance RTS, with the highest contribution by liquid petroleum, then coal and electricity. The highest RTS is in agriculture in the presence of diesel, followed by manufacturing in the presence of electricity and mining in the presence of liquid petroleum. The whole economy, manufacturing and mining sectors exhibit diminishing Returns to Scale in the presence of the various energy types, but there are increasing Returns to Scale in the presence of diesel in agriculture.

The C-D framework of Chapter five shows that all energy types enhance per capita income in the whole economy, but kerosene is insignificant in manufacturing, while coal is insignificant in agriculture and mining. The share of residential kerosene has been falling since the post-apartheid era, but that of transport sector has been rising. Kerosene in transport is mainly used in the aviation industry, which contributes significantly to transport GDP. Given that the transport sector takes all the gasoline, and more than 50 percent of the kerosene, their positive effects on per capita income in this chapter[79] can be explained by the increasing weight of the transport sector in national income.

Electricity responds more than proportionately to increases in income for all sectors of the economy, with the greatest magnitudes being in agriculture and mining. Diesel and gas in whole economy and manufacturing, and coal in mining also respond more than proportionately. Income contributes significantly to increases in demand for gasoline and coal in the whole economy and for diesel in agriculture. The results are similar for per capita income, although the magnitudes vary somewhat. A case for concern is gasoline, on which income has positive effect. This implies that economic growth may lead to higher gasoline use (through luxury cars), which in turn slows the growth process.

6.2.2 Energy and Other Factors of Production

A causal relationship runs from total energy to capital and labour (with feedback for labour) in the entire economy. In the manufacturing sector, causality is from capital and labour to total energy (with feedback for capital). In the agricultural and mining sectors, there is bidirectional causality between total energy and labour. Total mining energy causes capital formation without feedback. Disaggregating energy types (and sectors) shows some differences in direction of causality between different energy types and GDP (and other factors). For example, electricity causes labour (with feedback) and capital in the whole economy. Manufacturing labour and capital cause electricity (with feedback for capital), while electricity causes labour in agricultural and mining

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[79] The dataset used for this chapter starts from 1993, while that of chapter four starts from 1971 and within this span, the share of transport to national GDP increased significantly.

sectors, but causes capital only in the mining sector. Diesel (liquid petroleum) behaves like electricity in manufacturing and agriculture (mining).

Gasoline and coal have negative co-integration relation with total labour and capital. Electricity, diesel and gas are associated with increased employment in the whole economy. Manufacturing coal, diesel and electricity co-integrate positively with capital and labour. In the agricultural sector, positive level relationships exist for electricity, diesel and kerosene respectively with capital. Labour negatively co-integrates with diesel, electricity and kerosene. Electricity and liquid petroleum uses in the mining sector have positive level relation with capital and labour (but negative for coal).

The VES production function estimates show that total energy is a complement to both capital and labour in whole economy and agriculture, but more of a substitute for capital (labour) and complement to labour (capital) in manufacturing (mining) sector. However, disaggregated energy types show that electricity is more a substitute for labour and complement to capital in whole economy and agriculture, but a strong substitute for (complement to) labour (capital) in manufacturing and mining sectors. Diesel complements both labour and capital in the whole economy, manufacturing and agriculture (moderately). Gas is a strong substitute for capital but complement for labour in the whole economy and manufacturing (moderately). Kerosene moderately complements capital and labour in the whole economy, but substitutes for them in the manufacturing sector. In agriculture, kerosene substitutes for labour but complements capital. Coal complements labour, but weakly substitutes for capital in the whole economy and manufacturing sector, while in agriculture, it is a substitute for both capital and labour. In mining sector, coal is a substitute for labour but a complement to capital, while liquid petroleum is a complement to labour but a substitute for capital.

In the C-D framework, the introduction of more productive energy types - electricity and diesel - generally reduces the coefficients of capital per labour compared to estimates without energy, or with less productive energy types. This reduction implies that capital estimates in traditional production functions where the main productive energy types are omitted may be biased, picking the effect of omitted energy.

6.2.3 Energy, Inequality and Poverty

All the energy types (except diesel in the whole economy) enhance total and between-group inequality. The impact is negative (except for gas) on within-group inequality. All the manufacturing energy types (except for gas) have positive overall total and between-group inequality elasticities, but negative within-group inequality elasticity. Diesel's positive effect on between-group inequality is weak, and significant only in manufacturing and agriculture, but has negative effect on within-group inequality. The possible explanation for negative effects of these energy types on within-group inequality is that energy's productivity eventually trickle-down to poorer members within-group through remittances for altruistic and other avenues.

Because of its insignificant effect on (between-group) inequality, diesel has poverty reducing effect in the whole economy. Total energy, gasoline, kerosene and coal in the whole economy, electricity, diesel and kerosene in manufacturing, and coal in agriculture are associated with higher poverty (for all three measures of poverty). One would say that the fruits of production from these energy types go to the rich. The strong complementarity of electricity with capital in production imply that electrification by itself may yield significant poverty reduction effects unless other factors such as capital (both physical, human and social) accompany it. The report of IEG (2008) supports this view.

The poverty elasticities of all mining energy types and electricity in agriculture are negative. This is possibly because both sectors are the main employers of unskilled labour. Capital's weak poverty (incidence) reducing effect and poverty (intensity and severity) enhancing effects in the whole economy and manufacturing sector, and its ineffectiveness on poverty in agriculture and mining sectors suggest that lack of adequate access to capital by the poor is the main hindrance to poverty reduction, and not just energy. These are consistent with the elasticities of substitution of the respective energy types with labour.

Higher between-group inequality results in higher demand for all energy types (except gasoline and gas in whole economy, gas in manufacturing). The possible reason why higher inequality may be associated with increased energy consumption is that while energy consumption does not decrease with relatively poorer people, it may increase faster with the richer group as inequality widens. This reason is suggested by the coefficients of price and income elasticities of demand. The price elasticities suggest that all energy types are necessities, implying that energy demand falls far slower than the rate of their respective prices increase (inelastic). On the other hand, income elasticity shows that one percent increase in income results in more than proportionate increase in the demand for the respective energy types. This implies that energy consumption would increase faster at the top end of income distribution, where a greater share of the fruits of economic growth goes to. Within-group inequality has negative effect on total energy and positive on liquid petroleum demands in mining. Since total mining energy is substitute to labour and complement with capital, while liquid petroleum is more a substitute to capital than labour, it would appear that increase in within-group inequality forces more individuals within (especially the poor) groups to seek employment in the mining sector, leading to higher use of labour complementing resources like liquid petroleum and less use of substitutes to labour such as coal. This corroborates the fact that coal does not significantly reduce poverty in the mining sector.

6.2.4 Other Findings

The other findings relate particularly to the production-inequality nexus and the relation to poverty in South Africa. There is a negative effect of between-group inequality on production (in all the sectors) which may be explained in theory by credit constraints, criminality and between race tensions. Within-group inequality impacts positively on production. This could be capturing the trickle-down effect of the fruits of growth. Such trickle-down mechanism can occur via social capital within-group, especially in African households where significant remittances may go to poorer individuals from the richer and well endowed ones. This may apply particularly for the whole economy and manufacturing sector. For agricultural and mining sectors, black economic empowerment effects may cause income at the top tail of within-group inequality to weigh positively in the overall income, causing its positive effect.

There is evidence of an inverted U-shape inequality-per capita income relationship for between-group inequality, but a U-shaped one for within-group inequality. Due to short data span, it may be difficult to relate this to the Kuznets U-shaped development-inequality hypothesis. These may rather agree with the active post-apartheid policies of Black Economic Empowerment, which, while yielding fruits in the reduction of between-group inequality, actually increases within-group inequality. This is supported by the coefficients of Government expenses on between-group and within-group inequality components (with significant negative and positive impacts respectively).

Per capita income has poverty reducing effects in the entire economy and in the respective sectors studied. Between-group inequality (in line with pro-poor growth theory) has poverty increasing effect, with the abjectly poor suffering more from inequality than others. The effect of within-group inequality makes sense in terms of within-group solidarity, where growth at first widens inequality within-group when the relatively well-endowed individuals access some of the fruits of economic growth. They then remit some of the growth returns to their poorer family members. This intuition is supported by the fact that first lag of capital has poverty reducing effects only in within-group inequality sub-model (this is the case only for total economy and the manufacturing sector). The strong effect on poverty severity implies that such remittances are for altruistic motives, with the very poor receiving more attention. Statistics South Africa (2002) reports that the most important source of income for the unemployed in South Africa is financial support from other working members of their household. By deduction (from the fact that government expenses reduce total and between-group inequalities) and in line with the correlation coefficients of government expenses (negative and significant) on all poverty measures, one would conclude that government efforts are yielding some anti-poverty fruits. However, as the coefficients indicate, these efforts are a little biased towards the just poor than the very poor.

6.2 Implication for Research

These findings have implications for research. Firstly, without controlling for endogeneity in the growth-inequality framework, single equations time series analyses are likely to give biased results. The same would happen when estimating energy demand functions separately from that of growth and/or production in a time series, because indeed, according to the DWH test, there is endogeneity between production and inequality on one hand and production and energy demand on the other.

Secondly, the elasticities of production and substitution noticeably vary over time and with factor ratios, for all factors of production, including disaggregated energy types. Therefore it may not be plausible to restrict the elasticities of substitution to unity or constant.

Thirdly, all the productive sectors including the whole economy exhibit diminishing Returns to Scale without energy. With energy types like electricity, diesel, gas and coal, the scale elasticities increase somewhat, but only in the agricultural sector are there increasing Returns to Scale with the use of diesel. Unitary and constant elasticity of substitution production functions constrain the substitution elasticities to unity and constant respectively. Such restrictions will not capture these details. Though these energy types contribute less to scale elasticity (RTS) (which is the determinant of an economy's growth path) than capital and labour in most cases, the graph of the time evolution shows that they set the pace for RTS. This implies that if the South African economy is less endowed with these resources, economic growth will be seriously jeopardised.

Fourth, various energy types have different effects on output (and also on growth by their contribution to the scale elasticity), inequality and poverty. The effects vary with economic sectors. This implies that aggregate energy measures may not give the true picture of the impact of energy on development.

Fifth, within and between-group inequalities have positive and negative effects on production respectively, suggesting that in multiracial and fragmented societies, it is important to decompose inequality into sub-group components.

6.3 Policy Implication

The outcome of this study suggests some implications for growth, energy demand, redistribution, and poverty policies.

The first implication is that different energy types have different impacts on production and economic growth. Electricity shows the strongest positive effect on the growth of the entire economy and the manufacturing sector, while diesel has the strongest effect on agricultural production and liquid petroleum on the mining sector. Gasoline and kerosene have negative production and growth effects in all the sectors where they are used. Coal has a negative effect only in the agricultural sector. This implies that any energy policy targeting growth must be disaggregated, laying particular emphasis on electricity and diesel with strong positive effects and taking note of the production attenuating effects of gasoline and kerosene. The negative effect of gasoline is indicative of luxury consumption at the expense of investment. However, that of kerosene may involve deeper household deprivation dynamics such that while any measure to reduce the consumption of gasoline may also have poverty reducing effects, the reduction of kerosene consumption is likely to affect the (severely poor) households if it is not simultaneously accompanied by improved access to and enhanced affordability of cleaner and more productive forms of energy like electricity.

The impact of diesel on agriculture is remarkable. Agriculture exhibits increasing Returns to Scale with diesel use. This implies that the uncertainty surrounding fossil fuels and their increasing prices pose a great threat to future food security. Equally, the combination of diesel’s high positive impact on per capita income and low and insignificant effect on the poverty increasing type of inequality makes its use in South Africa a poverty reducing energy type. This anti-poverty role is very strong in agriculture. Therefore, more has to be done to increase diesel’s available and affordability (such as more subsidized diesel) in the agricultural sector. Though electricity has the highest impact on labour productivity, its contribution to production goes almost exclusively to the rich owners of capital (and skilled labour), such that its effect on poverty is positive. This suggests that its weak association with labour in the whole economy is biased towards skilled labour; hence its poverty effect is not significant except in agriculture and mining sectors. Since both energy types are strong complements to capital, any effort for equitable access to these growth enhancing energy types must be accompanied by broadened access to both human and physical capital by the poor. The only manufacturing energy type with strong association with labour and hence high poverty reducing effect is gas. This is most likely due to its use by the poor in motorcar repairs and art and craft industries.

Total energy, electricity, diesel and coal in the whole economy, manufacturing and agriculture have between-group inequality enhancing effects. However, their effects on within-group inequality are negative. This suggests that the fruits of energy’s contribution to economic growth are still being appropriated relatively more by the richer groups of society.

Given that between-group inequality shows a negative effect on growth while within-group inequality shows positive effect, redistribution policies in South Africa have to focus on the interracial divide. This redistribution can be done through increases in (both level and quality of) employment, but equally and more importantly, increased access to energy (electricity and diesel) and capital goods. However, it is worth mentioning that active redistribution policies as captured by Government expenses show significant negative impact on total and between-group inequalities.

Because the demand for most energy types is price inelastic, pricing measures may not be an effective instrument to check energy consumption, it can lead to poverty traps, where the poor lack access to the proper kind of energy (and capital) for production. However, targeted taxes (taxing energy for those at the top of income distribution for redistribution) may be applicable. However, this needs to be undertaken with caution so as not to lower incentives for investment. This recommendation stems from the fact that higher inequality is associated with increased energy consumption. This is possibly due to the fact that while energy consumption does not decrease with relatively poorer people, it increases faster with the richer group as inequality widens on the one hand. On the other hand, the income elasticity shows that a one percent increase in income results in a more than proportionate increase in the demand for the respective energy types. This implies that energy consumption would increase faster at the top end of income distribution curve, where a greater share of the fruits of economic growth goes to.

Redistribution efforts should focus on the '*bad*' type of inequality – between-group. The effect of Government expenses shows that public effort is doing a great deal to ameliorate between-group inequality and should be encouraged. Efforts to reduce between-group inequality can also be associated with energy conservation, since it tends to increase the demand for all energy types except gas. A possible reason is that while energy consumption does not decrease with relatively poorer people, it may increase faster with the richer group as inequality widens. This reason is suggested by the coefficients of price and income elasticities of demand in chapter four and here.

Access to energy types like electricity, diesel and gas are crucial for economic growth, but for them to yield significant anti-poverty fruits, efforts must go beyond energy to (both physical and human) capital.

6.4 Caveats and Further Research

In conclusion, some limitations to this analysis and areas of further research are worth mentioning. First, chapters four and five have not taken the problem of unit roots into account. This is due to the fact that in a limited observations dataset, simultaneous equations modelling limits degrees of freedom. If variables are to be differenced, then little leeway will be available for the estimates. Besides, interaction terms in VES framework make differencing complicated and can even result in non-linearity. However time trends have been used in all the models to minimise the biases due to variables trending over time. Chapter three takes care of unit root issues and from comparison of results, there seem to be some robustness. Secondly, the time series of poverty and inequality data in chapter five only span (1993 to 2007) though it has been adjusted to 20 observations. Because the span is this short, the findings of the chapter may not be usable for projections. In addition, the partial equilibrium approach used in this work can only capture some of the many avenues through which energy affects growth, inequality and poverty. A more embracive approach would be a general equilibrium methodology. Notwithstanding, each method has its trade-offs and the choice of any one type depends on the point of focus. However, these do not water down the validity of the policy conclusions here. In terms of further research, there is need for further verification either in panel data or longer time series as more data becomes available, with possibility of extension to other sub-Saharan African Countries. Due to space, time and data limitations, other sectors like residential, commercial and transport were not included in the analysis, which merit further investigation.

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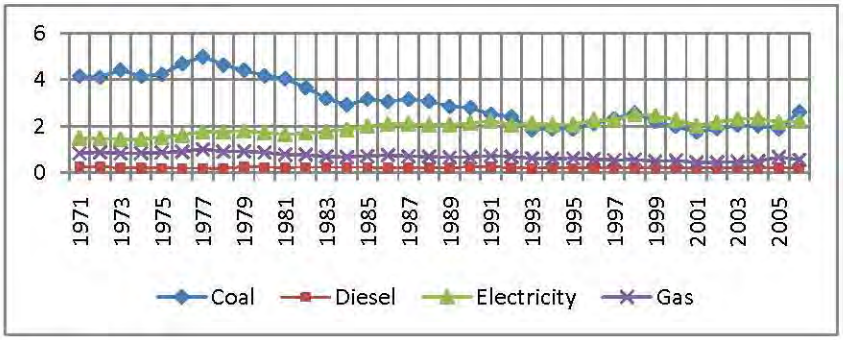
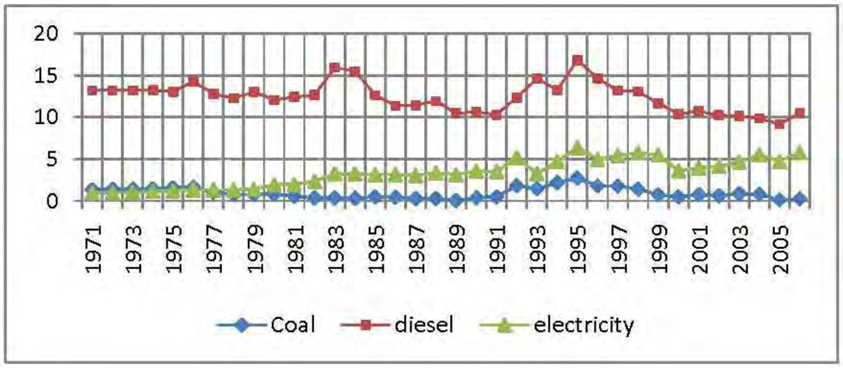
Appendix A: Energy Intensities

Figure A 1: Sector-wise Energy Intensities

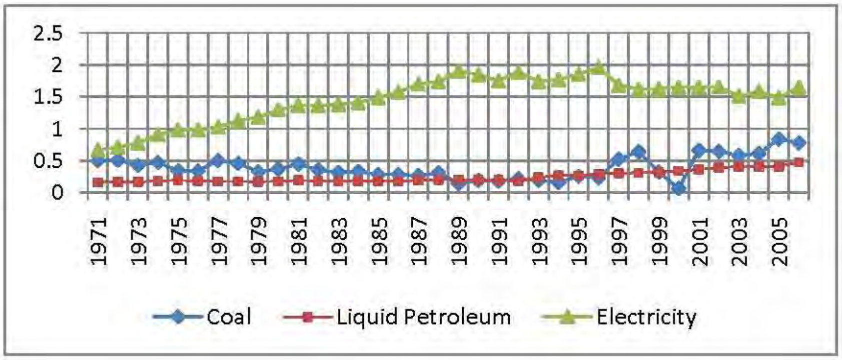
Manufacturing



Agriculture



Mining



Appendix B: Unit Root Tests

Table B 1: Unit Root Test - Whole Economy

Variable in log		level		1st diff		V Variable in log		level		1st diff	
	c/t[80] (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)		c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)
GDP	- (0.35)	2	0.292 (0.98)	1	-3.90a (0.002)	Gasoline	c/t (0.081)	1	-1.933 (0.64)	0	-6.5a (0.000)
Capital	- (0.27)	3	-0.358 (0.918)	2	-3.143b (0.023)	Gas	- (0.721)	1	-3.106b (0.026)	1	-6.57a (0.000)
Labour	- (0.28)	4	-0.312 (0.92)	1	-2.966b (0.038)	Kerosene	- (0.115)	1	-0.082 (0.951)	0	-4.82a 0.000)
Total Energy	c/t (0.008)	3	-3.110 (0.103)	0	-5.26a (0.000)	Coal	- (0.95)	1	-2.187 (0.21)	0	-5.02a (0.000)
Electricity	c/t (0.012)	1	-3.248c (0.075)	0	-4.36a (0.000)	Pop	c/t (0.000)	5	3.121 (1.00)	4	0.50 (0.99)
Diesel	- (0.131)	1	-0.825 (0.812)	0	-4.02a (0.002)						

Table B 2: Unit Root Test - Manufacturing

Variable in log		level		1st diff		Variable in log		level		1st diff	
	c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)		c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)
GDP	c/t (0.066)	1	-2.445 (0.356)	0	-4.33a (0.000)	Diesel	c/t (0.075)	1	-2.559 (0.299)	0	-5.98a (0.000)
Capital	- (0.190)	3	-1.424 (0.571)	2	-3.36b (0.013)	Gas	- (0.603)	1	-2.581c (0.097)	0	-6.57a (0.000)
Labour	c/t (0.017)	2	-1.907 (0.651)	1	-3.155b (0.023)	Kerosene	- (0.289)	1	-1.777 (0.392)	0	-6.44a (0.000)
Total Energy	- (0.582)	3	-2.404 (0.141)	0	-4.13a (0.001)	Coal	- (0.631)	2	-1.699 (0.432)	0	-3.61a (0.006)
Electricity	- (0.146)	1	-2.093 (0.247)	0	-5.17a (0.000)						

Table B 3: Unit Root Test - Agriculture

Variable in log		level		1st diff		Variable in log		level		1st diff	
	c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)		c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)
GDP	c/t (0.000)	3	-4.67a (0.001)	2	-8.93a (0.000)	Electricity	- (0.323)	1	-1.709 (0.426)	0	-6.82a (0.000)
Capital	- (0.251)	2	-1.80 (0.383)	3	-4.27a (0.001)	Diesel	- (0.388)	1	-2.019 (0.279)	1	-7.42a (0.000)
Labour	- (0.344)	5	-2.325 (0.164)	5	-3.97a (0.002)	Kerosene	- (0.145)	1	-1.052 (0.734)	0	-5.21a (0.000)
Total Energy	- (0.264)	1	-1.396 (0.584)	0	-4.82a (0.000)	Coal	- (0.856)	1	-2.57 (0.10)	1	-7.59a (0.000)

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[80] Makinnon's critical values without trend is -3.689, -2.975 and -2.619; with trend is -4.288, -3.560 and -3.216 for 1%, 5% and 10% level of significance respectively

Table B 4: Unit Root Test - Mining

Variable in log		level		1st diff		Variable in log		level		1st diff	
	c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)		c/t (p-val)	Lag AIC	PP-stat (p-val)	Lag AIC	PP-stat (p-val)
GDP	- (0.970)	1	-3.46a (0.009)	0	-4.91a (0.000)	Electricity	- (0.632)	1	-3.21b (0.019)	0	-5.20a (0.000)
Capital	- (0.440)	3	-2.699c (0.074)	2	-3.83b (0.003)	Liquid Petroleum	c/t (0.050)	3	-0.863 (0.96)	0	-5.97a (0.000)
Labour	c/t (0.035)	2	-1.610 (0.788)	1	-3.48a (0.009)	Coal	- (0.594)	1	-3.353b (0.013)	3	-9.40a (0.000)
Total Energy	- (0.151)	1	-1.38 (0.592)	0	-5.59a (0.000)						

Appendix C: DWH Test and σ Variation with Factor Ratios and Time

Table C 1: DWH Test for Endogeneity

	Total Inequality		Between-group		Within-group	
t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
Whole Economy	0.829	2.48	1.186	0.061	1.578	1.46
Manufacturing	1.117	2.43	-1.224	-0.49	2.867	1.65
Agriculture	-0.469	-1.45	-0.861	-1.42	0.789	1.28
Mining	0.604	0.67	0.656	0.34	0.663	0.37

Figure C 1: Elasticity of Substitution and Factor Ratios-whole Economy

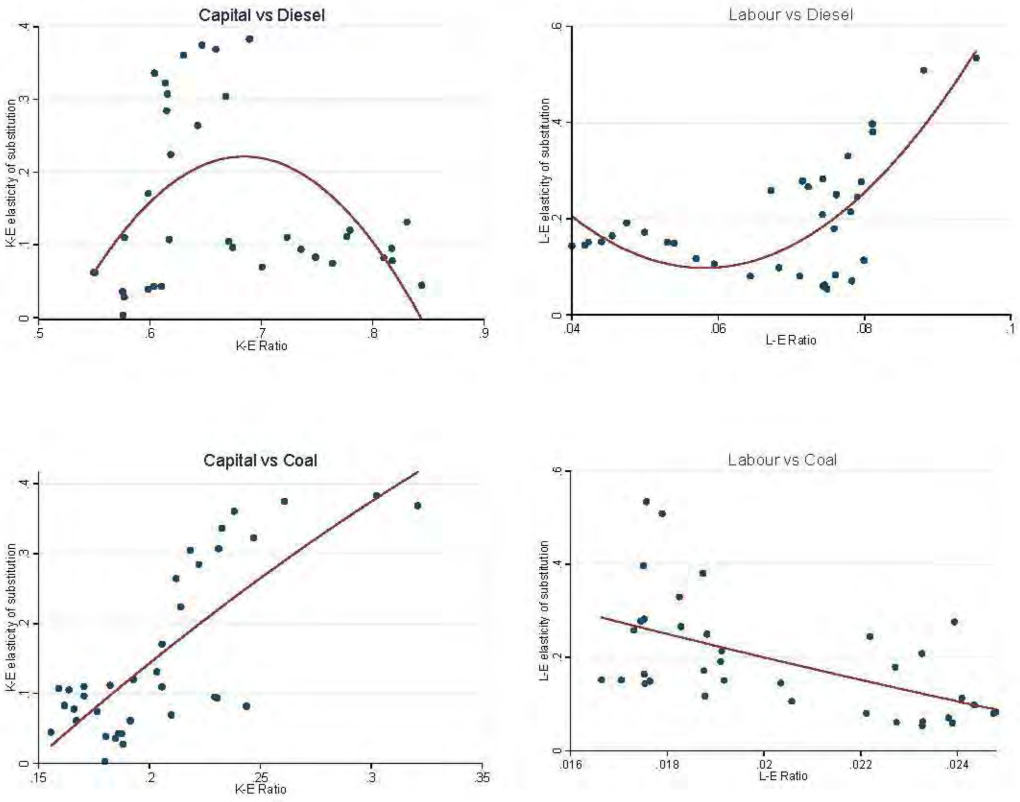


Figure C 2: Elasticity of Substitution and Factor Ratios – Manufacturing

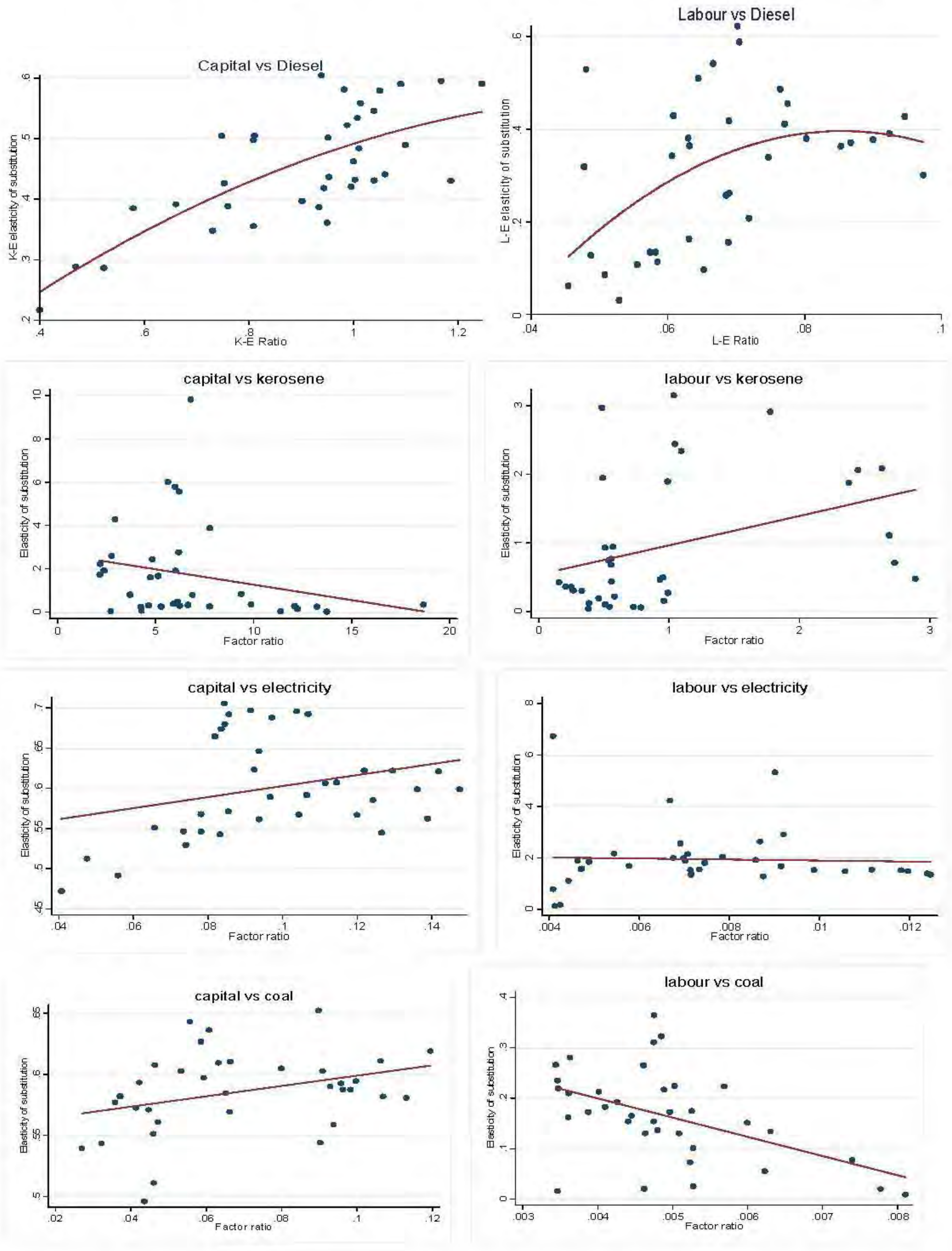
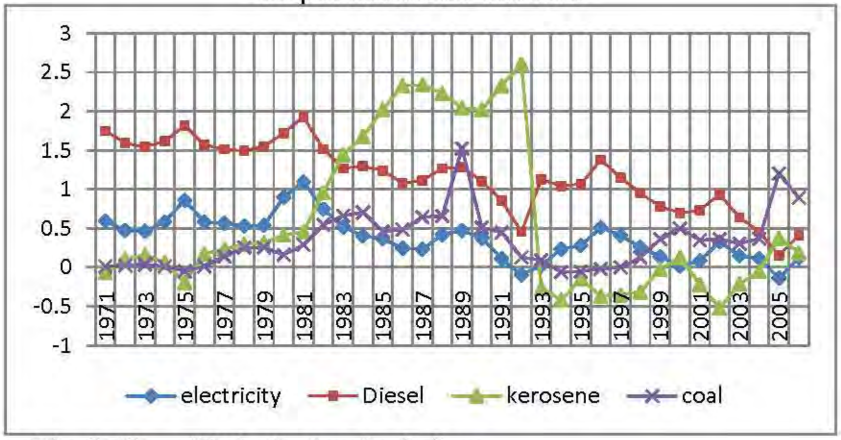
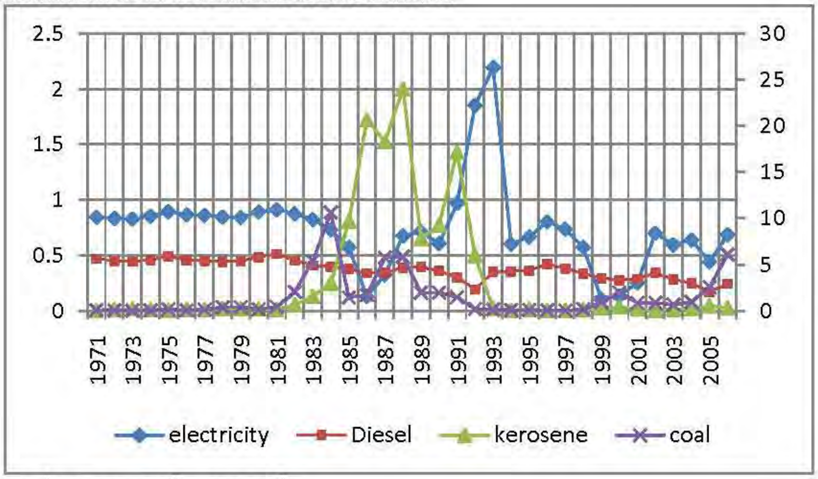


Figure C 3: Variations in Elasticities over Time - Agriculture

Output elasticities and RTS

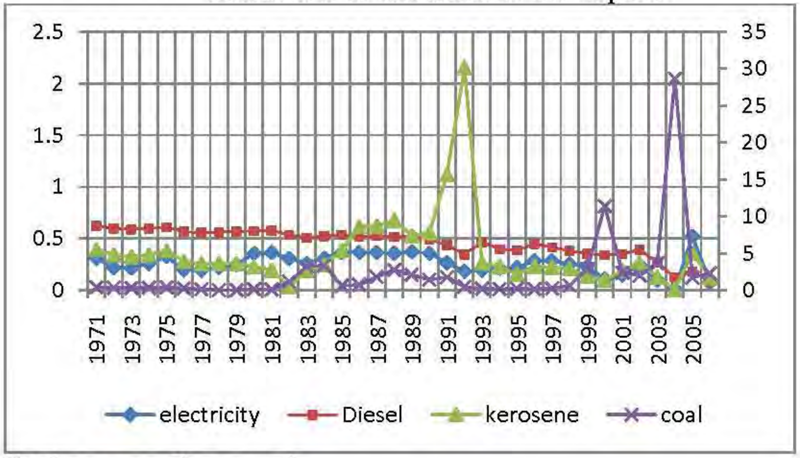


Elasticities of Substitution for Labour



coal on secondary y-axis

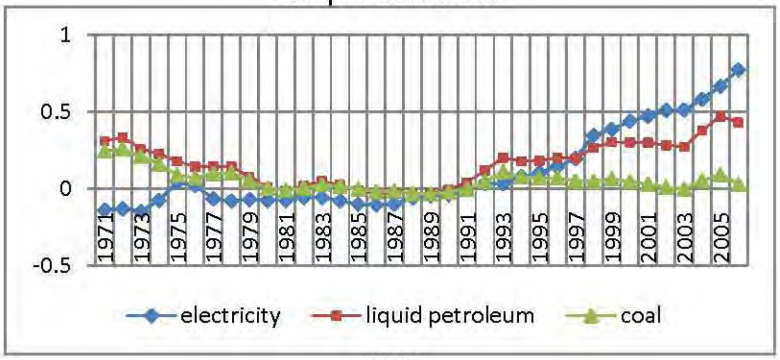
Elasticities of Substitution for Capital



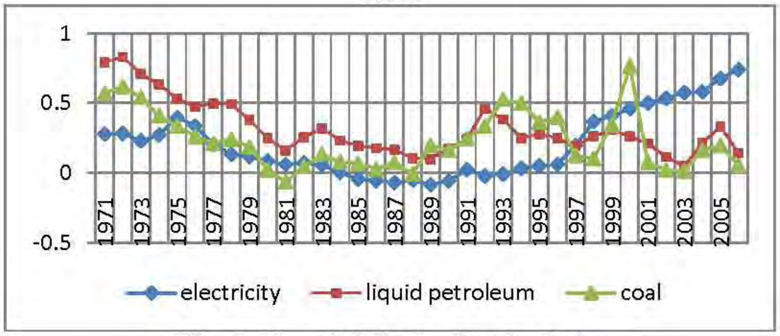
Coal on secondary y-axis

Figure C 4: Variations in Elasticities over Time - Mining

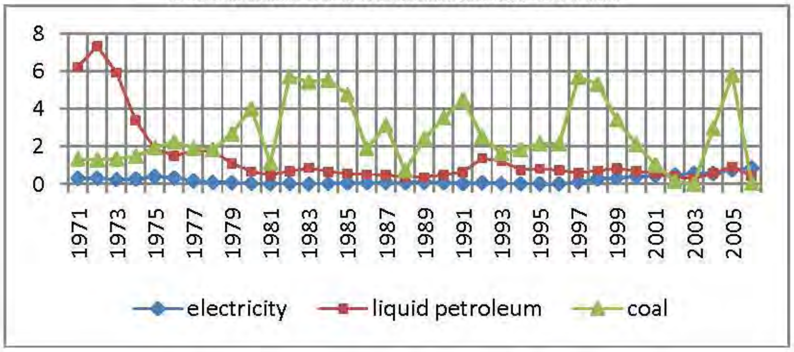
Output elasticities



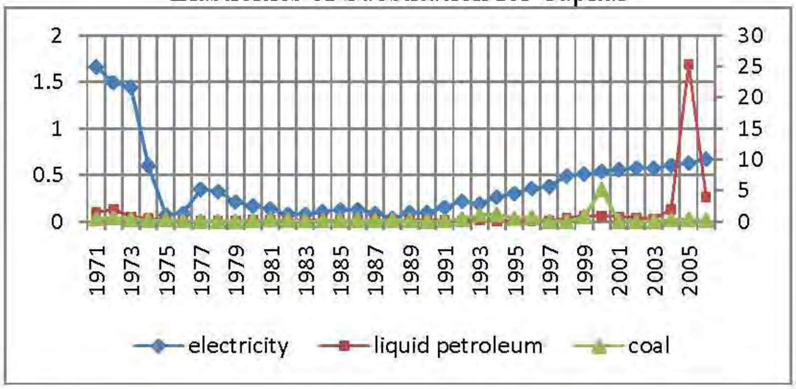
RTS



Elasticities of Substitution for Labour



Elasticities of Substitution for Capital



Appendix D: Detailed 3sls Results for Disaggregated Energy types

Table D1. 1: 3sls for Electricity - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.446^a	-0.445^a	-0.447^a	0.022	0.022	0.022	-0.077^b	-0.075^b	-0.077^b
lnk_t	-0.002	-0.003	-0.003	-0.055	-0.055	-0.056	0.033	0.028	0.035
lne_t	1.002^a	1.003^a	1.003^a	1.055^a	1.055^a	1.056^a	0.967^a	0.972^a	0.965^a
α_0	0.407^a	0.406^a	0.406^a	0.378^b	0.378^b	0.377^b	0.424^a	0.418^a	0.426^a
$ln\theta_{1t}$	0.394^a	0.392^a	0.391^a	0.109^b	0.112^b	0.109^b	-0.103^b	-0.110^b	-0.124^b
lny_t	1.007^a	1.010^a	1.013^a	1.232^a	1.237^a	1.226^a	1.319^a	1.337^a	1.370^a
$lnpe_t$	-0.009	-0.004	-0.001	-0.213	-0.223	-0.201	-0.275^c	-0.295^b	-0.333^b
β_0	-0.421^b	-0.448^b	-0.472^b	-1.924^b	-1.972^b	-1.867^b	-2.629^a	-2.764^a	-3.021^a
lny_t	-6.434^b	-6.415^b	-5.925^b	19.147^a	18.687^a	17.474^a	-19.824^a	-20.333^a	-19.657^a
lny_{t-1}	0.661^b	0.659^b	0.602^b	-2.413^a	-2.369^a	-2.237^a	2.389^a	2.453^a	2.381^a
lng_t	0.009	0.004	0.001	-0.378^a	-0.370^a	-0.376^a	0.233^a	0.204^a	0.203^a
lne_t	0.865^a	0.874^a	0.880^a	1.587^a	1.640^a	1.729^a	-0.069	-0.051	-0.093
γ_0	12.023^b	11.942^b	10.865^b	-44.948^a	-43.991^a	-41.562^a	40.705^a	41.602^a	40.206^a
lnk_t	-0.488^b	-0.626^c	-0.544	-0.227^c	-0.272	-0.050	-0.245^c	-0.314	-0.101
$ln\theta_{1t}$	-0.361	-0.732	-1.017	0.621^a	0.869^a	1.128^a	-0.703^a	-1.031^a	-1.339^a
lne_t	0.479	0.687	0.570	0.439^b	0.602^b	0.414	0.789^a	1.162^a	1.132^b
δ_0	3.210^a	1.995^c	1.736	3.199^a	2.130^a	2.011^b	0.855^c	-1.416^c	-2.570^b
$\mathbf{R_y^2}$	**0.99**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.98**	**0.98**	**0.98**
$\mathbf{R_e^2}$	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**
$\mathbf{R_\theta^2}$	**0.67**	**0.67**	**0.67**	**0.89**	**0.89**	**0.90**	**0.96**	**0.96**	**0.96**
$\mathbf{R_P^2}$	**0.49**	**0.39**	**0.32**	**0.80**	**0.67**	**0.57**	**0.78**	**0.70**	**0.62**

Table D1. 2: 3sls for Diesel - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.553^a	-0.553^a	-0.550^a	0.151^a	0.151^a	0.151^a	-0.134^a	-0.134^a	-0.134^a
lnk_t	0.078^b	0.078^b	0.080^b	0.164^a	0.164^a	0.164^a	0.047^b	0.047^b	0.048^b
lne_t	0.922^b	0.922^b	0.920^b	0.836^a	0.836^a	0.836^a	0.953^a	0.953^a	0.952^a
α_0	1.259^a	1.259^a	1.259^a	1.364^a	1.365^a	1.365^a	1.201^a	1.201^a	1.200^a
$ln\theta_{1t}$	0.413^b	0.411^b	0.412^b	-0.138^c	-0.137^c	-0.141^c	0.174^b	0.174^b	0.181^b
lny_t	1.042^a	1.038^a	1.042^a	1.073^a	1.070^a	1.073^a	1.028^a	1.029^a	1.031^a
$lnpe_t$	-0.011	-0.012	-0.011	-0.001	-0.002	-0.001	-0.009	-0.010	-0.012
β_0	-1.588^a	-1.578^a	-1.589^a	-1.803^a	-1.793^a	-1.802^a	-1.316^a	-1.317^a	-1.307^a
lny_t	-1.922	-2.118	-2.068	23.687^a	23.004^a	21.276^a	-21.554^a	-21.729^a	-21.40^a
lny_{t-1}	0.123	0.146	0.139	-2.760^a	-2.677^a	-2.473^a	2.463^a	2.483^a	2.435^a
lng_t	-0.146^b	-0.142^b	-0.149^b	-0.486^a	-0.469^a	-0.498^a	0.192^c	0.176^c	0.138^c
lne_t	1.175^a	1.167^a	1.185^a	0.309	0.249	0.281	0.939^b	0.971^b	1.108^b

γ_0	2.308	2.749	2.598	-52.951^{a}	-51.373^{a}	-47.849^{a}	43.720^{a}	43.994^{a}	43.034^{a}
lnk_t	-0.055	-0.100	0.162	-0.412^{b}	-0.600^{c}	-0.379	-0.323	-0.545^{c}	-0.439
$ln\theta_{1t}$	-0.377	-0.656	-0.844	0.728^{a}	1.029^{a}	1.258^{a}	-0.795^{a}	-1.178^{a}	-1.436^{a}
lne_t	-0.068	-0.004	-0.343	-0.483^{a}	-0.534^{b}	-0.434	-0.508^{a}	-0.590^{a}	-0.541
δ_0	4.204^{a}	3.382^{a}	3.229^{a}	3.427^{a}	2.353^{a}	2.071^{a}	1.366^{b}	-0.841	-1.957
$\mathbf{R_y^2}$	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**
$\mathbf{R_e^2}$	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**
$\mathbf{R_\theta^2}$	**0.70**	**0.70**	**0.70**	**0.85**	**0.85**	**0.86**	**0.97**	**0.97**	**0.97**
$\mathbf{R_P^2}$	**0.42**	**0.33**	**0.31**	**0.81**	**0.69**	**0.59**	**0.77**	**0.72**	**0.67**

Table D1. 3: 3sls for Gasoline - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.260	0.256	0.257	-0.411^{a}	-0.405^{a}	-0.414^{a}	0.533^{a}	0.534^{a}	0.536^{a}
lnk_t	0.459^{a}	0.461^{a}	0.460^{a}	0.240^{b}	0.246^{b}	0.239^{b}	-0.054	-0.055	-0.056
lne_t	0.541^{a}	0.539^{a}	0.540^{a}	0.760^{a}	0.754^{a}	0.761^{a}	1.054^{a}	1.055^{a}	1.056^{a}
α_0	1.402^{a}	1.403^{a}	1.403^{a}	0.895^{a}	0.904^{a}	0.891^{a}	1.373^{a}	1.374^{a}	1.374^{a}
$ln\theta_{1t}$	-0.197	-0.192	-0.194	0.337^{a}	0.310^{a}	0.335^{a}	-0.403^{a}	-0.363^{a}	-0.343^{a}
lny_t	1.216^{a}	1.220^{a}	1.221^{a}	1.128^{a}	1.167^{a}	1.147^{a}	1.164^{a}	1.173^{a}	1.184^{a}
$lnpe_t$	-0.187^{a}	-0.189^{a}	-0.189^{b}	-0.115^{a}	-0.131^{a}	-0.120^{a}	-0.068^{c}	-0.084^{b}	-0.093^{b}
β_0	-1.036^{b}	-1.045^{b}	-1.049^{b}	-0.743^{c}	-0.855^{b}	-0.802^{b}	-1.696^{a}	-1.630^{a}	-1.615^{a}
lny_t	-8.145	-7.991	-7.814	5.467	3.133	1.885	-13.493^{b}	-13.882^{b}	-12.844^{b}
lny_{t-1}	0.979	0.961	0.942	-0.673	-0.404	-0.268	1.680^{b}	1.724^{b}	1.614^{b}
lng_t	-0.067	-0.069	-0.070	-0.389^{a}	-0.398^{a}	-0.371^{a}	0.237^{a}	0.237^{a}	0.201^{b}
lne_t	0.180	0.173	0.166	0.971^{b}	1.044^{a}	1.102^{a}	-0.684^{b}	-0.667^{b}	-0.714^{b}
γ_0	16.143	15.821	15.451	-15.468	-10.683	-7.982	28.645^{b}	29.441^{b}	27.112^{b}
lnk_t	-0.563^{a}	-0.736^{a}	-0.776^{a}	-0.235^{a}	-0.389^{a}	-0.301	-0.312^{b}	-0.540^{b}	-0.366
$ln\theta_{1t}$	0.361	0.355	0.131	0.322^{a}	0.366^{a}	0.599^{b}	-0.176	-0.147	-0.412
lne_t	0.954^{a}	1.356^{a}	1.435^{a}	0.548^{a}	0.944^{a}	0.849^{b}	0.762^{a}	1.246^{a}	1.174^{b}
δ_0	2.115^{a}	0.476	-0.198	2.875^{a}	1.237^{b}	1.017	1.970^{a}	0.214	-0.681
$\mathbf{R_y^2}$	**0.93**	**0.93**	**0.93**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**
$\mathbf{R_e^2}$	**0.90**	**0.90**	**0.90**	**0.88**	**0.89**	**0.89**	**0.89**	**0.90**	**0.90**
$\mathbf{R_\theta^2}$	**0.63**	**0.63**	**0.63**	**0.87**	**0.87**	**0.87**	**0.96**	**0.96**	**0.96**
$\mathbf{R_P^2}$	**0.85**	**0.86**	**0.73**	**0.89**	**0.87**	**0.75**	**0.83**	**0.85**	**0.74**

Table D1. 4: 3sls for Gas - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.688^{c}	-0.686^{c}	-0.686^{c}	0.315^{a}	0.316^{a}	0.316^{a}	-0.210^{b}	-0.211^{b}	-0.209^{b}
lnk_t	0.685^{a}	0.684^{a}	0.684^{a}	0.674^{a}	0.673^{a}	0.673^{a}	0.741^{a}	0.743^{a}	0.740^{a}
lne_t	0.315^{a}	0.316^{a}	0.316^{a}	0.326^{a}	0.327^{a}	0.327^{a}	0.259^{b}	0.257^{b}	0.260^{b}
α_0	1.942^{a}	1.943^{a}	1.943^{a}	2.221^{a}	2.222^{a}	2.223^{a}	1.792^{a}	1.791^{a}	1.793^{a}
$ln\theta_{1t}$	-0.091	-0.078	-0.086	-1.021^{a}	-1.031^{a}	-1.023^{a}	1.079^{a}	1.099^{a}	1.075^{a}

lny_t	-0.973	-0.894	-0.898	-0.031	0.097	0.086	-0.778	-0.681	-0.731
$lnpe_t$	-0.848	-0.803	-0.807	-0.014	-0.086	-0.075	-0.093	-0.027	-0.072
β_0	2.417	2.278	2.279	1.507	1.270	1.276	5.879^{a}	5.773^{a}	5.771^{a}
lny_t	-5.440	-5.304	-5.334	13.753^{a}	13.201^{b}	12.702^{b}	-17.697^{a}	-17.606^{a}	-16.90^{a}
lny_{t-1}	0.657	0.642	0.644	-1.565^{b}	-1.503^{b}	-1.443^{b}	2.140^{a}	2.132^{a}	2.053^{a}
lng_t	0.015	0.013	0.017	-0.338^{b}	-0.327^{b}	-0.331^{b}	0.138	0.127	0.107
lne_t	-0.052	-0.049	-0.052	-0.405^{b}	-0.419^{a}	-0.421^{a}	0.236^{b}	0.244^{b}	0.261^{b}
γ_0	11.275	10.967	11.058	-30.457^{a}	-29.202^{b}	-28.155^{b}	35.306^{a}	35.042^{a}	33.407^{a}
lnk_t	0.029	0.101	0.155	0.050	0.100	0.142	0.193^{b}	0.332^{b}	0.478^{b}
$ln\theta_{1t}$	-0.371	-0.731	-1.063	0.442^{a}	0.606^{a}	0.847^{a}	-0.392^{a}	-0.601^{a}	-0.867^{a}
lne_t	-0.405^{a}	-0.553^{a}	-0.687^{a}	-0.126	-0.176	-0.128	-0.216^{b}	-0.270^{c}	-0.249
δ_0	4.627^{a}	4.003^{a}	3.634^{a}	4.348^{a}	3.721^{a}	3.206^{a}	3.537^{a}	2.408^{a}	1.295
$\mathbf{R_y^2}$	**0.89**	**0.89**	**0.89**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**
$\mathbf{R_e^2}$	**0.58**	**0.58**	**0.58**	**0.73**	**0.72**	**0.72**	**0.68**	**0.67**	**0.68**
$\mathbf{R_\theta^2}$	**0.61**	**0.61**	**0.61**	**0.85**	**0.85**	**0.85**	**0.96**	**0.96**	**0.96**
$\mathbf{R_P^2}$	**0.71**	**0.62**	**0.54**	**0.80**	**0.69**	**0.61**	**0.78**	**0.69**	**0.64**

Table D1. 5: 3sls for Kerosene - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-1.050^{b}	-1.048^{b}	-1.048^{b}	0.350^{b}	0.352^{b}	0.354^{b}	-0.284^{b}	-0.282^{b}	-0.281^{b}
lnk_t	0.682^{a}	0.681^{a}	0.681^{a}	0.775^{a}	0.778^{a}	0.781^{a}	0.833^{a}	0.827^{a}	0.826^{a}
lne_t	0.318^{b}	0.319^{b}	0.319^{b}	0.225	0.222	0.219	0.167	0.173	0.174
α_0	1.932^{a}	1.933^{a}	1.933^{a}	2.214^{a}	2.214^{a}	2.214^{a}	1.700^{a}	1.705^{a}	1.706^{a}
$ln\theta_{1t}$	-0.537	-0.538	-0.540	0.595^{b}	0.582^{b}	0.568^{b}	-1.162^{a}	-1.176^{a}	-1.212^{a}
lny_t	2.149^{a}	2.144^{a}	2.140^{a}	1.950^{a}	1.957^{a}	1.964^{a}	2.461^{a}	2.456^{a}	2.437^{a}
$lnpe_t$	-0.289^{a}	-0.287^{a}	-0.286^{a}	-0.157^{c}	-0.162^{b}	-0.167^{b}	-0.048	-0.043	-0.027
β_0	-5.924^{a}	-5.909^{a}	-5.898^{a}	-5.228^{a}	-5.246^{a}	-5.265^{a}	-9.354^{a}	-9.368^{a}	-9.391^{a}
lny_t	-15.589^{c}	-15.169^{c}	-14.106^{c}	-11.403	-11.543	-11.627	-6.419	-6.757	-3.887
lny_{t-1}	1.811^{c}	1.764^{c}	1.643^{c}	1.264	1.279	1.290	0.873	0.918	0.595
lng_t	-0.007	-0.012	-0.015	-0.405^{a}	-0.405^{a}	-0.407^{a}	0.222^{a}	0.197^{a}	0.182^{b}
lne_t	0.259	0.251	0.228	0.685^{a}	0.688^{a}	0.691^{a}	-0.424^{b}	-0.418^{b}	-0.481^{b}
γ_0	32.908^{c}	31.976^{c}	29.676	23.052	23.355	23.522	11.706	12.289	6.038
lnk_t	-0.513^{a}	-0.652^{a}	-0.700^{a}	-0.211^{b}	-0.314^{b}	-0.260	-0.254^{c}	-0.349	-0.166
$ln\theta_{1t}$	0.255	0.133	-0.065	0.346^{a}	0.421^{b}	0.613^{b}	-0.209^{c}	-0.281	-0.560^{c}
lne_t	0.403^{a}	0.568^{a}	0.603^{a}	0.254^{a}	0.392^{a}	0.365^{b}	0.317^{a}	0.472^{a}	0.444^{b}
δ_0	4.362^{a}	3.641^{a}	3.186^{a}	4.154^{a}	3.460^{a}	3.028^{a}	3.709^{a}	2.849^{a}	1.732^{b}
$\mathbf{R_y^2}$	**0.88**	**0.88**	**0.88**	**0.84**	**0.84**	**0.84**	**0.89**	**0.89**	**0.89**
$\mathbf{R_e^2}$	**0.88**	**0.88**	**0.88**	**0.88**	**0.88**	**0.88**	**0.91**	**0.91**	**0.90**
$\mathbf{R_\theta^2}$	**0.63**	**0.63**	**0.64**	**0.90**	**0.90**	**0.90**	**0.97**	**0.97**	**0.96**
$\mathbf{R_P^2}$	**0.79**	**0.73**	**0.63**	**0.87**	**0.80**	**0.71**	**0.80**	**0.75**	**0.68**

Table D1. 6: 3sls for Coal - Whole Economy

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.232	-0.232	-0.233	-0.506^{a}	-0.504^{a}	-0.493^{a}	0.207^{c}	0.209^{c}	0.205^{c}
lnk_t	0.477^{a}	0.477^{a}	0.477^{a}	0.146^{b}	0.148^{b}	0.157^{b}	0.250^{c}	0.248^{c}	0.252^{c}
lne_t	0.523^{a}	0.523^{a}	0.523^{a}	0.854^{a}	0.852^{a}	0.843^{a}	0.750^{a}	0.752^{a}	0.748^{a}
α_0	1.082^{a}	1.082^{a}	1.082^{a}	0.249	0.254	0.275	0.937^{a}	0.936^{a}	0.939^{a}
$ln\theta_{1t}$	0.142	0.143	0.144	0.774^{a}	0.772^{a}	0.761^{a}	-0.586^{a}	-0.584^{a}	-0.577^{a}
lny_t	0.700^{a}	0.698^{a}	0.697^{a}	1.026^{a}	1.029^{a}	1.035^{a}	1.129^{a}	1.128^{a}	1.138^{a}
$lnpe_t$	-0.078	-0.076	-0.075	0.030	0.024	0.009	0.100	0.098	0.077
β_0	1.301^{c}	1.299^{c}	1.297^{c}	-0.107	-0.092	-0.048	-1.954^{b}	-1.942^{b}	-1.871^{b}
lny_t	-9.713^{b}	-9.390^{b}	-8.859^{b}	11.610^{a}	10.871^{a}	9.931^{a}	-21.788^{a}	-21.840^{a}	-20.560^{a}
lny_{t-1}	1.125^{b}	1.089^{b}	1.027^{b}	-1.384^{a}	-1.304^{a}	-1.194^{a}	2.605^{a}	2.615^{a}	2.470^{a}
lng_t	0.040	0.035	0.036	-0.286^{a}	-0.272^{a}	-0.282^{a}	0.270^{a}	0.257^{b}	0.250^{b}
lne_t	0.291^{b}	0.283^{b}	0.272^{b}	0.401^{a}	0.430^{a}	0.459^{a}	-0.081	-0.086	-0.122
γ_0	19.780^{b}	19.084^{b}	17.98^{b}	-26.928^{a}	-25.335^{a}	-23.45^{a}	45.247^{a}	45.300^{a}	42.608^{a}
lnk_t	-0.379^{a}	-0.461^{a}	-0.486^{b}	-0.180^{b}	-0.220	-0.077	-0.166	-0.165	0.020
$ln\theta_{1t}$	-0.373	-0.762	-1.137	0.353^{a}	0.486^{b}	0.788^{b}	-0.304^{b}	-0.465^{b}	-0.751^{b}
lne_t	0.577^{a}	0.808^{a}	0.889^{a}	0.362^{a}	0.504^{b}	0.368	0.497^{a}	0.690^{a}	0.651^{b}
δ_0	2.541^{a}	1.085^{c}	0.315	3.174^{a}	2.085^{a}	1.998^{b}	2.104^{a}	0.488	-0.543
$\mathbf{R_y^2}$	**0.92**	**0.92**	**0.92**	**0.92**	**0.92**	**0.92**	**0.90**	**0.90**	**0.90**
$\mathbf{R_e^2}$	**0.66**	**0.66**	**0.66**	**0.83**	**0.83**	**0.83**	**0.78**	**0.78**	**0.78**
$\mathbf{R_\theta^2}$	**0.64**	**0.64**	**0.64**	**0.88**	**0.88**	**0.88**	**0.96**	**0.96**	**0.96**
$\mathbf{R_P^2}$	**0.75**	**0.66**	**0.55**	**0.82**	**0.72**	**0.62**	**0.80**	**0.71**	**0.65**

Table D2. 1: 3sls for Electricity - Manufacturing

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.662^{b}	-0.660^{b}	-0.659^{b}	-0.005	-0.006	-0.004	-0.060	-0.060	-0.060
lnk_t	0.144	0.141	0.139	0.040	0.038	0.043	0.065	0.067	0.066
lne_t	0.856^{a}	0.859^{a}	0.861^{a}	0.960^{a}	0.962^{a}	0.957^{a}	0.935^{a}	0.933^{a}	0.934^{a}
α_0	-0.488	-0.494	-0.499	-0.697^{c}	-0.704^{c}	-0.688^{c}	-0.682^{b}	-0.678^{b}	-0.679^{b}
$ln\theta_{1t}$	1.131^{a}	1.112^{a}	1.103^{a}	0.193	0.213^{c}	0.224^{c}	0.092	0.071	0.083
lny_t	0.388^{a}	0.413^{a}	0.431^{a}	0.921^{a}	0.979^{a}	1.011^{a}	0.649^{a}	0.690^{a}	0.673^{a}
$lnpe_t$	-0.394^{a}	-0.404^{a}	-0.368^{a}	-0.556^{b}	-0.450^{b}	-0.390^{c}	-0.761	-0.714	-0.722
β_0	6.543^{a}	6.309^{a}	6.127^{a}	2.749^{b}	2.227^{b}	1.935^{c}	4.445	4.118	4.225
lny_t	-11.185^{a}	-11.071^{a}	-10.742^{a}	13.584^{a}	14.418^{a}	13.638^{a}	-23.677^{a}	-23.872^{a}	-23.360^{a}
lny_{t-1}	1.222^{a}	1.209^{a}	1.172^{a}	-1.576^{a}	-1.671^{a}	-1.584^{a}	2.713^{a}	2.735^{a}	2.683^{a}
lng_t	-0.045	-0.047	-0.048	-0.355^{a}	-0.343^{a}	-0.360^{a}	0.167^{b}	0.158^{b}	0.147^{b}
lne_t	0.525^{a}	0.529^{a}	0.525^{a}	0.481^{b}	0.469^{b}	0.504^{b}	0.189	0.200	0.181
γ_0	22.662^{a}	22.386^{a}	21.659^{a}	-32.860^{a}	-34.618^{a}	-33.077^{a}	49.914^{a}	50.269^{a}	49.126^{a}
lnk_t	-0.423^{b}	$-0.493^{\mathbf{b}}$	-0.488^{c}	-0.065	0.016	0.179	-0.118	-0.038	0.135
$ln\theta_{1t}$	-0.631	-1.145^{c}	-1.517^{c}	0.581^{a}	0.847^{a}	1.118^{a}	-0.565^{a}	-0.863^{a}	-1.142^{a}

lne_t	0.425^{b}	0.563^{b}	0.568	0.182^{c}	0.190	0.082	0.451^{a}	0.584^{a}	0.570^{b}
δ_0	2.818^{a}	1.535	0.977	3.538^{a}	2.736^{a}	2.543^{a}	1.389^{b}	-0.512	-1.653
$\mathbf{R_y^2}$	**0.92**	**0.92**	**0.92**	**0.89**	**0.89**	**0.89**	**0.90**	**0.90**	**0.90**
$\mathbf{R_e^2}$	**0.96**	**0.96**	**0.96**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**
$\mathbf{R_\theta^2}$	**0.69**	**0.69**	**0.69**	**0.89**	**0.89**	**0.89**	**0.98**	**0.98**	**0.98**
$\mathbf{R_P^2}$	**0.43**	**0.29**	**0.23**	**0.77**	**0.64**	**0.58**	**0.72**	**0.62**	**0.59**

Table D2. 2: 3sls for Diesel - Manufacturing

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.191	-0.194	-0.193	-0.071	-0.067	-0.066	0.023	0.023	0.023
lnk_t	0.059	0.061	0.059	0.002	0.008	0.010	0.000	-0.001	-0.001
lne_t	0.941^{a}	0.939^{a}	0.941^{a}	0.998^{a}	0.992^{a}	0.990^{a}	1.000^{a}	1.001^{a}	1.001^{a}
α_0	1.624^{a}	1.624^{a}	1.624^{a}	1.586^{a}	1.588^{a}	1.589^{a}	1.656^{a}	1.656^{a}	1.656^{a}
$ln\theta_{1t}$	0.358	0.364	0.361	0.110	0.090	0.092	-0.033	-0.037	-0.039
lny_t	1.112^{a}	1.122^{a}	1.114^{a}	1.080^{a}	1.104^{a}	1.101^{a}	1.093^{a}	1.100^{a}	1.096^{a}
$lnpe_t$	-0.050^{b}	-0.053^{b}	-0.050^{b}	-0.014	-0.025	-0.023	-0.022	-0.023	-0.021
β_0	-1.880^{a}	-1.908^{a}	-1.885^{a}	-1.850^{a}	-1.922^{a}	-1.912^{a}	-1.976^{a}	-2.007^{a}	-1.998^{a}
lny_t	-6.661^{b}	-6.289^{b}	-5.902^{c}	20.677^{a}	20.229^{a}	19.351^{a}	-22.233^{a}	-22.079^{a}	-21.648^{a}
lny_{t-1}	0.738^{b}	0.698^{b}	0.655^{c}	-2.335^{a}	-2.282^{a}	-2.181^{a}	2.551^{a}	2.536^{a}	2.492^{a}
lng_t	-0.021	-0.025	-0.028	-0.351^{a}	-0.377^{a}	-0.402^{a}	0.182^{b}	0.178^{b}	0.167^{b}
lne_t	0.317^{c}	0.310^{c}	0.305^{c}	0.199	0.222	0.251	0.178	0.170	0.149
γ_0	14.019^{b}	13.175^{c}	12.298^{c}	-47.406^{a}	-46.563^{a}	-44.766^{a}	47.207^{a}	46.849^{a}	45.840^{a}
lnk_t	-0.304^{c}	-0.322	-0.247	-0.074	0.032	0.229	-0.123	-0.059	0.100
$ln\theta_{1t}$	-0.550	-0.990	-1.299	0.629^{a}	0.919^{a}	1.193^{a}	-0.620^{a}	-0.936^{a}	-1.212^{a}
lne_t	0.290	0.355	0.253	0.236^{c}	0.219	0.052	0.555^{a}	0.743^{a}	0.744^{b}
δ_0	3.899^{a}	3.010^{a}	2.577^{a}	3.891^{a}	3.121^{a}	2.740^{a}	2.156^{a}	0.454	-0.721
$\mathbf{R_y^2}$	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**	**0.93**	**0.93**	**0.93**
$\mathbf{R_e^2}$	**0.95**	**0.95**	**0.95**	**0.94**	**0.95**	**0.95**	**0.94**	**0.94**	**0.94**
$\mathbf{R_\theta^2}$	**0.62**	**0.62**	**0.62**	**0.86**	**0.86**	**0.86**	**0.98**	**0.98**	**0.98**
$\mathbf{R_P^2}$	**0.43**	**0.31**	**0.26**	**0.78**	**0.64**	**0.57**	**0.74**	**0.64**	**0.60**

Table D2. 3: 3sls for Gas - Manufacturing

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-0.725	-0.724	-0.723	0.323^{b}	0.322^{b}	0.324^{b}	-0.208^{c}	-0.205^{c}	-0.201^{c}
lnk_t	0.636^{a}	0.635^{a}	0.635^{a}	0.658^{a}	0.658^{a}	0.659^{a}	0.730^{a}	0.724^{a}	0.716^{a}
lne_t	0.364^{a}	0.365^{a}	0.365^{a}	0.342^{a}	0.342^{a}	0.341^{a}	0.270^{b}	0.276^{b}	0.284^{b}
α_0	1.203^{a}	1.202^{a}	1.202^{a}	1.509^{a}	1.507^{a}	1.509^{a}	1.176^{a}	1.172^{a}	1.167^{a}
$ln\theta_{1t}$	1.543	1.535	1.520	-1.256^{a}	-1.248^{a}	-1.246^{a}	1.765^{a}	1.739^{a}	1.698^{a}
lny_t	-0.011	-0.031	-0.071	0.003	0.010	-0.063	-1.066^{b}	-1.150^{b}	-1.268^{b}

$lnpe_t$	0.226	0.240	0.266	-0.046	-0.046	-0.002	-0.054	0.013	0.110
β_0	3.001^{c}	3.031^{c}	3.090^{c}	3.158^{b}	3.135^{b}	3.262^{b}	10.347^{a}	10.401^{a}	10.458^{a}
lny_t	-2.035	-1.690	-1.463	14.856^{a}	14.854^{a}	14.101^{a}	-12.530^{a}	-12.144^{a}	-11.315^{a}
lny_{t-1}	0.253	0.215	0.189	-1.652^{a}	-1.650^{a}	-1.566^{a}	1.495^{a}	1.455^{a}	1.370^{a}
lng_t	-0.045	-0.050	-0.053	-0.294^{b}	-0.301^{b}	-0.299^{b}	0.039	0.020	-0.023
lne_t	0.090	0.095	0.099	-0.259^{b}	-0.254^{b}	-0.259^{b}	0.242^{a}	0.252^{a}	0.277^{a}
γ_0	3.571	2.765	2.234	-33.431^{a}	-33.468^{a}	-31.770^{a}	24.357^{a}	23.370^{a}	21.228^{a}
lnk_t	0.004	0.083	0.127	0.074^{b}	0.152^{b}	0.214^{b}	0.136^{b}	0.262^{b}	0.367^{b}
$ln\theta_{1t}$	0.018	-0.164	-0.317	0.362^{a}	0.482^{a}	0.680^{a}	-0.263^{b}	-0.405^{b}	-0.581^{b}
lne_t	-0.386^{a}	-0.568^{a}	-0.699^{a}	-0.213^{a}	-0.338^{a}	-0.373^{b}	-0.267^{a}	-0.386^{a}	-0.425^{a}
δ_0	5.379^{a}	5.120^{a}	4.999^{a}	4.767^{a}	4.391^{a}	4.001^{a}	4.319^{a}	3.580^{a}	2.794^{a}
$\mathbf{R_y^2}$	**0.82**	**0.82**	**0.82**	**0.83**	**0.83**	**0.83**	**0.84**	**0.84**	**0.84**
$\mathbf{R_e^2}$	**0.48**	**0.49**	**0.49**	**0.69**	**0.69**	**0.69**	**0.76**	**0.77**	**0.78**
$\mathbf{R_\theta^2}$	**0.60**	**0.60**	**0.60**	**0.85**	**0.85**	**0.85**	**0.99**	**0.99**	**0.99**
$\mathbf{R_P^2}$	**0.80**	**0.74**	**0.63**	**0.87**	**0.79**	**0.70**	**0.85**	**0.81**	**0.74**

Table D2. 4: 3sls for Kerosene - Manufacturing

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-1.124^{c}	-1.126^{c}	-1.124^{c}	0.597^{b}	0.588^{b}	0.581^{b}	-0.524^{a}	-0.525^{a}	-0.524^{a}
lnk_t	0.980^{a}	0.980^{a}	0.980^{a}	1.012^{a}	1.011^{a}	1.010^{a}	1.037^{a}	1.037^{a}	1.037^{a}
lne_t	0.020	0.020	0.020	-0.012	-0.011	-0.010	-0.037	-0.037	-0.037
α_0	1.599^{a}	1.598^{a}	1.599^{a}	2.022^{a}	2.017^{a}	2.014^{a}	1.091^{a}	1.091^{a}	1.092^{a}
$ln\theta_{1t}$	1.288	1.271	1.318	2.825	2.615	2.713	-7.564^{c}	-7.525^{c}	-7.519^{c}
lny_t	3.946	4.077	3.910	4.562	4.888	4.613	7.095^{b}	7.098^{b}	6.781^{b}
$lnpe_t$	-2.397	-2.433	-2.389	-1.996	-2.124	-2.027	-0.883	-0.896	-0.811
β_0	-5.865	-6.279	-5.738	-8.590	-9.587	-8.749	-33.569^{b}	-33.489^{b}	-32.468^{b}
lny_t	-9.448^{c}	-9.606^{c}	-9.858^{c}	3.243	4.822	5.709	-30.716^{a}	-30.810^{a}	-30.593^{a}
lny_{t-1}	1.105^{c}	1.122^{c}	1.150^{c}	-0.308	-0.487	-0.589	3.565^{a}	3.574^{a}	3.551^{a}
lng_t	-0.061	-0.058	-0.053	-0.483^{a}	-0.482^{a}	-0.477^{a}	0.043	0.048	0.043
lne_t	0.025	0.026	0.026	0.055^{b}	0.051^{b}	0.049^{b}	0.030^{c}	0.030^{c}	0.030^{c}
γ_0	19.969	20.333	20.914	-9.665	-13.131	-15.053	65.166^{a}	65.403^{a}	64.896^{a}
lnk_t	-0.075	-0.035	-0.022	0.082^{c}	0.152^{c}	0.203^{c}	0.215^{a}	0.409^{a}	0.620^{a}
$ln\theta_{1t}$	-0.032	-0.304	-0.586	0.597^{a}	0.833^{a}	1.092^{a}	-0.520^{a}	-0.854^{a}	-1.261^{a}
lne_t	0.040^{a}	0.055^{a}	0.063^{b}	0.004	0.006	-0.001	0.007	0.003	-0.014
δ_0	4.098^{a}	3.238^{a}	2.689^{a}	4.090^{a}	3.336^{a}	2.889^{a}	2.849^{a}	1.294^{b}	-0.132
$\mathbf{R_y^2}$	**0.78**	**0.78**	**0.78**	**0.77**	**0.77**	**0.77**	**0.85**	**0.85**	**0.85**
$\mathbf{R_e^2}$	**0.55**	**0.55**	**0.55**	**0.57**	**0.56**	**0.57**	**0.59**	**0.59**	**0.59**
$\mathbf{R_\theta^2}$	**0.65**	**0.65**	**0.65**	**0.85**	**0.85**	**0.85**	**0.98**	**0.98**	**0.98**
$\mathbf{R_P^2}$	**0.60**	**0.48**	**0.42**	**0.77**	**0.65**	**0.60**	**0.67**	**0.61**	**0.61**

Table D2. 5: 3sls for Coal - Manufacturing

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-1.128^{b}	-1.129^{b}	-1.131^{b}	0.107	0.109	0.116	-0.147	-0.147	-0.147
lnk_t	0.466^{a}	0.466^{a}	0.466^{a}	0.426^{a}	0.429^{a}	0.442^{a}	0.493^{a}	0.492^{a}	0.491^{a}
lne_t	0.534^{a}	0.534^{a}	0.534^{a}	0.574^{a}	0.571^{a}	0.558^{a}	0.507^{a}	0.508^{a}	0.509^{a}
α_0	0.297	0.296	0.296	0.354	0.362	0.397	0.311	0.310	0.307
$ln\theta_{1t}$	2.473^{a}	2.479^{a}	2.489^{a}	0.410	0.399	0.386	0.285	0.282	0.275
lny_t	0.655^{b}	0.651^{b}	0.647^{b}	1.141^{a}	1.152^{a}	1.177^{a}	0.787	0.785	0.788
$lnpe_t$	-0.134	-0.130	-0.127	0.008	-0.016	-0.061	-0.180	-0.174	-0.167
β_0	3.114^{a}	3.112^{a}	3.115^{a}	0.343	0.413	0.522	2.834	2.804	2.749
lny_t	-4.871^{b}	-4.688^{b}	-4.380^{b}	17.739^{a}	17.755^{a}	16.740^{a}	-21.752^{a}	-21.672^{a}	-21.205^{a}
lny_{t-1}	0.551^{b}	0.531^{b}	0.497^{b}	-1.978^{a}	-1.978^{a}	-1.866^{a}	2.513^{a}	2.504^{a}	2.456^{a}
lng_t	-0.019	-0.019	-0.021	-0.433^{a}	-0.441^{a}	-0.444^{a}	0.161^{b}	0.160^{b}	0.143^{b}
lne_t	0.188^{a}	0.187^{a}	0.186^{a}	0.112	0.114	0.129	0.081	0.080	0.075
γ_0	9.674^{b}	9.268^{c}	8.578^{c}	-41.541^{a}	-41.628^{a}	-39.424^{a}	45.887^{a}	45.709^{a}	44.585^{a}
lnk_t	-0.131	-0.099	-0.111	0.129^{b}	0.273^{b}	0.377^{b}	0.169^{c}	0.340^{b}	0.458^{b}
$ln\theta_{1t}$	-0.405	-0.735	-1.083	0.643^{a}	0.937^{a}	1.205^{a}	-0.569^{a}	-0.848^{a}	-1.104^{a}
lne_t	0.009	-0.021	0.008	-0.055	-0.136	-0.183	0.083	0.074	0.112
δ_0	4.193^{a}	3.512^{a}	2.881^{b}	4.276^{a}	3.772^{a}	3.426^{a}	2.511^{a}	1.111^{c}	-0.121
$\mathbf{R_y^2}$	**0.83**	**0.83**	**0.83**	**0.77**	**0.77**	**0.77**	**0.80**	**0.80**	**0.80**
$\mathbf{R_e^2}$	**0.74**	**0.74**	**0.74**	**0.71**	**0.71**	**0.71**	**0.68**	**0.68**	**0.68**
$\mathbf{R_\theta^2}$	**0.68**	**0.68**	**0.69**	**0.87**	**0.87**	**0.87**	**0.98**	**0.98**	**0.98**
$\mathbf{R_P^2}$	**0.42**	**0.32**	**0.28**	**0.79**	**0.70**	**0.64**	**0.66**	**0.60**	**0.60**

Table D3. 1: 3sls for Electricity - Agriculture

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.039	0.036	0.034	-0.417^{c}	-0.416^{c}	-0.416^{c}	0.189	0.188	0.188
lnk_t	0.384^{b}	0.379^{b}	0.377^{b}	0.500^{a}	0.493^{a}	0.491^{a}	0.470^{a}	0.465^{a}	0.463^{a}
lne_t	0.616^{a}	0.621^{a}	0.623^{a}	0.500^{a}	0.507^{a}	0.509^{a}	0.530^{a}	0.535^{a}	0.537^{a}
α_0	-1.044^{a}	-1.051^{a}	-1.054^{a}	-1.195^{a}	-1.203^{a}	-1.206^{a}	-0.776^{a}	-0.784^{a}	-0.787^{a}
$ln\theta_{1t}$	1.152	1.157	1.155	0.372	0.360	0.359	-0.115	-0.105	-0.100
lny_t	0.979^{a}	0.974^{a}	0.972^{a}	1.031^{a}	1.041^{a}	1.045^{a}	0.986^{a}	0.980^{a}	0.980^{a}
$lnpe_t$	0.127	0.112	0.105	-0.242	-0.175	-0.154	-0.247	-0.236	-0.223
β_0	1.340	1.386	1.408	2.430	2.230	2.170	2.145	2.132	2.103
lny_t	-0.369	-0.264	-0.215	1.667^{a}	1.614^{a}	1.557^{a}	-1.646^{b}	-1.461^{b}	-1.375^{b}
lny_{t-1}	0.098	0.068	0.052	-0.641^{a}	-0.626^{a}	-0.602^{a}	0.583^{b}	0.520^{b}	0.484^{b}
lng_t	0.128^{b}	0.118^{b}	0.116^{b}	-0.328^{a}	-0.326^{a}	-0.336^{a}	0.595^{a}	0.597^{a}	0.608^{a}
lne_t	0.018	0.018	0.019	0.238^{a}	0.240^{a}	0.241^{a}	-0.205^{b}	-0.205^{b}	-0.202^{b}
γ_0	0.359	0.258	0.216	-2.874^{a}	-2.834^{a}	-2.816^{a}	1.642^{b}	1.513^{b}	1.469^{b}
lnk_t	0.004	0.020	0.016	0.069	0.093	0.109	0.024	0.039	0.041
$ln\theta_{1t}$	-0.421	-0.426	-0.432	0.459^{a}	0.555^{a}	0.612^{a}	-0.264^{a}	-0.297^{b}	-0.321^{b}

lne_t	-0.154^{c}	-0.224^{c}	-0.286^{c}	-0.063	-0.107	-0.161	-0.053	-0.102	-0.150
δ_0	4.324^{a}	3.784^{a}	3.484^{a}	4.302^{a}	3.738^{a}	3.426^{a}	3.795^{a}	3.165^{a}	2.798^{a}
$\mathbf{R_y^2}$	**0.63**	**0.63**	**0.63**	**0.67**	**0.67**	**0.67**	**0.66**	**0.66**	**0.66**
$\mathbf{R_e^2}$	**0.67**	**0.67**	**0.67**	**0.68**	**0.68**	**0.68**	**0.67**	**0.67**	**0.67**
$\mathbf{R_\theta^2}$	**0.50**	**0.51**	**0.52**	**0.85**	**0.85**	**0.85**	**0.89**	**0.90**	**0.90**
$\mathbf{R_P^2}$	**0.39**	**0.33**	**0.32**	**0.81**	**0.69**	**0.63**	**0.67**	**0.57**	**0.53**

Table D3. 2: 3sls for Diesel - Agriculture

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	2.719^{a}	2.746^{a}	2.753^{a}	-1.169^{a}	-1.171^{a}	-1.173^{a}	0.834^{a}	0.834^{a}	0.833^{a}
lnk_t	0.254	0.240	0.236	0.084	0.087	0.085	-0.002	-0.003	-0.001
lne_t	0.746^{a}	0.760^{a}	0.764^{a}	0.916^{a}	0.913^{a}	0.915^{a}	1.002^{a}	1.003^{a}	1.001^{a}
α_0	-1.708^{a}	-1.740^{a}	-1.748^{a}	-3.120^{a}	-3.116^{a}	-3.122^{a}	-1.782^{a}	-1.783^{a}	-1.780^{a}
$ln\theta_{1t}$	-0.876	-0.930	-0.946	0.851^{a}	0.837^{a}	0.828^{a}	-0.814^{a}	-0.813^{a}	-0.798^{a}
lny_t	0.904^{a}	0.903^{a}	0.905^{a}	0.940^{a}	0.941^{a}	0.945^{a}	1.000^{a}	1.001^{a}	1.002^{a}
$lnpe_t$	-0.127^{b}	-0.121^{b}	-0.120^{b}	-0.051	-0.055	-0.059	-0.005	-0.006	-0.011
β_0	3.148^{a}	3.120^{a}	3.112^{a}	3.411^{a}	3.419^{a}	3.423^{a}	1.818^{a}	1.822^{a}	1.854^{a}
lny_t	0.094	0.116	0.088	1.052^{c}	0.796	0.619	-0.276	-0.067	0.007
lny_{t-1}	-0.010	-0.019	-0.011	-0.452^{b}	-0.390^{b}	-0.337^{b}	0.258	0.195	0.166
lng_t	0.074	0.076	0.079	-0.204^{b}	-0.166^{c}	-0.161^{c}	0.321^{b}	0.312^{b}	0.319^{b}
lne_t	-0.075	-0.073	-0.071	0.271^{b}	0.310^{b}	0.325^{b}	-0.543^{a}	-0.558^{a}	-0.557^{a}
γ_0	0.200	0.183	0.201	-2.582^{a}	-2.447^{a}	-2.364^{a}	1.531^{b}	1.414^{b}	1.372^{b}
lnk_t	-0.119	-0.137	-0.146	0.051	0.071	0.080	0.078	0.086	0.109
$ln\theta_{1t}$	-0.742^{c}	-0.923^{c}	-1.122	0.512^{a}	0.644^{a}	0.743^{a}	-0.319^{a}	-0.386^{a}	-0.459^{b}
lne_t	0.027	-0.012	-0.084	-0.083	-0.149	-0.231	-0.142	-0.200	-0.287
δ_0	3.934^{a}	3.379^{a}	3.175^{a}	4.504^{a}	4.098^{a}	3.986^{a}	4.056^{a}	3.489^{a}	3.240^{a}
$\mathbf{R_y^2}$	**0.69**	**0.68**	**0.68**	**0.82**	**0.82**	**0.82**	**0.87**	**0.87**	**0.87**
$\mathbf{R_e^2}$	**0.63**	**0.62**	**0.62**	**0.64**	**0.64**	**0.64**	**0.68**	**0.68**	**0.69**
$\mathbf{R_\theta^2}$	**0.50**	**0.51**	**0.51**	**0.83**	**0.82**	**0.82**	**0.89**	**0.89**	**0.89**
$\mathbf{R_P^2}$	**0.38**	**0.33**	**0.32**	**0.78**	**0.66**	**0.60**	**0.67**	**0.57**	**0.53**

Table D3. 3: 3sls for Kerosene - Agriculture

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.678	0.684	0.685	-0.361	-0.363	-0.363	0.204	0.205	0.205
lnk_t	0.830^{a}	0.830^{a}	0.830^{a}	0.876^{a}	0.877^{a}	0.877^{a}	0.868^{a}	0.868^{a}	0.868^{a}
lne_t	0.170^{b}	0.170^{b}	0.170^{b}	0.124	0.123	0.123	0.132	0.132	0.132
α_0	-0.060	-0.060	-0.060	-0.397^{c}	-0.399^{c}	-0.399^{c}	0.039	0.039	0.039
$ln\theta_{1t}$	-0.603	-0.567	-0.477	2.278^{c}	2.243^{c}	2.248^{c}	-1.374	-1.303	-1.201
lny_t	1.963^{a}	2.000^{a}	2.037^{a}	2.576^{a}	2.628^{a}	2.655^{a}	2.407^{a}	2.450^{a}	2.463^{a}
$lnpe_t$	-0.136	-0.151	-0.171	0.007	-0.020	-0.028	0.051	0.015	-0.021

β_0	-1.214	-1.192	-1.144	-1.099^{c}	-1.070^{c}	-1.066^{c}	-3.845	-3.675	-3.437
lny_t	-0.167	-0.003	0.099	1.829^{b}	1.490	1.293	-0.835	-0.518	-0.357
lny_{t-1}	0.044	-0.001	-0.031	-0.648^{b}	-0.554^{b}	-0.492^{c}	0.315	0.221	0.169
lng_t	0.133^{b}	0.119^{b}	0.113^{c}	-0.293^{a}	-0.271^{b}	-0.273^{b}	0.543^{a}	0.532^{a}	0.534^{a}
lne_t	-0.018	-0.025	-0.029	0.028	0.044	0.054	-0.092	-0.107	-0.114^{c}
γ_0	0.262	0.110	0.022	-2.360^{a}	-2.061^{b}	-1.923^{b}	0.460	0.203	0.092
lnk_t	-0.189^{b}	-0.263^{b}	-0.313^{b}	-0.047	-0.093	-0.132	-0.078	-0.139	-0.186
$ln\theta_{1t}$	-0.587^{c}	-0.702	-0.817	0.485^{a}	0.586^{a}	0.651^{a}	-0.271^{a}	-0.315^{a}	-0.351^{b}
lne_t	0.004	0.009	-0.003	0.023	0.032	0.027	0.022	0.033	0.030
δ_0	4.165^{a}	3.551^{a}	3.148^{a}	4.299^{a}	3.714^{a}	3.342^{a}	3.776^{a}	3.108^{a}	2.669^{a}
$\mathbf{R_y^2}$	**0.65**	**0.65**	**0.65**	**0.70**	**0.70**	**0.70**	**0.69**	**0.69**	**0.69**
$\mathbf{R_e^2}$	**0.57**	**0.57**	**0.57**	**0.60**	**0.60**	**0.60**	**0.59**	**0.59**	**0.59**
$\mathbf{R_\theta^2}$	**0.51**	**0.52**	**0.53**	**0.82**	**0.82**	**0.82**	**0.90**	**0.90**	**0.90**
$\mathbf{R_P^2}$	**0.34**	**0.29**	**0.27**	**0.80**	**0.69**	**0.62**	**0.68**	**0.58**	**0.53**

Table D3. 4: 3sls for Coal - Agriculture

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	0.037	0.035	0.033	-0.437	-0.436	-0.434	0.183	0.181	0.178
lnk_t	1.045^{a}	1.045^{a}	1.045^{a}	0.998^{a}	0.998^{a}	0.999^{a}	1.021^{a}	1.021^{a}	1.022^{a}
lne_t	-0.045	-0.045	-0.045	0.002	0.002	0.001	-0.021	-0.021	-0.022
α_0	-0.232^{a}	-0.232^{a}	-0.232^{a}	-0.530	-0.530	-0.528	-0.073	-0.075	-0.077
$ln\theta_{1t}$	-7.635^{c}	-7.641^{c}	-7.661^{c}	6.960^{a}	6.981^{a}	6.972^{a}	-5.602^{a}	-5.579^{a}	-5.574^{a}
lny_t	-2.095^{b}	-2.113^{b}	-2.143^{b}	0.180	0.176	0.156	-0.018	-0.054	-0.100
$lnpe_t$	0.983	1.011	1.056	1.022	1.046	1.065	2.745^{b}	2.765^{b}	2.824^{b}
β_0	-1.280	-1.399	-1.588	0.768	0.669	0.596	-17.402^{b}	-17.438^{b}	-17.665^{b}
lny_t	-0.061	-0.011	-0.050	0.752	0.697	0.662	-0.744	-0.612	-0.643
lny_{t-1}	-0.001	-0.018	-0.005	-0.264	-0.250	-0.240	0.230	0.184	0.192
lng_t	0.103	0.101	0.103	-0.166^{c}	-0.155^{c}	-0.150^{c}	0.409^{a}	0.404^{a}	0.409^{a}
lne_t	-0.015	-0.017	-0.016	0.081^{a}	0.083^{a}	0.083^{a}	-0.081^{b}	-0.085^{b}	-0.084^{b}
γ_0	0.168	0.130	0.161	-1.545^{b}	-1.484^{b}	-1.449^{b}	0.354	0.258	0.290
lnk_t	-0.091^{b}	-0.126^{c}	-0.188^{c}	-0.017	-0.046	-0.082	-0.060	-0.112	-0.160
$ln\theta_{1t}$	0.041	0.150	0.105	0.327^{b}	0.358	0.556^{c}	-0.055	0.010	-0.040
lne_t	0.060^{a}	0.080^{a}	0.085^{b}	0.024	0.035	0.014	0.054^{b}	0.081^{b}	0.078^{c}
δ_0	3.974^{a}	3.291^{a}	2.896^{a}	4.129^{a}	3.462^{a}	3.200^{a}	3.882^{a}	3.265^{a}	2.817^{a}
$\mathbf{R_y^2}$	**0.73**	**0.73**	**0.73**	**0.71**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**
$\mathbf{R_e^2}$	**0.53**	**0.53**	**0.53**	**0.71**	**0.71**	**0.71**	**0.76**	**0.76**	**0.76**
$\mathbf{R_\theta^2}$	**0.50**	**0.50**	**0.50**	**0.83**	**0.83**	**0.83**	**0.89**	**0.89**	**0.89**
$\mathbf{R_P^2}$	**0.74**	**0.63**	**0.52**	**0.80**	**0.68**	**0.60**	**0.74**	**0.63**	**0.53**

Table D4. 1: 3sls for Electricity - Mining

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	1.019^{a}	1.027^{a}	1.056^{a}	-0.379^{a}	-0.392^{a}	-0.401^{a}	0.290^{a}	0.297^{a}	0.309^{a}
lnk_t	0.076	0.074	0.066	0.079^{b}	0.069^{b}	0.060^{c}	0.047^{b}	0.040^{c}	0.029
lne_t	0.924^{a}	0.926^{a}	0.934^{a}	0.921^{a}	0.931^{a}	0.940^{a}	0.953^{a}	0.960^{a}	0.971^{a}
α_0	-0.283^{b}	-0.286^{b}	-0.301^{b}	-0.618^{a}	-0.650^{a}	-0.676^{a}	-0.173^{a}	-0.182^{a}	-0.198^{a}
$ln\theta_{1t}$	-0.219	-0.221	-0.236	0.155	0.159	0.164	-0.022	-0.017	-0.013
lny_t	0.911^{a}	0.906^{a}	0.898^{a}	0.917^{a}	0.909^{a}	0.904^{a}	0.827^{a}	0.818^{a}	0.809^{a}
$lnpe_t$	0.326^{c}	0.303^{c}	0.260	0.263^{b}	0.222^{c}	0.189	0.161^{b}	0.138^{c}	0.116
β_0	0.056	0.140	0.289	0.321	0.468	0.581	0.880^{b}	0.985^{b}	1.089^{b}
lny_t	1.238	1.120	1.151	5.027^{b}	4.440^{b}	4.197^{b}	-0.975	-0.536	0.041
lny_{t-1}	-0.112	-0.099	-0.101	-0.555^{b}	-0.496^{b}	-0.467^{b}	0.161	0.121	0.059
lng_t	-0.060	-0.059	-0.063	-0.272^{c}	-0.250^{c}	-0.265^{c}	0.130^{c}	0.089^{c}	0.085
lne_t	0.033	0.028	0.026	0.151	0.157	0.137	-0.025	-0.040	-0.021
γ_0	-3.649	-3.351	-3.437	-13.172^{b}	-11.721^{b}	-11.145^{b}	0.504	-0.645	-2.080
lnk_t	0.078	0.150	0.169	0.095^{b}	0.162^{b}	0.177^{c}	0.166^{a}	0.262^{a}	0.332^{b}
$ln\theta_{1t}$	0.188	-0.007	-0.116	0.439^{a}	0.565^{a}	0.765^{a}	-0.400^{b}	-0.577^{b}	-0.881^{b}
lne_t	-0.427^{a}	-0.591^{a}	-0.663^{a}	-0.204^{b}	-0.328^{b}	-0.307	-0.220^{b}	-0.309^{c}	-0.231
δ_0	5.881^{a}	5.772^{a}	5.592^{a}	4.980^{a}	4.783^{a}	4.290^{a}	4.199^{a}	3.503^{a}	2.146
$\mathbf{R_y^2}$	**0.96**	**0.96**	**0.96**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**
$\mathbf{R_e^2}$	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**
$\mathbf{R_\theta^2}$	**0.63**	**0.63**	**0.63**	**0.81**	**0.81**	**0.81**	**0.92**	**0.92**	**0.92**
$\mathbf{R_P^2}$	**0.69**	**0.60**	**0.50**	**0.83**	**0.72**	**0.63**	**0.79**	**0.73**	**0.67**

Table D4. 2: 3sls for Liquid Petroleum - Mining

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-4.280^{a}	-4.283^{a}	-4.278^{a}	1.491^{a}	1.500^{a}	1.503^{a}	-1.117^{a}	-1.117^{a}	-1.122^{a}
lnk_t	0.243	0.241	0.242	0.049	0.049	0.051	0.048	0.048	0.042
lne_t	0.757^{a}	0.759^{a}	0.758^{a}	0.951^{a}	0.951^{a}	0.949^{a}	0.952^{a}	0.952^{a}	0.958^{a}
α_0	0.970^{a}	0.968^{a}	0.969^{a}	2.237^{a}	2.244^{a}	2.248^{a}	0.238^{c}	0.238^{c}	0.231^{c}
$ln\theta_{1t}$	1.286	1.308	1.370	-0.031	-0.001	0.001	0.823^{b}	0.832^{b}	0.866^{b}
lny_t	1.375^{a}	1.372^{a}	1.370^{a}	1.525^{a}	1.500^{a}	1.483^{a}	1.188^{a}	1.183^{a}	1.150^{a}
$lnpe_t$	0.094	0.094	0.089	0.097	0.114	0.122	0.017	0.016	0.020
β_0	-3.250^{a}	-3.231^{a}	-3.193^{a}	-4.068^{a}	-4.013^{a}	-3.969^{a}	-1.415	-1.380	-1.216
lny_t	0.442	0.408	0.607	6.092^{b}	5.260^{b}	4.556^{c}	-3.387	-2.865	-2.037
lny_{t-1}	-0.041	-0.037	-0.057	-0.638^{b}	-0.555^{b}	-0.483^{b}	0.366	0.314	0.228
lng_t	-0.140	-0.139	-0.148	-0.333^{c}	-0.312^{c}	-0.330^{c}	0.125	0.067	0.031
lne_t	0.142^{c}	0.142^{c}	0.142^{c}	-0.055	-0.044	-0.014	0.262^{c}	0.282^{c}	0.296^{c}
γ_0	-1.917	-1.831	-2.333	-15.409^{b}	-13.365^{b}	-11.768^{c}	6.213	4.762	2.687
lnk_t	0.074	0.134	0.168	0.032	0.073	0.088	0.110^{b}	0.176^{b}	0.256^{c}

$ln\theta_{1t}$	0.485	0.463	0.492	0.466^{a}	0.604^{a}	0.775^{a}	-0.492^{a}	-0.727^{a}	-1.022^{a}
lne_t	-0.213^{a}	-0.291^{a}	-0.349^{a}	-0.034	-0.066	-0.065	-0.011	-0.004	0.019
δ_0	4.452^{a}	3.822^{a}	3.435^{a}	4.256^{a}	3.620^{a}	3.204^{a}	3.196^{a}	2.049^{a}	0.996
$\mathbf{R_y^2}$	**0.72**	**0.72**	**0.72**	**0.68**	**0.68**	**0.68**	**0.85**	**0.85**	**0.85**
$\mathbf{R_e^2}$	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**	**0.96**
$\mathbf{R_\theta^2}$	**0.68**	**0.68**	**0.68**	**0.81**	**0.81**	**0.81**	**0.92**	**0.92**	**0.92**
$\mathbf{R_P^2}$	**0.49**	**0.39**	**0.36**	**0.78**	**0.66**	**0.61**	**0.74**	**0.67**	**0.65**

Table D4. 3: 3sls for Coal - Mining

Variable	Total inequality			Between-Group			Within-Group		
	P^0	P^1	P^2	P^0	P^1	P^2	P^0	P^1	P^2
$ln\theta_{1t}$	-3.324^{a}	-3.322^{a}	-3.323^{a}	0.747^{b}	0.747^{b}	0.747^{b}	-0.715^{a}	-0.715^{a}	-0.716^{a}
lnk_t	0.959^{a}	0.959^{a}	0.960^{a}	0.987^{a}	0.987^{a}	0.987^{a}	0.930^{a}	0.930^{a}	0.929^{a}
lne_t	0.041	0.041	0.040	0.013	0.013	0.013	0.070	0.070	0.071
α_0	1.391^{a}	1.391^{a}	1.391^{a}	2.172^{a}	2.172^{a}	2.172^{a}	1.005^{a}	1.005^{a}	1.004^{a}
$ln\theta_{1t}$	0.895	0.903	0.822	0.239	0.246	0.240	-1.365	-1.353	-1.345
lny_t	1.588	1.551	1.499	1.546	1.563	1.524	2.485	2.491	2.487
$lnpe_t$	1.962	2.029	2.163	2.436	2.410	2.480	2.194	2.163	2.160
β_0	-13.689^{b}	-13.861^{b}	-14.302^{b}	-15.802^{b}	-15.747^{b}	-15.923^{b}	-20.238^{c}	-20.104^{c}	-20.063^{c}
lny_t	0.907	1.023	1.269	6.765^{b}	6.484^{b}	6.667^{b}	-3.229	-2.852	-2.749
lny_{t-1}	-0.071	-0.082	-0.109	-0.721^{b}	-0.690^{b}	-0.702^{b}	0.398	0.361	0.346
lng_t	-0.111	-0.117	-0.115	-0.353^{c}	-0.362^{c}	-0.415^{b}	0.165	0.145	0.174
lne_t	0.010	0.011	0.011	0.018	0.018	0.019	-0.019	-0.018	-0.019
γ_0	-2.932	-3.225	-3.792	-17.039^{b}	-16.414^{b}	-17.063^{b}	5.811	4.843	4.720
lnk_t	-0.087^{c}	-0.093	-0.140	0.030	0.046	0.033	0.141^{b}	0.220^{b}	0.285^{b}
$ln\theta_{1t}$	0.236	0.092	0.111	0.491^{a}	0.662^{a}	0.879^{a}	-0.518^{a}	-0.753^{a}	-1.037^{a}
lne_t	-0.039^{c}	-0.049	-0.041	-0.017	-0.019	0.002	-0.019	-0.021	-0.001
δ_0	4.318^{a}	3.635^{a}	3.259^{a}	4.221^{a}	3.579^{a}	3.209^{a}	3.111^{a}	1.959^{a}	0.968^{c}
$\mathbf{R_y^2}$	**0.69**	**0.69**	**0.69**	**0.59**	**0.59**	**0.59**	**0.72**	**0.72**	**0.72**
$\mathbf{R_e^2}$	**0.68**	**0.68**	**0.68**	**0.69**	**0.69**	**0.69**	**0.69**	**0.69**	**0.69**
$\mathbf{R_\theta^2}$	**0.65**	**0.65**	**0.65**	**0.82**	**0.82**	**0.83**	**0.91**	**0.91**	**0.91**
$\mathbf{R_P^2}$	**0.50**	**0.39**	**0.30**	**0.81**	**0.68**	**0.60**	**0.78**	**0.70**	**0.65**