SIMPLE EXPORTS ALSO MATTER: KNOWLEDGE CREATION AND GROWTH IN NATURAL RESOURCE ABUNDANT COUNTRIES

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Abstract

There is a great deal of pessimism towards natural resource oriented development in modern developmental literature but little is made of the countries which thrive in the face of resource abundance. This paper models the nature of innovation in resource abundant countries and sets about testing for the existence of a special club of successful resource abundant countries. The model shows that policy which is biased against the resource sector will lead to a suboptimal static welfare outcome and that the sustainability of resource sector output will decline in the presence of such policy. The empirical analysis of existing literature alludes to a possible misspecification of resource curse models and indicates that the possibility of a special club of resource abundant countries is possible. However, testing is constrained by lack of adequate data.

Plagiarism Declaration

I know the meaning of plagiarism and declare that all of the work in the following dissertation, save for that which is properly acknowledged, is my own.

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Part 1:

A THEORY OF NATURAL RESOURCE ORIENTED GROWTH

1. Introduction

There is an implicit recognition in modern development models that productivity and income growth are achieved through the development of the secondary sector and that the primary natural resource sectors serve only as input industries to more advanced activities. To drive home this point numerous examples of underdevelopment in resource rich countries are compared to the post-War miracles of Asia and more often than not the broad conclusions drawn are clear in their judgment that countries which are outward oriented in manufacturing develop and prosper while countries which equate natural resource abundance to wealth flounder (Sachs and Warner, 1997). This 'paradox of plenty' has given rise to the resource curse hypothesis which enumerates a number of feedback loops through channels of political economy which essentially doom poor resource abundant nations to low income equilibriums (for example see Sachs and Warner, 1997 and Prebisch (1959)). The recommendations for the amelioration of resource excess range from macroeconomic adjustments, such as foreign reserve accumulation to prevent excess currency appreciation, to industrial and trade policies which implicitly promote import substitution. The bias toward value-added manufacturing stems primarily from the numerous positive externalities imparted on the broader economy and the sustainability of these industries. The latter is a result of economies of scale, product diversification and progressive value addition, all qualities attributable to many classes of manufactured products. In contrast, finite natural resources are characterized by diminishing returns with no means of product diversification (Gyfalson ,2001).

Although resource pessimism dates back to the very beginning of economics with Adam Smith warning against the perils of "sinking" investments down mine shafts (see Smith(1776)), history is dotted with counterexamples too large to ignore. For instance, in the late 19th century, manufacturing and technological development in the U.S. centred on the development of the petrochemical industry; Australia experienced sustained and rapid growth at the same time that exports in minerals were on the rise through most of the second half of the 20th century (Wright and Czeluta, 2007). Even in Africa, where evidence for the resource curse is cited as strongest, one of the most resource abundant countries (South Africa) is also the most developed. Almost half of all Scandinavian exports are of low added value and primary timber based products (Blomström and Kokko, 2007).Had these countries industrialized despite resource abundance they could be dismissed as outliers, especially if their convergence to high income paths was delayed. However, what stands out about most high growth and high income countries which started with (or discovered) large endowments of natural resources is that the primary resource sector played a central role in shaping the structure of their economies. In countries where resource extraction and exploration was encouraged, manufacturing productivity increased rapidly as extraction and exploration investment yielded spillovers into the broader economy in the form of new industries and technologies. The knowledge intensification of exploration also extended the lifetimes of mines and deposits well beyond initial estimates, offsetting and in some cases reversing the declining returns to extractive investment (Lorentzen, 2008). Ironically, in countries where resource-driven development was not actively pursued, the mineral depletion schedule was far steeper (Wright and Czelusta, 2007). What emerges from case studies of these countries is that the link between capital accumulation and resource extraction is far more complex than previously thought with the importance of learning institutions such as Universities playing a vital role in channelling the innovative capacity of the economy into the natural resource extraction and exploration industries and in linking these industries successfully to the manufacturing sector. This enabled channels of innovation to exist between the dominant primary sector and the broader economy, fuelling sustained productivity growth. In countries where such linkages are not leveraged, the economy is characterized by the co-existence of unrelated sclerotic manufacturing and primary sectors competing for scarce human capital. These two possible scenarios create a bimodal picture of resource abundant economies. On the one hand there are the low-growth, low-income economies which fail to ignite innovation because of such effects as the Dutch Disease or reasons of political economy such as point-resource conflict and gateway states in which militant regimes seek to maximize resource rents, rather than economic welfare. On the other hand there are the dynamic, high-growth, high-income economies which have successfully established links between the resource sector and the broader economy in order to leverage the relative size of the resource sector as well as the knowledge intensification of extraction and exploration. The former group is the discussion of resource curse literature. This paper seeks to explore what policy and structural features characterize the latter group, the *resource blessed*.

The paper is divided into 2 parts, the first establishing the theoretical foundations for the argument of a bimodal picture of resource oriented development and the second investigating the empirical plausibility of this picture as well as investigating the robustness of some modern analyses of resource driven sclerosis. Part 1 starts by outlining the theoretical and empirical aspects of the resource curse as well as why some popular arguments for resource pessimism are theoretically invalid or empirically unsupported. In Section 3 the successful resource abundant nations (and those which appear to be succeeding) are investigated with special emphasis on how the negative human capital accumulation effects of resource abundance are dealt with in these countries. Section 4 then develops a simple model to demonstrate and investigate the contrast between resource abundant countries which complement their manufacturing and resource sectors with those which attempt to suppress the growth of their resource sector. In 2007, Ricardo Hausmann, Dani Rodrik and Jason Hwang released a paper using UN COMTRADE data to demonstrate that countries which oriented their economy toward manufacturing tended to higher income paths than those which exported simple commodities (2007). Part 2 of the paper investigates the robustness of their results and investigates whether some of the outliers in their analysis were in fact successful resource abundant nations which did not fit this prescribed model of development.

References

1. Blomström , M. and A. Kokko. 2007. "From Natural Resources to High-Tech Production: The Evolution of Industrial Competitiveness in Sweden and Finland", ", *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*

2. Gyfalson, T. 2001. "Nature, Power and Growth". *Center for Economic Studies & Ifo Institute for Economic Research Poschingerstr. 5, 81679 Munich, Germany*, CESifo Working Papers, Working Paper No. 413,

3. Hausmann. R, J. Hwang and D, Rodrik. 2007. "What you export matters.", Journal of Economics: Growth (2007) pp. 12:1–25, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA

4. Lorentzen, J. 2008. "Knowledge intensification in resource-based economies". Resource Intensity, Knowledge and Development Insights from Africa and South America.

5. Prebisch, R 1959. "Commercial Policy in the Underdeveloped Countries". The American Economic Review, Vol. 49, No. 2, Papers and Proceedings of the Seventy-first Annual Meeting of the American Economic Association. (May, 1959), pp. 251-273.

6. Sachs, J.D. and A.M. 1997. Warner "Natural Resource Abundance and Economic Growth", *Centre for International Development and Harvard Institute for International Development*, Havard University, Cambridge MA.

7. Smith, A (1776). "The Wealth of Nations". Oxford. Clarendon Press, 1976.

8. Wright, G. and J. Czelusta. 2007. "Resource based growth: past and present", *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*

2. The Resource Curse

The attitude of mainstream economics toward natural resources has always drifted between caution and pessimism. The policy prescriptions have ranged from prudent extraction coupled with compensating macroeconomic policies to complete avoidance if possible. Contemporary pessimism is fuelled by failed development in resource abundant countries contrasted by the post-War growth miracles in resource poor regions. The most pessimistic theoretical explanations endogenize policy failure in a political-economy black hole from which no resource abundant country can escape. The event-horizon beyond which ordinary countries become 'trapped' by a windfall discovery of natural resources has come to be known as the *resource curse*. Since Sachs and Warner (2007) reenergized the debate the resource curse has become the catchall cause behind the developmental failures of sub-Saharan Africa and Latin America. However, in contrast to the resource curse hypothesis, many resource abundant countries have thrived in spite of their endowments. The notable feature of these resource successes is that their fastest growth periods more often than not coincided with increased extraction (Wright and Czelusta, 2007). These countries did not just ameliorate the consequences of resource abundance; they seemed to thrive because of it. This section investigates whether natural resource endowments present an opportunity or pose a threat to national development.

An historical perspective of natural resources

The notion that an abundance of natural value is an economic wolf in sheep's clothing is not new; Adam Smith warned that mining projects absorb, rather than produce capital and that prudent authorities '...would least chuse [sic] to give any extraordinary encouragement' to mining ventures(Smith, 1776, cited in Wright, 2007). More recently, in his model in which countries are either at the mainly industrial exporting centre or the mostly commodity exporting periphery, Prebisch (1959) argued that the low income elasticities of demand for basic commodities contrasted with the relatively higher income elasticities of demand for manufactures implies declining terms of trade for commodity exporters which must be ameliorated either through import substitution or currency devaluation, both of which imply increased industrialisation. In other words, in order to enjoy a constant standard of living without changing the structure of the economy, resource exporters must constantly increase their export volumes in order to offset the long term trend of declining relative prices, *ceteris paribus*.

While Prebisch's work was based on the Latin American experience in the early 20th century, his results have been assumed to be widely applicable to all basic commodity exporters. The post-World War period has thus been dominated by an implicit bias toward manufacturing oriented industrialisation, strengthened by examples of East Asian success and sub-Saharan African and Latin American stagnation. Yet it was not until the mid-1990s that the debate was reopened when Sachs and Warner (1997) demonstrated that since the 1970s, natural resource dependent countries have indeed been cursed to slow growth, controlling for corruption, rates of investment and other exogenous forces sub-Saharan Africa and Latin America have been dealing with in the contemporary period. Since then, there have been many attempts to directly and indirectly link natural resource abundance to inadequate growth performance (for example, see Deaton (1999); Bulte, Damania and Deacon (2005); Neumayer (2004)). Absent from the resource curse literature, however, are any adequate explanations as to why the exceptions to the rule count among them some of the most successful economies of the modern period including the USA, Sweden, Australia, Germany and the UK.

Theoretical foundations of the resource curse

The curse of resource abundance is thought to operate both through political and economic channels in such a way that the negative effects on both are mutually amplified. Economically, the reliance on a concentration of few commodities for export income unsurprisingly injects external price volatility into the entire monetary and financial system. For countries with pegged exchange rates, this feeds into consumer price volatility and often high rates of inflation and unusually high price levels. Sachs and Warner (1997) argue that such volatility creates uncertainty at the firm level which reduces factor accumulation. For countries with floating exchange rates, the volatility is primarily in external prices but what seems to pervade most resource exporters is an overvalued real exchange rate in boom times. The crowding out of the tradable sectors in favour of the local non-tradable sectors is the Dutch Disease phenomenon. Indeed, Sachs and Warner (1997) report a higher ratio of services to manufacturing output in resource dependent economies than in similar resource poor economies. Even in the absence of exchange rate appreciation, their model of Dutch Disease shows that an external increase in demand for natural resources increases the local demand for non-tradables, diverting labour and other resources away from the manufacturing sector.

Prebisch (1959) argued that commodity dependent exporters were doomed to face a secular decline in their terms of trade with manufacturing exporters, driven chiefly by the differential in the elasticities of demand for commodities and manufactures. He warned that unfettered markets would lead to underemployment of labour in resource abundant economies and that either their economic growth would be limited, exchange rates would continually depreciate or protectionist policies would need to be implemented to prevent unsustainable imbalances of trade from occurring. The recommendation was simply that these countries had to industrialise through manufacturing if they were to expand output sustainably.

Suppose, however, that a particular country can increase mineral production at a rate sufficient to offset the declining terms of trade. Why should this be inferior to the expansion of manufacturing exports? Some argue that the evidence suggests that natural resource sectors have few linkages to the rest of the economy, productivity growth is low and there are fewer positive externalities than in manufacturing (see Hirschman, 1958; Sachs and Warner (1997); Hidalgo, 2007). Furthermore, basic commodities are not as prone to scale economies and the efficient division of labour is limited. The Dutch Disease then, is bad for growth simply because it shifts resources in the economy in such a way that manufacturing derived positive spillovers and linkages are reduced. If the risk to investing is a negative function of existing networks of linkages and capabilities then investment will inevitably be lower in natural resource exporters which have on average fewer inter industry linkages.

Resource abundant economies are also likely to experience a sub-optimal accumulation of human capital. Sachs and Warner (1997) present a model of education in which school leavers are enticed to work directly in the non-tradable sector in a resource abundant economy where wages are higher than the value of the marginal product of the manufacturing sector. In a resource poor economy where such wage distortions do not exist, school leavers are incentivised to invest in higher education so that they may earn high-skilled wage premiums in the manufacturing sector. In the long run, the productivity paths of resource abundant countries are likely to lie permanently below their resource poor counterparts. This is supported by Gylfasson (2000) who reported that natural resource abundance does indeed crowd out education.

Political Economy

Having identified the capital market failures present in resource abundant countries, policy makers can be guided to correct and encourage activities which produce positive spillovers. However the scourge of the resource curse is that it prevents correction through the endogenisation of corruption. Gelb (1988) showed that governments which earned large portions of their revenue through resource extraction were more corrupt in general.

Point resources, in particular, impact negatively on the creation and maintenance of important institutions which are essential for growth (Bulte et al, 2005). This holds for both renewable and depleting resources. The rationalisation of this argument is two-fold. Firstly, gatekeeper states have an incentive to keep their power base concentrated; industrialisation dilutes power. Secondly, a government poor in resources has an incentive to develop in order to increase tax revenue and is therefore accountable to some degree. Resource abundant governments enjoy windfalls irrespective of the welfare of the broader population.

Counter examples to the resource curse hypothesis

The resource curse literature mostly ignores the successful resource abundant countries. The most common explanation is that conditions when Britain and Germany were first industrialising were very different from today. However, there are a number of contemporary exceptions, most notably the Australian experience since the Second World War. Here, there were two phases of economic policy, the first of which was aimed at moving away from reliance on mineral exports. This was partially successful but growth only accelerated when policy emphasis on extraction and exploration became more pronounced. Australia's fastest periods of growth directly coincided with periods of increased mineral extraction (Wright and Czelusta, 2007). In Africa, the most developed mining infrastructure is undoubtedly in South Africa (the continent's most developed country) where gold, platinum and coal still account for the largest share of export revenue. In the USA, the knowledge intensification of the petrochemical industry was a cornerstone in their manufacturing sector which grew to become the largest in the late 19th century (Wright and Czelusta, 2007). The Scandinavian experience has seen a knowledge economy built on timber exports by linking innovation in Universities and other knowledge institutions to industry; many of these links still operate and thrive today. Yet forestry still accounts for the largest share of exports in Sweden and Finland (Blomström and Kokko, 2007). In contrast to the resource curse hypothesis, Maloney (2002) contends that countries which fail to grow in the presence of natural resources have barriers to learning and knowledge creation.

Unravelling the subtleties of resource dependence

The endemic nature of the resource curse is that it diverts human capital from manufacturing to the resource sector where productivity growth is low. In contrast to this, Bravo-Ortega and de Gregorio (2007) find that the marginal effect of the resource stock increases, the greater the availability of human capital, and beyond some threshold becomes positive. Rather than suppressing human capital accumulation, resource abundance requires a well educated workforce for it to have a positive effect on growth. The link between the stock of human capital and the knowledge it generates and the abundance of resources is further explored in section 3 and 4 but it is sufficient for now to say that, if the nature of a curse in economics is exogenous endowment then the complementarity of human capital and resource abundance is evidence alone that the outlier countries did not merely develop by luckily escaping the curse. The failure of the resource curse hypothesis is the lack of appreciation for the complexity of the link between natural resource abundance and growth. Papyrakis and Gerlagh (2002) show that the direct effect of resource abundance on growth is negative if considered in isolation but positive if investment, corruption, openness, terms of trade and schooling are controlled for. That aggregate human capital contributes positively to growth in resource rich countries beyond a threshold might indicate that the marginal product of human capital in the resource sector is positive. Moreover, it might suggest that in resource abundant, human capital scarce countries, instead of an over allocation of human capital to the resource sector there might in fact be an under-allocation. Policy which targets aggregate stocks instead of marginal contribution is prone errors of this kind. The link between resource abundance and growth is not simple and direct. Instead the types of policy chosen can not only mitigate the negative aspects of resource abundance but, as in the most successful cases, actively assist in building sophisticated knowledge economies around the important and policy assisted extraction industries.

References

9. Blomström , M. and A. Kokko. 2007. "From Natural Resources to High-Tech Production: The Evolution of Industrial Competitiveness in Sweden and Finland", ", *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*
10. Bulte, E.H., R. Damania and R.T. Deacon, 2005. Resource Intensity, Institutions and Development, World Development 33: 1029-1044
11. Claudio Bravo-Ortega, C. and de Gregorio, José. 2007. " The Relative Richness of the Poor? Natural Resources, Human Capital, and Economic Growth, *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*
12. Deaton. 1999. "Commodity Prices and Growth in Africa", *Journal of Economic Perspectives, Vol. 13.3 pp 23-40, 1999.*
13. Gelb, Alan. 1988. *Oil Windfalls: Blessing or Curse?* New York: Oxford University Press.
14. Gylfason, T. 2000. "Natural Resources, Education and Economic Development", *International Macroeconomics, 2594, Centre for Economic Policy research, www.cepr.org.*
15. Hidalgo, C.A., B. Klinger, A.L. Barabasim R. Hausmann. 2007. "The Product Space Conditions for the Development of Nations.", *Science 317, 482, vol. 317. American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005*
16. Maloney, William. 2002. .Innovation and Growth in Resource Rich Economies. Mimeographed. Office of the Chief Economist for Latin America and the Caribbean, The World Bank, Washington, DC.
17. Neumayer, Eric. 2004. "Does the 'Resource Curse' Hold for Growth in Genuine Income as Well?" *World Development* 32 (10): 1627–40. Hirschman, 1958
18. Papyrakis, E. And R. Gerlagh. 2002. "The resource curse hypothesis and its transmission channels", *Journal of Comparative Economics, vol 12.2, pp 1-13., IVM, Institute for Environmental Studies, VrijeUniversiteit, Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands*
19. Prebisch, Raúl. 1950. "The Economic Development of Latin America and its Principal Problems." Reprinted in *Economic Bulletin for Latin America* 7 (1): 1–22, 1962.
20. Sachs, J.D. and A.M. 1997. Warner "Natural Resource Abundance and Economic Growth", *Centre for International Development and Harvard Institute for International Development*, Havard University, Cambridge MA.
21. Smith, A (1776). "The Wealth of Nations". Oxford. Clarendon Press, 1976.
22. Wright, G. and J. Czelusta. 2007. "Resource based growth: past and present", *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*

3. Developing a Model of resource-driven innovation

There is an emerging body of literature which points to the dynamism and innovation potential of the natural resource exploration and extraction sectors (henceforth the resource sector).[1] Unlike what is proposed in the resource curse literature, innovation is driven by the knowledge intensification of extraction and exploration. There are 3 principle channels through which the resource sector benefits the broader economy:

1. **Sustainability**: the improvements in exploration and in recycling previously unusable mining waste has extended the lifetime of mines manifold over the past century. Some geologists are beginning to challenge the notion that natural resources are a finite stock, instead suggesting some minerals such as copper asymptotically decline (Lasky, 1950, cited in Lorentzen, 2008).
2. **Backward linkages into local services and manufacturing:** The primary sector is often associated with little to no value addition. However, what usually emerges is an industrial complex of supporting input industries in and around the points of extraction. [2]In a sense these industries form part of a value chain in which the final product is the natural resource ready for export.
3. **Knowledge production and spillovers:** Technology and knowledge generated in the resource sector often find uses in other, often unrelated, industries. This key process driving manufacturing diversification in resource abundant countries is what Jo Lorentzen (2008) calls lateral migration. For instance mine waste sorters in Costa Rica were adapted and fitted with advanced colour optical sensors, allowing them to be used in food sorting and storage. Lateral migration is a key channel through which innovation in the resource sector benefits the entire economy in general and strengthens local manufacturing capabilities locally.

[1]Jo Lorentzen (2008) investigates on the knowledge intensification of extraction; Wright and Czelusta (2007) document historical and modern case studies; Blomström and Kokko expand on the institutional knowledge economy built around forestry in the Nordic countries.
[2]In South Africa the non-service industries with the most backward linkages are the various mining industries (STATSSA).

Technological progress is driven both locally through domestic innovation and internationally through imported technologies and offshored industries. Local innovation is usually based on existing capabilities and infrastructure. Therefore any industrial policy seeking to promote local innovation should build on and extend from local conditions and institutions. This is an evolutionary process.

The appropriation of foreign technologies and the establishment of offshored industries are both characterized by greater risk and uncertainty. For instance, consider Lesotho attempting to establish an electronics cluster. Firstly, no such firms exist so the knowledge of operating in local conditions is limited. Secondly specific infrastructure is probably lacking as well as suitably skilled workers. Should Lesotho succeed in establishing a local electronics industry, the door will be opened to similar forms of innovation such as microchip manufacture simply because of the existence of complementary infrastructure and knowledge and because local actors now possess knowledge and experience relating to the cost of establishing such industries. In the words of Hausmann, Hwang and Rodrik (2007), this sort of experimentation generates positive cost discovery externalities where local cost conditions are revealed to later entrants.

Technological progress in every country is driven by both international and local developments. While relative endowments determine comparative advantages, institutions and existing capabilities determine the ability to exploit these advantages. Poor, resource abundant countries with export profiles dominated by basic mineral commodities are likely to have capabilities and infrastructure suited and adapted to the resource sector. If local innovation is indeed evolutionary then one would expect much of it to flow from the resource sector in these countries because of the large relative size of the sector. Yet resource curse advocates suggest that such innovation is non-existent and that resource abundant countries should seek to industrialise in hitherto non-existent, foreign industries (Sachs and Warner, 1997; Hausmann, Hwang and Rodrik, 2007). In a sense they are suggesting that, unlike in most developed countries where innovation is built both on local capabilities and through international learning, resource abundant countries should first attempt to solely develop through the adoption of foreign production techniques. This sort of policy prescription dismisses local innovation in resource abundant countries as irrelevant or too narrowly confined to unproductive channels. It is little wonder then that countries which follow such policy prescriptions experience a slower than expected pace of development, fuelling a self-fulfilling prophecy of underdevelopment. Instead, as Wright and Czelusta (2007) and Lorentzen (2007) have pointed out, resource abundant countries which succeed are those which encourage local knowledge creation and intensification of resources built on local conditions. The model elucidated below analyzes the implications of underinvestment in local capabilities in resource abundant countries.

Model

There are 2 important aspects of resource oriented development. The first is the misallocation of human capital across sectors in the economy. This is different from the argument that innovation is suboptimal in that it asserts that, no matter how high or low aggregate innovation is, policies which articulate the development of the secondary sector as the driver of development will lead to too little innovation in the resource sector and too much innovation in the secondary sectors. The second aspect is an institutional one. In countries with institutional frameworks which support the knowledge intensification of resource extraction and exploration, both the output and sustainability of the resource sector itself will be vastly improved.

To demonstrate these points, a model is required which will encapsulate the dynamics that drive the relationship between the resource sector and the broader economy. To start with, society is endowed with innovators. These are entrepreneurs, scientists and engineers who exploit and create knowledge and who collectively drive growth in the technological frontier. Here, innovators differ from regular entrepreneurs and investors in that they seek out new activities and the creation of new markets (or the transformation of existing markets) rather than to replicate existing activities or to enter into existing markets. Innovators either discover and appropriate technologies and industries from abroad or they build on local capabilities and generate technology and knowledge externalities domestically. These externalities are often grouped under the umbrella of first-move externalities because once it has been demonstrated that a particular activity is possible, others may follow with less uncertainty. The risk discovery is borne solely by the innovator but the benefits are socialized through demonstration effects and knowledge spillovers through labour turnover and other disseminating forces. This implies that innovation is suboptimal which requires a degree of social planning to correct. Moreover, in this model the level of innovators is constant which means that the social planner is concerned with the allocation, not the provision of innovators across sectors.

In this model society has to choose how to allocate its innovators between the dynamic manufacturing export sector (what will be referred to from now on as the manufacturing sector) and the natural resource extraction and exploration sector (henceforth, the resource sector). In a resource abundant country, the relative size of the manufacturing sector is initially small; the majority of local capabilities, institutions and infrastructure will be geared toward the resource sector. Therefore in this model, innovators in the manufacturing sector will be mostly engaged with the appropriation of foreign technology while innovators in the resource sector will be chiefly concerned with building on local capabilities through the 3 channels of knowledge intensification outlined in the introduction of this section. The model abstracts from the manner in which society allocates innovators (whether through the creation of export processing zones, import substituting trade policies, chemical engineering subsidies etc.) and merely assumes that it has some mechanism with which to allocate innovators. The task of the social planner is to allocate innovators across the manufacturing and resource sectors so that their marginal value products are equal. There are m innovators in society, θm of which are engaged in the knowledge intensification of the resource sector and the rest, $(1-\theta)m$, invest in the manufacturing sector, $\theta \in (0,1)$. Since m is constant and exogenous, it can be dropped from further analysis. The social planner must choose θ. Innovators are the only factors of production (although later, relative labour, natural resources and human capital endowments are implicitly captured through the relationship between the economy and the natural resource stock).

Resource Sector

To simplify, there is only one type of natural resource, S. Every country is endowed with an initial stock of S, determining the extent of their comparative advantage in natural resources. The resource sector production (or simply extraction) function is captured by

$$E = E(\overset{+}{S}, \overset{+}{\theta}).$$

Extraction is a positive function of the level of innovators committed to the resource sector, capturing both the improvements in exploration and extraction technologies. Considering the model is aimed at assisting policy analysis in poor developing countries (and for the sake of model parsimony) the price of the resource is exogenously determined as p. The social payoff of the resource sector is

$$\pi_R = pE(S, \theta)$$

Knowledge Production and Innovation

The number of new industries that the manufacturing sector can specialise in depends on its capacity to appropriate both local and foreign innovation which depends on existing capabilities as well as local cost conditions. Let the subset of possible new manufacturing industries be *A*. This is based on current technologies which either exist in other countries or which exist locally but have not been implemented yet, both because of cost uncertainty. *A* is a set of all *possible* new technologies which can be locally implemented, given current capabilities, and differs for each country. For instance, the set *A* for Mauritius might include advanced clothing production techniques found only in Italy since Mauritius already possesses clothing and textile capabilities. On the other hand, it would not include advanced microchip design since Mauritius currently possesses no microchip and advanced electronic related industries. *A* can also include locally produced technology which is awaiting implementation such as dormant patents. For resource abundant countries let

$$A = A(\overset{-}{\pi}_R, \overset{+}{\theta}). \tag{1}$$

Resource revenue enters negatively into *A* through the Dutch disease effect by appreciating the real exchange rate, reducing competitiveness and hence the number of suitable foreign industries. In the resource curse literature, the resource sector is seen as a drain on human capital: human capital is needed in the resource sector but it fails to generate knowledge spillovers. In the model this means that an increase in θ would decrease (or have no effect on) A. Instead this model assumes that innovation occurs in both the resource and manufacturing sector. In a resource abundant country, most of the innovative capacity is likely to be in the resource sector (since it is the largest). In contrast to the resource curse literature, increasing θ, ceteris paribus, will positively affect A as knowledge spillovers and lateral migration create opportunities for innovators in the manufacturing sector. The greater the amount of innovators in the relatively larger resource sector, the more opportunities there are for innovators in the manufacturing sector as technologies are adapted and migrated from the former to the latter. Of course an increase in innovators in the resource means a decrease in innovators in the resource sector so, although A increases with θ, there will be fewer innovators in the manufacturing sector to appropriate members of A.

Knowledge spillovers into the manufacturing sector

The process of cost discovery in the manufacturing sector involves risks and innovators are not guaranteed to succeed when attempting to introduce new activities into the economy. In the model each innovator can only bring at most one new product to the domestic economy. The probability that a project succeeds is α $(\alpha \in (0,1))$ and the social payoff to successfully starting a new activity is D for every new activity[3]. The expected payoff to society for committing innovators to the modern sector is

$$\pi_M = (1-\theta)\alpha D.$$

The probability that a given project succeeds is a positive function of the amount of possible projects available to the economy,

$$\alpha = \alpha(\overset{+}{A}).$$

From (1) we can see that

$$\alpha = \alpha[\overset{+}{A}(\overset{-}{\pi_R}, \overset{+}{\theta})].$$

$$\Rightarrow \alpha = \alpha(\overset{-}{\pi_R}, \overset{+}{\theta}).$$

Since p is exogenous and fixed this is reduced to

[3] Allowing D to vary or indexing D does not change the nature of the outcome of the model, only the degree.

$$\alpha = \alpha(\overset{-}{E}, \overset{+}{\theta}).$$

The total benefit to the economy from local innovation is

$$\pi_T = \pi_R + \pi_M.$$

The problem of allocating innovators in such a way as to optimize the returns to innovation is expressed as

$$\underset{\theta}{MAX}\ \pi_T = pE(S,\theta) + (1-\theta)\alpha D$$

where

$$\alpha = \alpha(A) \text{ and } A = A(E,\theta)$$

To optimize, set

$$\left.\frac{\partial \pi_T}{\partial \theta}\right|_{\text{m,s fixed}} = 0.$$

This yields the following first order condition:

$$\frac{p\partial E(S,\theta)}{\partial \theta} = D(\alpha - (1-\theta)[\overset{-}{\frac{\partial \alpha}{\partial E}} \frac{\partial E}{\partial \theta} + \overset{+}{\frac{\partial \alpha}{\partial \theta}}]) \qquad (2)$$

The left hand side of the equation is the marginal revenue product of the resource sector and the right hand side is the negative marginal revenue product of the manufacturing sector both with respect to innovators. In the discussion that follows the right hand side of Equation (2) will be referred to as the social marginal cost (or simply marginal cost) of moving innovators out of the resource sector. Therefore the point of optimality is just where marginal cost and marginal revenue intersect (provided the usual second order conditions are satisfied).

Dynamics

This section contrasts the planning scenario in which positive knowledge externalities created in the resource sector are recognized by the social planner with the scenario in which the resource sector is seen as a drain on human capital. Equation (2) represents the former scenario. In the marginal cost equation the inner term,

$$\overset{-}{\frac{\partial \alpha}{\partial E}} \frac{\partial E}{\partial \theta} + \overset{+}{\frac{\partial \alpha}{\partial \theta}}$$

represents the tension between the cost lowering effects of innovation and the crowding out effect of extraction improvements through the exchange rate.

To keep the analysis of the model simple and parsimonious, a few basic assumptions are needed. Firstly, the effect that additional innovators in the resource sector has on creating technology and knowledge spillovers is always positive but declining,

$$\frac{\partial \alpha}{\partial \theta} > 0, \frac{\partial^2 \alpha}{\partial \theta^2} < 0.$$

Let the Dutch disease effect, $\frac{\partial \alpha}{\partial E}$ and the marginal extraction of resource innovators, $\frac{\partial E}{\partial \theta}$ be constant. Innovators in the resource sector create opportunities for innovators in the manufacturing sector by building on the capabilities and technologies of the resource sector. They also directly improve the productivity of extraction which strengthens the resource sector and crowds out some manufacturing activity through real exchange rate appreciation. The net effect of committing innovators to the resource sector on the probability of individual innovators starting new activities in the manufacturing sector is shown in Figure 1.

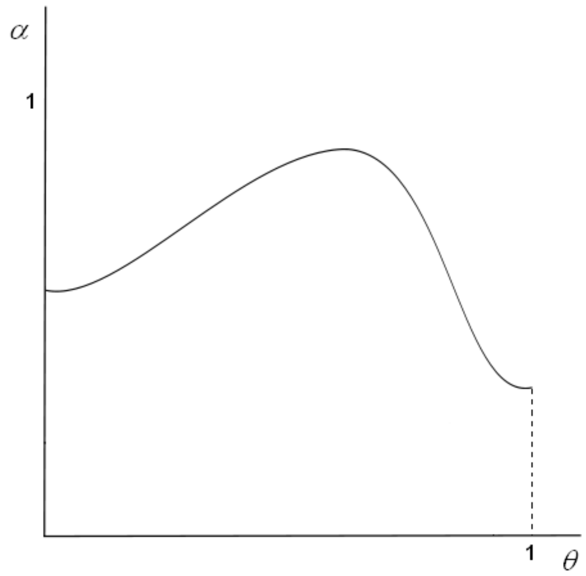

FIGURE 1. THE INDIVIDUAL PROBABILITY OF SUCCESS FOR INNOVATORS IN THE MANUFACTURING SECTOR

The curvature of the α curve is driven by the diminishing returns to knowledge spillovers from the resource sector and the turning point is influenced by the extent to which innovation in the resource sector increases resource export revenue.

Consider the second scenario in which the social planner has incomplete information and does not recognize the positive knowledge and technology externalities which flow from the knowledge intensification of extraction and exploration. In this case, Equation (2) would collapse to

$$\frac{p\partial E(S,\theta)}{\partial \theta} = D(\alpha - (1-\theta)[\frac{\partial \alpha}{\partial E}\frac{\partial E}{\partial \theta}]) \qquad (3),$$

and committing innovators to the resource sector would unambiguously reduce the profitability of the manufacturing sector through the Dutch Disease effect on the real exchange rate. Here the marginal cost with respect to innovators in the resource sector would be unambiguously negative.

In Figure 2 the marginal cost taking into account knowledge spillovers from the resource sector is contrasted with the marginal cost in a scenario where the resource sector does not generate any economically useful knowledge or technology. MC_i is the marginal cost curve in the scenario where innovation in the resource sector creates knowledge externalities which can be appropriated by the manufacturing sector. This is the right hand side of Equation (2). The difference between the curves is the marginal revenue product of innovation in the resource sector on new activities in the manufacturing sector. MC_n is driven by the Dutch Disease phenomenon of crowding out manufacturing through real exchange rate appreciation which, as mentioned above, is constant in this model. This is the right hand side of (3).

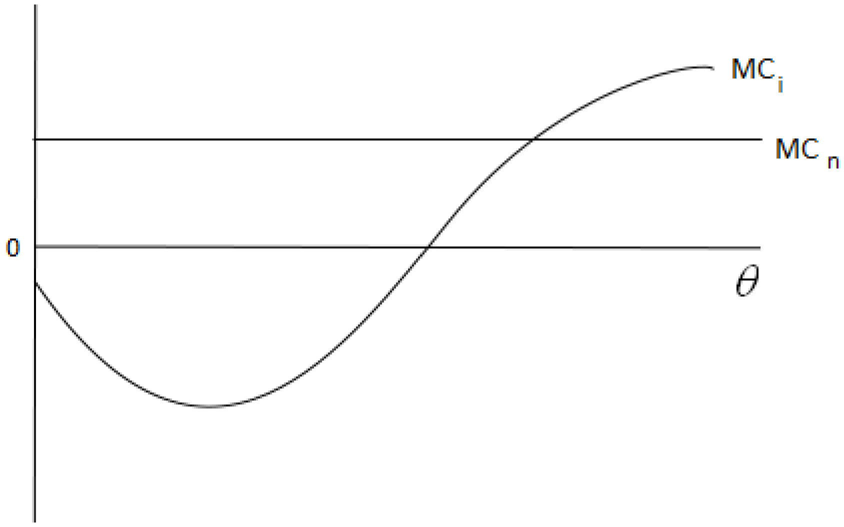

FIGURE 2. MARGINAL REVENUE IN MANUFACTURING WITH RESPECT TO RESOURCE INNOVATORS

Institutional Support for Innovation

The 2 scenarios outlined above are contrasted to illustrate the problem of under-allocation of innovators to the resource sector which can occur if social planning is based upon the assumption that the resource sector is dead to innovation and knowledge creation. The second aspect of this model seeks to demonstrate the importance of assisting extraction and exploration in the resource sector. While the resource-pessimist school might suggest that such institutional support will only crowd out the manufacturing sector further, it is important to consider the effect that exploration improvements have on sustainability and whether this does in fact harm the broader economy.

Marginal revenue in the resource sector, MR, is positive with respect to innovation in the resource sector. However, in the case of no institutional support, innovators simply increase extraction and hence depletion. In the first presence of institutional support innovators create knowledge in the resource sector, exploration is improved and the stock of known resources increases with innovation. The marginal extraction with respect to innovators will be more steeply declining where there is no institutional support as the stock of known and available resources unambiguously declines when improvements in exploration are not accounted for.

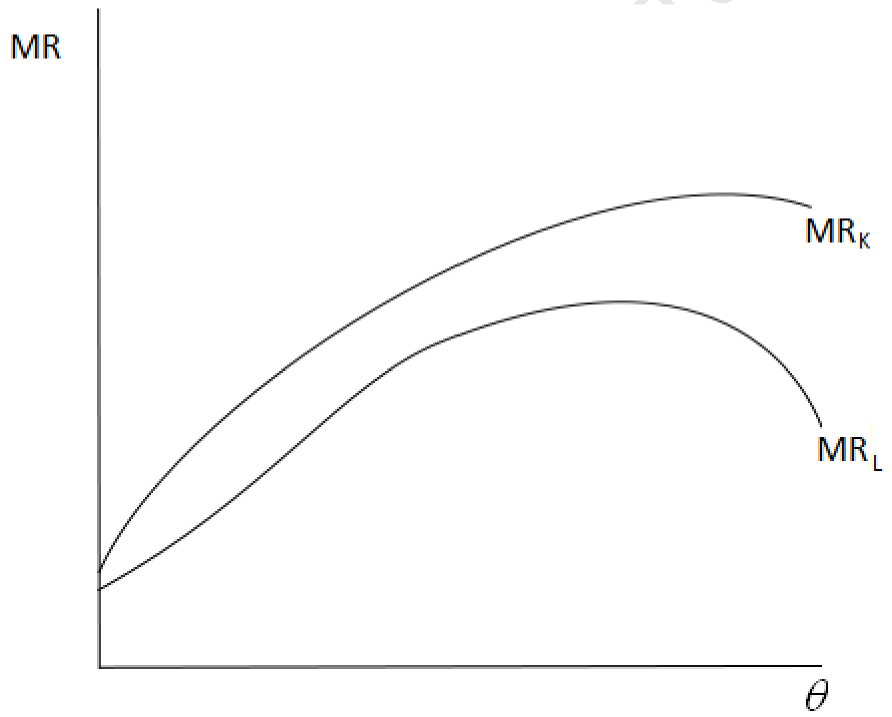

Figure 3. Marginal revenue in the resource sector with respect to innovators

In Figure 3, subscript K and L represent institutional support for knowledge creation and a laissez faire approach respectively.

Figures 4 illustrates the optimal allocation of innovators in the case where there is institutional support for resource knowledge creation and where the social planner acknowledges the spillovers. This is the best case for resource abundant countries.

Figure 5 illustrates the allocation when there is little to know institutional bridges between the resource sector and the manufacturing sector and when the social planner only acknowledges the Dutch Disease. Putting all the curves on one set of axes (Figure 6) displays 4 possible equlibria, 2 of which are shown.

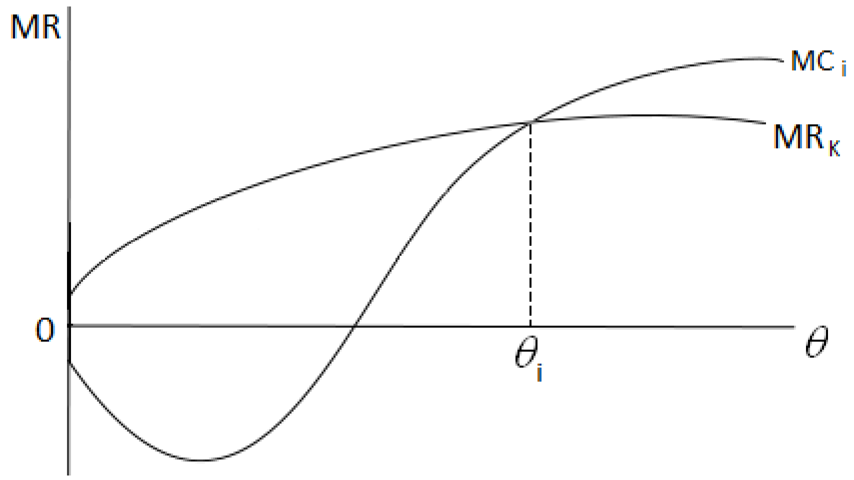

Figure 4. The optimal solution with innovation spillovers.

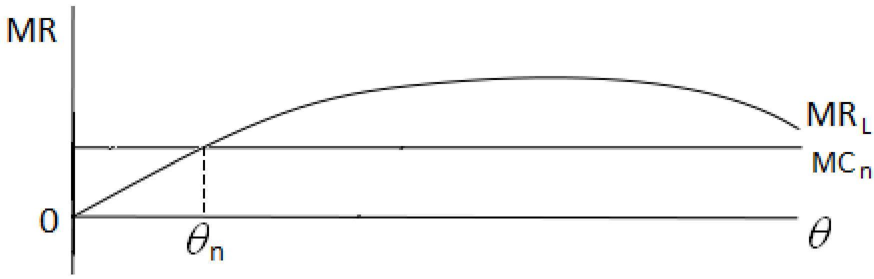

Figure 5. The optimal solution without innovation spillovers.

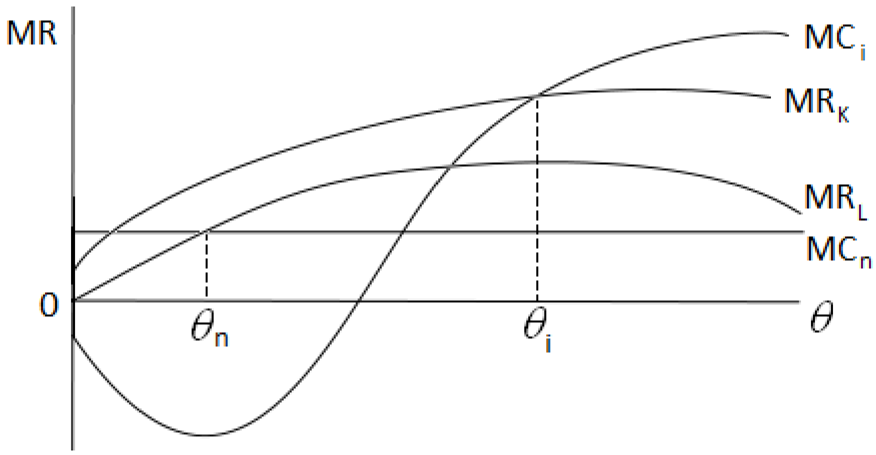

Figure 6. A comparison of optimal solutions under 2 scenarios.

Conclusions

Innovators in the resource sector improve the profitability and sustainability of the resource sector through improvements in both exploration and extraction. The technologies and knowledge developed in pursuit of resource revenue sometimes find use in other sectors through lateral migration and in some cases spawn entirely new industries. Figure 6 shows that failure to recognize both these channels of innovation would result in a suboptimal allocation of innovators to the resource sector, reducing potential revenue in the resource sector and innovation in the manufacturing sector. This endowment determined model is consistent with the Heckscher-Olin model of comparative advantage. However it goes one step further by suggesting that not only should the resource sector not be suppressed in resource abundant countries (such as in the case of free trade) but that its growth and the incentives it creates for the entry of domestic innovators should be actively supported by policy. This is the complete opposite of the typical policy prescriptions emanating from the resource curse camp and deserves further elaborating. The next part of the paper investigates in greater detail some case studies in which resource abundant countries have benefited from the exploitation of the knowledge intensification of the resource sector. However, for now it is clear from the model, that if static optimization happens at the margin, and if the resource sector is characterized by positive growth externalities similar to the secondary sector then secondary sector biased policy which leads to misallocation of human capital is both detrimental to growth in both the short and the long runs.

References

23. Hausmann. R, J. Hwang and D, Rodrik. 2007. "What you export matters.", Journal of Economics: Growth (2007) pp. 12:1–25, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA

24. Lasky, S.G. 1950. "How Tonnage and Grade Relations Help Predict Ore Reserves." Engineering and Mining Journal 151: 81–85.Lorentzen

25. Lorentzen, J. 2008. "Knowledge intensification in resource-based economies". Resource Intensity, Knowledge and Development Insights from Africa and South America.

26. Sachs, J.D. and A.M. 1997. Warner "Natural Resource Abundance and Economic Growth", *Centre for International Development and Harvard Institute for International Development*, Havard University, Cambridge MA.

27. Wright, G. and J. Czelusta. 2007. "Resource based growth: past and present", *Natural Resources: Neither Curse Nor destiny, pp. 183-212,The International Bank for Reconstruction and Development / The World Bank, 2007.*

Part 2:

AN EMPIRICAL ANALYSIS OF THE PRESENCE OF INNOVATION IN THE FACE OF RESOURCE ABUNDANCE

1. Innovation in the Face of Uncertainty

Since the advent of New Trade Theory (see Krugman, 1980) there have been a number of attempts to explain complex patterns of trade between developed countries and between the North and South which seem to be unexplained by Ricardian and Heckscher-Olin theories of comparative advantage. More recently there has been an attempt to link the sophistication of exports to levels of industrialisation (Lall et al, 2004) and to explain the differences in the quality of goods in export baskets by domestic market failures which require remedial industrial policy to correct (Hausmann, 2003). Here, rich countries are rich because they produce goods which other rich countries produce and poor countries are poor because they produce mostly poor country goods. More formally, countries which export chiefly primary goods tend to have lower levels of income than countries which export mainly high technology manufactures (Hausmann et al (2007);Lall et al(2004)). Against this backdrop it is tempting to conclude that low income countries which wish to grow should attempt to upgrade their industrial mix to match that of higher income countries. The model developed in part 1 suggests that, contrary to these arguments, exports in resources should be actively encouraged in resource abundant countries since domestic systems of innovation are more likely to be natural resource oriented. As a corollary it can be inferred that suppressing the resource sector in these countries (through manufacturing biased industrial policy, for instance) will have negative growth consequences for the manufacturing sector by reducing aggregate innovation.

In short, this requires that the discrepancies between the model and the evidence which supports manufacturing oriented exports need to be resolved before an investigation into the validity of the model can be conducted. This part of the paper will attempt to do just that, first by outlining the broad arguments supporting high technology export oriented growth and then in later sections it will show that the theoretical concepts which underpin these arguments are in fact consistent with the model developed in part 1.

Cost Discovery Externalities

The swing from the failures of strong government intervention to a trend of economic liberalization in the 1980s and 1990s in many developing countries was meant to herald a new era of private-sector driven growth. What followed was instead mostly stagnation. In many resource abundant countries with publicly owned mines, ownership changed but the wealth and power remained concentrated in the hands of the few as the great private sector in waiting never seemed to emerge. The global despondency toward the policies embodied in the Washington Consensus have led to the development of a new strand of thinking which asserts that the negative externalities of government failure are not the only forces which reduce levels of entrepreneurship. Ironically, the very reasons society values entrepreneurship is what leads to its under-provision in a free and open market: positive externalities. The fact that, in the absence of compensating mechanisms, entrepreneurs cannot internalize the benefits they bestow upon society means that public encouragement for entrepreneurial risk taking is required if society is to avoid suboptimal levels of innovation. Therefore societies must guard against removing all government support in an effort to rid themselves of government failure, lest they create a suboptimal welfare outcome. In particular one class of externalities of interest to policy makers who wish to encourage new activities should be those that second comers internalize. It is this class of externalities that Rodrik and Hausmann refer to as cost discovery externalities (2003).

When a firm introduces a new technique of production it does so with no knowledge or experience of whether it will work and what the costs will be. Even for technologies that are imported, the local cost conditions, infrastructure, institutions and any other idiosyncrasies will greatly influence the final costs incurred. The firm does not only face risk, it faces great uncertainty. If the firm succeeds it will create local knowledge and experience relating to the use of the new technique. Firstly it demonstrates to other would-be entrants that such a technique is possible and secondly much of the knowledge of implementation will be embodied in the workforce who, through labour turnover, and other similar mechanisms, will gradually disseminate the knowledge locally. Thus costs which were unknown have been discovered, opening a door to future entrants and perhaps facilitating the creation of similar industries. The benefits of cost discovery are certainly not captured by the pioneering firm but the risks of failure are almost fully internalized. This situation leads to a socially suboptimal level of innovation. For new techniques which can be patented, intellectual property laws act to correct cost discovery externalities but for many techniques which cannot be protected such as local adaptations of foreign technologies imported into developing countries there are no analogous institutions.

Structural transformation in the face of cost uncertainty

Cost uncertainty raises the cost of firms experimenting in unfamiliar territory. Ex ante one would expect industrial transformation to be dominated by an evolutionary progression as new industries are established which are closely linked to existing industries rather than erratic innovation. This pattern of incremental innovation is necessitated by cost uncertainty as firms branch into relatively familiar territory to mitigate uncertainty. For instance, one would expect firms in the software industry to produce and invest in software related innovation, rather than experiment in cosmetics. Hidalgo et al (2007) set about constructing a visual two-dimensional map of the relationship between the products countries export. The point of this map was to visually group industries which were similar. However, the approach was "agnostic to theory" (Hidalgo, 2007: pp. 4) to avoid biasing the outcome to suit conventional economic models. Taking the export baskets of every country, for any 2 products which occurred in the same export basket, the visual proximity between the products was relatively closer than for products which did not appear together. The closeness was proportional to the number of export baskets that product pairs occurred in. For instance, desktop computers and monitors were very proximate on the map because most countries which exported one also exported the other. Coffee, on the other hand is situated far from coffee machines as the two hardly ever occupied the same basket.

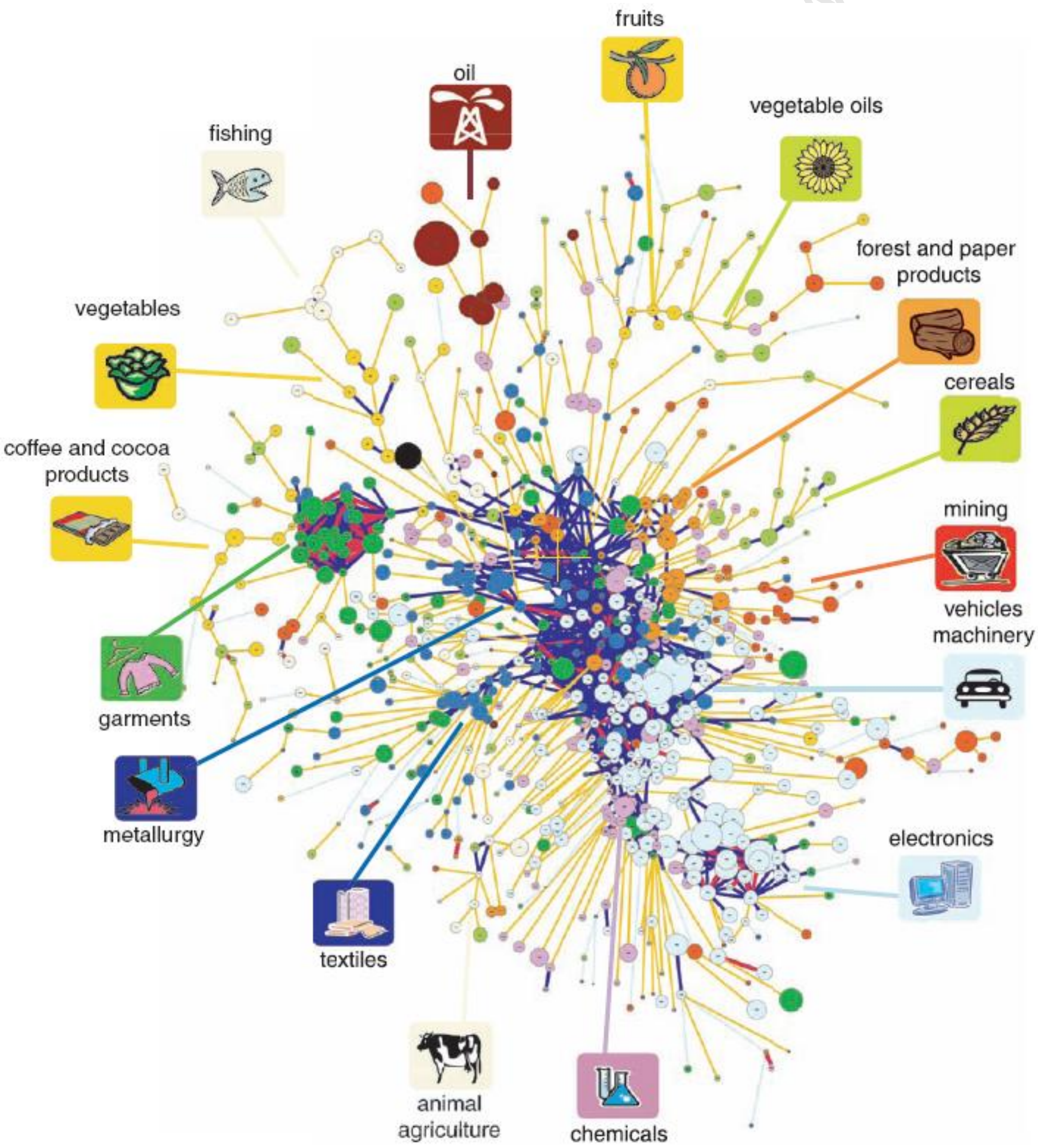

FIGURE 1: THE PRODUCT SPACE. (SOURCE: HIDALGO, 2007)

What emerged was a picture of industry clusters revealing the nature of the countries which exported them. For instance, most electronic goods clustered closely together because countries which exported one type of electronic tended to export others as well. In Figure 1 the size of the nodes indicated the relative sizes of industries.

What Hidalgo found was that high growth countries (such as the NIEs) and high income countries in the OECD tended to have most of their export industries positioned in the dense parts of the product space graph where goods were clustered. Low growth and low income countries on the other hand tended to see most of their export industries spread out on the sparse periphery. Moreover, the periphery of sparse clusters was mostly made up of natural resource industries such as oil, mining and forestry. This relationship between growth and industrial structure held both across countries and across time within countries (Hidalgo et al, 2007).

Amelioration of cost uncertainty through proximate product placement

In the framework of industrial experimentation in the face of cost discovery externalities, structural transformation occurs mostly through evolutionary innovation as firms attempt to minimize the cost of uncertainty by branching out into familiar industries. In support of this notion, Hidalgo and Hausmann (2009) found that high growth countries in Asia initially had a few industries in the dense clustered core groups such as electronics. Over time firms in these industries branched out to similar (nearby on the product space) industries. The informational leap for these firms was relatively small due to the similarities and so the risks of cost uncertainties were minimized. For countries which found their industrial structure initially seated in dense clusters, product diversification and industrial transformation increased rapidly over the course of the 20th century resulting in astonishing rates of income growth. Assuming that the framework of incremental innovation is accurate in explaining structural transformation, Hidalgo's map of product proximity provides a possible road map for emerging economies: in order to experience continual productivity improvements, countries should position their industries in dense clusters of closely related products so that cloth stitching firms, for instance, can branch into shoe assembly, dying and tanning, full garment production and perhaps textile production eventually.

Incremental Development

Building on the model of cost discovery externalities, Hausmann et al(2007) argue that the types of goods exported reflect a country's productivity levels and that when firms discover and produce sophisticated products, productivity (and income) levels improve. To support this last conclusion, they constructed a measure of average export productivity for a large sample of countries using export data. In a similar vein to the Hidalgo product space, goods in an export basket were weighted by the average income levels of all countries which exported them. Therefore high technology goods such as embedded electronic systems were assigned a higher weight than primary goods such as natural resources because the average incomes of countries which exported the former tended to converge on South Korea's income whereas primary good exporters were found mostly in sub-Saharan Africa and Latin America where income levels were far lower. The weight given to each good was used to illustrate the implied productivity in their production. With such a measure, they could then construct a measure of average export productivity for each country by summing the values of each export multiplied by its productivity adjusted weight. The higher this measure (labelled EXPY in their paper) the higher the implied average level of productivity in production. This means that countries with export baskets that were heavily loaded with high technology products had a higher EXPY than countries with export baskets dominated by primary goods. EXPY adjusted for the relative sizes of economies. For instance, even though the total value of Nigerian exports is greater than Iceland's, it has a lower EXPY. Figure 2 illustrates the graphical relationship between GDP per capita and EXPY across countries in 2003.

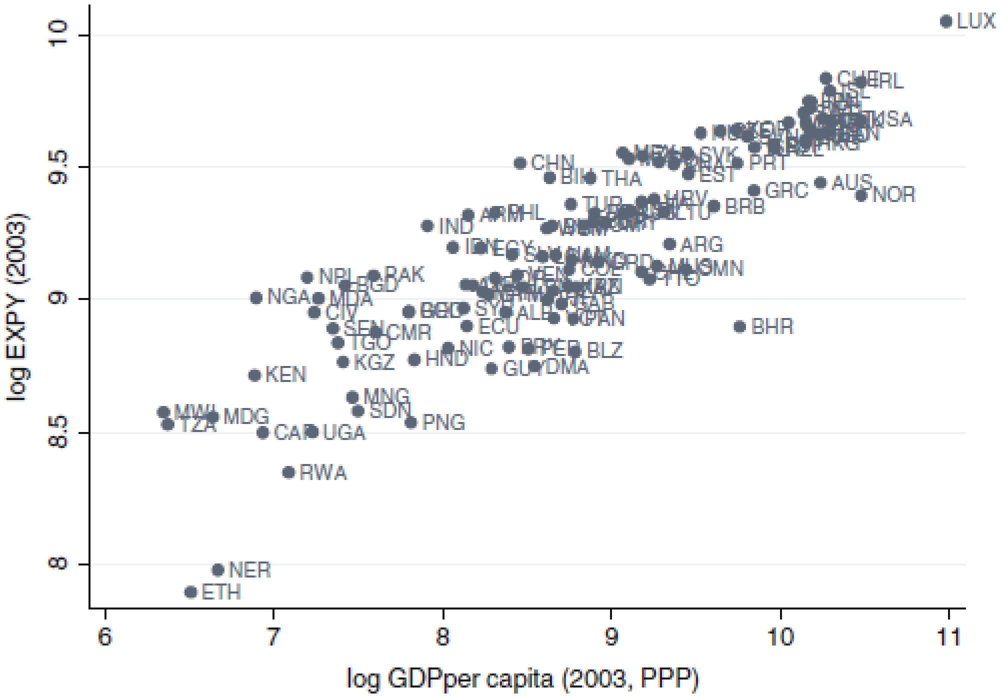

Figure 2: Relationship between GDP per capita and EXPY. (source: Hausmann et al, 2007)

It is clear from Figure 2 that average income in 2003 was strongly correlated with EXPY. A regression of EXPY as a predictor of GDP per capita confirms this. Controlling for the usual explanatory variables such as initial GDP per capita Hausmann et al (2007) constructed growth regressions for the period 1992 to 2003 and 1994 to 2003. What they found was that EXPY at the beginning of the period was a very strong positive predictor of subsequent growth. In particular they were able to partition developing countries into 2 groups. In the first group were countries with initial EXPY levels far higher than the expected level for their income. The second group was composed of countries which had lower than expected initial EXPY levels. The first group experienced rapid economic growth in the subsequent period. This group included China and India. The second group stagnated in the subsequent period. Importantly, their results strongly suggest that the quality of exports matter – that those countries which are able to increase the relative sophistication of their exports (as implied by the average income of countries which export particular products) will grow faster than countries which continue to export basic commodities.

Where to for resource abundant countries?

It would appear that resource abundant countries face no other choice but to pursue policies which promote production in goods typical of high income countries. However, amongst the few natural resource abundant success stories, the common thread certainly is not industrial escape from the bondage of resource dependence. The next section enumerates some case studies of resource abundant countries which have succeeded and what the salient features of their industrialisation are. As will become clear, what distinguishes many of these countries is that their export basket is surprisingly still heavily weighted by primary goods.

References

1. Hausmann, R and D. Rodrik. 2003. "Economic development as self discovery", Revised April 2003 John F. Kennedy School of Government Harvard University79 Kennedy Street Cambridge, MA 02138(617) 496-3740ricardo_hausmann@harvard.eduJohn F. Kennedy School of Government Harvard University79 Kennedy Street Cambridge, MA 02138(617) 495-9454dani_rodrik@harvard.edu
2. Hausmann. R, J. Hwang and D, Rodrik. 2007. "What you export matters.", Journal of Economics: Growth (2007) pp. 12:1–25, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA

3. **Hidalgo Cesar, Hausmann Ricardo** 2009 " The building blocks of economic complexity" *Proceedings of the National Academy of Sciences* **106** 10570–10575Rodrik South Africa
4. Hidalgo, C.A., B. Klinger, A.L. Barabasim R. Hausmann. 2007. "The Product Space Conditions for the Development of Nations.", *Science 317, 482, vol. 317. American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005*

5. Krugman, P. (1980), "Scale Economies, Product Differentiation, and the Pattern of Trade", *American Economic Review* 70, 950-959.
6. **Lall, S., John Weiss and Jinkang Zhang. 2004. "**The 'Sophistication' Of Exports: A New Measure Of Product Characteristics", QEH Working Paper Series – QEHWPS 123.

2. The Mineral Economy

In the previous section it was shown that the relationship between the relative sophistication of the goods a country exports and its level of development is significant and positive. However, history has been dotted with examples of industrialisation in which natural resource dominated exports played a significant role. This section investigates these peculiar countries in an attempt to determine how the standard 'rules' of growth were violated without negative consequence and whether the resource sector deserves its place under the sun.

The mineral industrial complex

As a thought experiment, consider a highly industrialised country which is also resource abundant and whose share of natural resources in the export basket is significant. Using the EXPY measure of Haussmann et al (2007) would weigh down the country's implied productivity because it exports products normally associated with sub-Saharan African countries, for instance. Therefore, such a country may have a highly industrialised domestic economy and it may even export high technology goods but the presence of so many natural resources in its exports would make it appear (from the outside) to have a primitive set of industries. So does such a country exist? After all, Heckscher-Olin style trade theory would suggest that if the country is high income it should have relatively high levels of capital (both human and physical). Furthermore, although it might have an absolute advantage in the quantity of natural resources it possesses it would nevertheless focus on capital intensive exports and leave the production of primary products to countries with low wage, unskilled labour. Therefore income levels are normally correlated with the capital intensity of exports.

It turns out, however, that there is such a set of anomalous high income countries with natural resource weighted trade baskets. Almost an entire quarter of Sweden's exports are in basic metals and forestry products. For Finland the proportion is higher, yet both of these countries are leaders in the knowledge economy, boasting companies such as Nokia and Ericsson (Blomström and Kokko, 2007). Conventional economic wisdom warns that in order to allow manufacturing to thrive, natural resource exports must not be allowed to flourish. Sweden, Finland (as well as many others in Latin America, Australia and elsewhere) demonstrate that there must be an alternative to this model of industrialisation.

A reassessment of the Dutch Disease

When windfalls of natural resources are discovered and exported the traditional export sectors are crowded out through a real exchange rate appreciation, a phenomenon modern literature refers to as the Dutch disease. However, a sudden discovery of resource abundance implies a sudden change in *relative* endowments of labour, capital and natural resources which implies a change in comparative advantage. The traditional export sectors are expected to decline as factors of production in the economy shift toward the new sectors in which the country now enjoys a comparative advantage.

However, this need not imply that manufacturing recede altogether, but merely that outward oriented manufacturing of goods typical of less naturally well-endowed countries is not appropriate to resource abundant countries. The industrial structure which evolves in natural resource abundant countries is likely to be consistent with comparative advantage and therefore differ from that of resource poor countries.

If resource abundance dictates that exports are heavily concentrated in primary exports, it does not require manufacturing to vanish. What may emerge in resource abundant countries is a system of manufacturing support for the production of natural resources. For instance, consider a country which engages in deep earth mining using drilling equipment bespoke for local geological conditions. It might be cheaper to have such equipment produced locally than imported. The presence of mining operations has thus created room for specialised drill manufacturing in the local economy. This itself requires drill bit production and specialised drill servicing operations. Thus an industrial structure could emerge as mining operation become increasingly sophisticated. Because of the relative size of mining in a resource abundant country one might expect such resource oriented manufacturing to make up a significant part of the industrial economy. This is the case in South Africa where a large part of the manufacturing industry exists in support of the mining industry (Lorentzen, 2008).

The Reverse Value Chain

The paradigm in distinguishing between primary, secondary and tertiary goods and services might not adequately fit the structural picture in resource abundant countries. To consider natural resources primary goods is misleading in that it creates the picture that these goods are inputs to more sophisticated goods such as automotives and electronics. This is indeed the case for countries which *import* natural resources for beneficiation. However, for countries which export them, a great deal of R&D and manufactured inputs might have gone into their exploration and extraction respectively. For these countries natural resources can be viewed as a final product at the end of a complex mineral-industrial value chain rather than a primary input into beneficiation.

The fundamental bias in the literature which shows that resource sectors crowd out manufacturing rely on export data to support this claim (see Sachs and Warner, 1997; Hausmann et al, 2007). Of course, when resource windfalls are discovered, resource exports will crowd out manufactured *exports*. This is then equated to de-industrialisation because primary exports are replacing secondary exports. The fundamental flaw in this approach is that it ignores the reverse value chain of resource production that emerges in these countries, in which resources are the final product.

Using an export-oriented measure of industrial sophistication such as Hausmann, Hwang and Rodrik's EXPY or Hidalgo's product space map will hide the complexity of resource oriented services and manufacturing which exist in resource abundant countries. Although these industries are not explicitly outward oriented they are indirectly driven by the external demand for the natural resources that necessitate their existence. It is therefore equally valid to view resource exports as manufactured outputs as it is to view them as primary inputs. This is the key empirical distinction that this paper will use to resolve the apparent paradox of de-industrialisation of exports coupled with income growth that some countries have experienced. While data availability deems the task of constructing a full industrial picture of every country impossible, the flaws in using export data can be demonstrated through statistical analysis.

Productivity and resource exports

In such a mineral-industrial complex, improvements in resource extraction most likely originate from increases in supportive manufacturing productivity or in the production of new mining techniques (Lorentzen, 2008). Thus, there exists a positive link between local manufacturing productivity growth and resource exports. This would help explain the observation by Wright and Czelusta (2007) that Australia's periods of highest growth coincided with its periods of highest extraction since extraction productivity is in part driven by manufacturing productivity improvements. In most industrial settings, falling prices in natural resources reduce price pressures on downstream manufacturing. In a mineral-industrial complex, falling prices drive the need for productivity improvements upstream. It may even be that the decline in the terms of trade in commodity exports observed by Prebisch (1959) is driven partly by improvements in the productivity of extraction in certain resource abundant countries. Wright and Czelusta (2007) show that the declining terms of trade was hardly observable for commodities which were only exported by typical resource cursed countries but was most pronounced for commodities exported by countries such as Chile, Australia, the U.S. and Brazil, all of which experienced vast improvements in extraction productivity since the 1950s.

Dispelling unsustainability

Suppose then that in response to a natural resource discovery policy makers create an enabling environment for maximum extraction and that manufacturing and technology firms establish themselves and grow in response to the needs of the new external sector. Is this form of industrialisation not subject to the inevitable decline of finite resources and does productivity growth not drive these industries closer to their fate with increasing speed? The idea that natural resources are finite endowments (and by implication, industries based upon their availability are unsustainable) has driven the pessimism in economic thought toward resource dependence in much of the related development literature (Prebisch, 1959; Smith, 1776). However, since the application of science to exploration, extraction, processing and reprocessing which began in the US oil fields in the first three decades of the twentieth century (Wright and Czelusta, 2007), mine production in countries that have well managed mineral supplies has grown consistently. Table 1 indicates some of these growth rates for 6 well managed countries. Importantly, Hotelling's prediction of exponential price rises from growing scarcity has not come to bear. Instead resource-based commodity prices have declined for most of the 20^{th} century.

	Australia	Brazil	Canada	Chile	Mexico	Peru	World
Bauxite	3.41	7.72	—	—	—	—	2.18
Cobalt	5.30	—	6.43	—	—	—	0.20
Copper	5.77	16.89	–0.22	6.93	9.02	1.96	2.91
Gold	14.04	4.45	5.14	9.49	9.02	16.39	2.38
Lead	2.08	–6.32	–3.54	–0.67	–0.63	1.83	–1.09
Nickel	3.03	8.93	1.69	—	—	—	2.61
Silver	3.73	5.47	1.03	8.12	2.16	2.90	2.55
Zinc	4.17	2.98	–0.62	13.17	2.63	2.96	1.08

Sources: USGS, *Minerals Yearbook* (selected years from 1978 to 2001).

Note: Growth rates are coefficients from a semi-log trend regression. Brazilian copper production in 1979 set equal to that of 1978 (100 metric tons).

Table 1. Average Annual Growth Rates of Mine Production 1978-2001. (Source: Wright and Czelusta, 2007)

Of course, it would seem plausible to argue that Hotelling's prediction of compound price increases has been staved off by discoveries of previously unexplored territories in places such as Latin America and sub-Saharan Africa and that it only makes sense in a world in which all deposits have been discovered. In a detailed analysis of the scarcity of resources and the price movements, Jeffrey Krautkramer concluded that new discoveries as well as improvements in extraction and substitute technologies "...have mitigated the scarcity of depleting existing deposits" (Krautkramer, 1998. Pp. 2066, 2091 cited in Wright and Czelusta).

What is important in the improvements in exploration processes and extraction technology is not the ability to discover previously hidden or unknown deposits. Instead it has been the ability to rediscover deposits, which were considered too difficult to mine, with technological progress. In other words, it is not so much that new deposits have been discovered as it is that existing deposits have been renewed. This continued progress in what Lorentzen (2008) refers to as the "knowledge intensification" of resource extraction over the past century has pushed back the frontier of what was considered marginal or impossible and thereby almost eradicated the notion that natural resource deposits are in fact an endowment, but rather a function of our collective geological knowledge.

What this implies, ironically, is that countries which do not apply exploration and extraction science to their mining techniques are expected to experience mineral depletion at a faster rate[4]. Resource endowments can only be strictly finite in the presence of constant technology and local geological knowledge. For countries with mining industries supported by research institutions, such as the U.S. Geological Survey, and which continually invest in technological improvements, finite resource endowments have grown almost exponentially. The positive spillovers have come from scientific and human capital development and through the upstream knock on effects of the mineral-industrial complex. The knowledge intensification of extraction and exploration makes possible the long run increasing returns to mining experienced in the US, Australia, Chile, Brazil and even Venezuela (Wright and Czelusta, 2007).

[4] Based on a consensus of many geological specialists, Wright and Czelusta (2007) propose an inverse relationship between the grade of copper ore and the available tonnage. The continual improvements of extraction and reprocessing technology have made possible the increase in production of copper through the 20th century, even in the face of a real price decline. To an extent, the decline in the copper grade is asymptotic. Casual inspection suggests that this relationship is not unique to copper given the continual reforming crustal processes of the earth.

References

28. Blomström , M. and A. Kokko. 2007. "From Natural Resources to High-Tech Production: The Evolution of Industrial Competitiveness in Sweden and Finland", ", *Natural Resources: Neither Curse Nor destiny, pp. 183-212, The International Bank for Reconstruction and Development / The World Bank, 2007.*

29. Hausmann. R, J. Hwang and D, Rodrik. 2007. "What you export matters.", Journal of Economics: Growth (2007) pp. 12:1–25, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA

30. Krautkraemer, Jeffrey A. 1998. "Nonrenewable Resource Scarcity." *Journal of Economic Literature* 36 (December 1998): 2065–107.

31. Lorentzen, J. 2008. "Knowledge intensification in resource-based economies". Resource Intensity, Knowledge and Development Insights from Africa and South America.
32. Prebisch, R 1959. "Commercial Policy in the Underdeveloped Countries". The American Economic Review, Vol. 49, No. 2, Papers and Proceedings of the Seventy-first Annual Meeting of the American Economic Association. (May, 1959), pp. 251-273.

33. Sachs, J.D. and A.M. 1997. Warner "Natural Resource Abundance and Economic Growth", *Centre for International Development and Harvard Institute for International Development*, Havard University, Cambridge MA.

34. Smith, A (1776). "The Wealth of Nations". Oxford. Clarendon Press, 1976.

35. Wright, G. and J. Czelusta. 2007. "Resource based growth: past and present", *Natural Resources: Neither Curse Nor destiny, pp. 183-212, The International Bank for Reconstruction and Development / The World Bank, 2007.*

3. Growth Analysis

It should be clear by now that countries with export profiles dominated by natural resources need not be poor as Hausmann et al (2007) and Hidalgo (2007) suggest. Instead the high levels of resource exports could be explained not just by an underdeveloped secondary sector but by productive mining industries supported by sophisticated manufacturing infrastructure coupled with knowledge producing institutions. In their analysis of export sophistication Hausmann et al(2007) show that the relative sophistication of exports is closely linked to a country's development path. Broadly speaking, his data shows that there are 2 groups of countries, the high growth and high income countries which export high quality products and the low income and low growth countries which export mostly primary products. The model developed in the first part of this paper and the evidence of knowledge intensification and resource oriented industrialisation presented in previous sections alluded to a third group of countries which demonstrate high growth or enjoy high levels of income but which have their productivity implied measures of export sophistication (EXPY in this case) weighed down by significant proportions of primary commodities – natural resources in particular. This group makes up a minority of resource exporters since the only way their EXPY values would predict low growth and low income is if it is mostly associated with poor, underdeveloped countries.

Country Grouping	Relative EXPY	Relative Income per capita
Resource scarce	High	High
Resource abundant	Low	Low
Resource abundant	Low to medium	High

TABLE 1: A PARTITION OF COUNTRIES BY INDUSTRIAL STRUCTURE

This section will test the hypothesis that there is a group of successful resource abundant countries by first replicating some of the key results of Hausmann et al(2007) and then attempting to control for the third group in Table 1.

Research methods and data[5]

The export data presented come from the United Nations Commodity Trade Statistics Database (COMTRADE). The trade data are disaggregated to the Harmonized System 6 digit level. The periods examined are from 1992-2003 and from 1994-2003 in concert with the analysis in Hausmann et al (2007). The reason for shortening the period by 2 years is that the number of reporting countries increases from 56 in 1992 to 100 in 1994. For the growth regressions this change in sample size will make an important impact on the significance of the results. In order to avoid problems of collinearity resulting from GDP per capita appearing on both sides of the equation, one set of PRODY values is used for the construction of every EXPY value. Like Hausmann et al (2007) the PRODY used is the average PRODY for the period 1999-2001.

PRODY was constructed using PPP GDP per capita data from the Penn World Tables (PENN). The EXPY measure was constructed using the PPP data as well as nominal current dollar GDP. This latter source proved to be unreliable due mostly to exchange rate fluctuations (especially during the Asian financial crisis at the end of the 1990s). Therefore EXPY was only constructed using GDP per capita PPP and the COMTRADE data mentioned above. Major oil exporting countries were excluded from the analysis to remain consistent with the approach of Hausmann et al (2007). Although they did not provide adequate explanation for this exclusion, it is probably because the growth performance of countries such as Angola is very closely correlated with the

[5] For details on the construction of PRODY and EXPY see the appendix. For a more thorough discussion see Hausmann et al (2007).

international oil price. Separating out major oil export countries was done by dropping countries whose oil exports were greater than 10% of GDP. The figure 10% is clearly subjective. However for every year in the sample it was clear that there was a significant drop off in oil intensity below the 10% level; countries above the threshold were mostly OPEC members or large oil exporting regions such as Sudan. The growth regressions make use of a natural resource intensity variable which is just the total value of all primary and mineral exports excluding agriculture and fishing (but including forestry) relative to GDP, classified using the Lall classifications of COMTRADE HS6 trade data (2007).

Descriptive Statistics

As Figure 1 illustrates, the relationship between EXPY is positive and strong. Upon inspection it may appear that this is partly by construction since PRODY uses GDP per capita in its construction. However, the relationship is not affected by the removal of countries' own export values from calculations in PRODY. Casual inspection suggests that the link

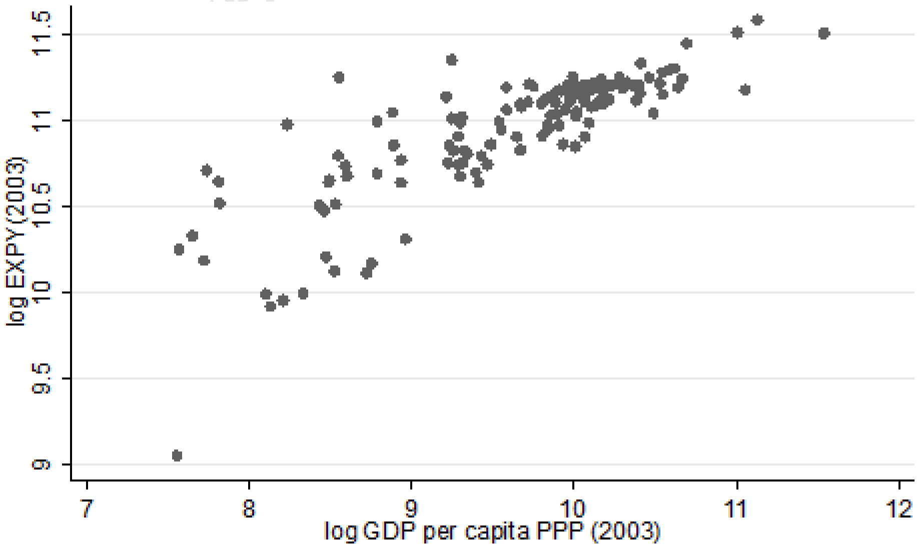

Figure 1. The relationship between EXPY and GDP per capita in 2003.

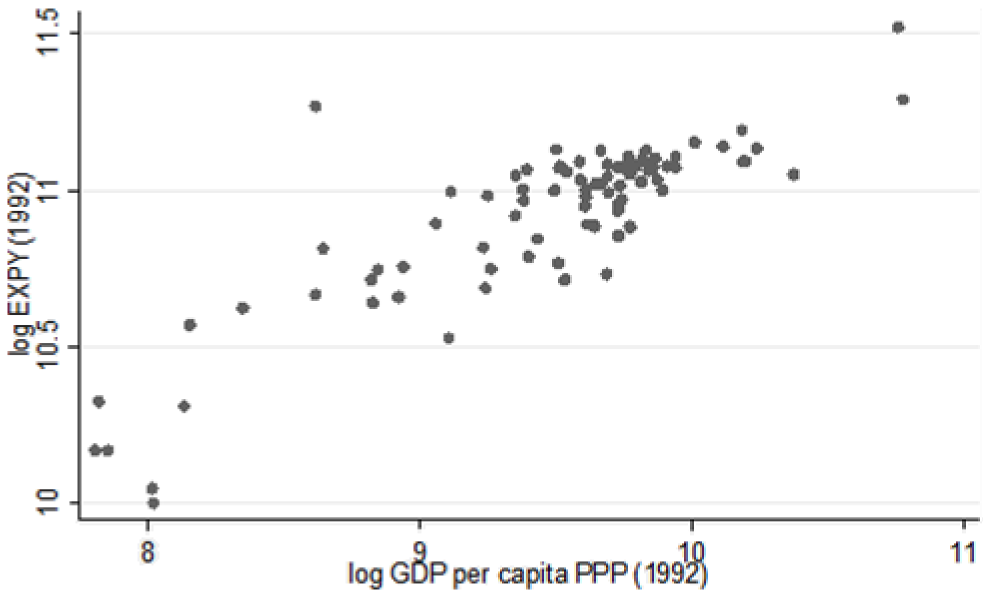

FIGURE 2. THE RELATIONSHIP BETWEEN EXPY AND GDP PER CAPITA IN 1992.

between EXPY and income is tighter for higher income countries . A comparison of Figures 1 and 2 show that this holds across time (although the number of reporting countries in 1992 is far lower than in 2003). Table 2 shows the correlation coefficients between EXPY and GDP per capita in 2003 partitioned into two groups of countries by income. In this table high income countries have GDP per capita greater than $13000.

Country Groups (High income>$13000)	Correlation between GDP PPP per capita and EXPY
High income	0.7256
Low income	0.5405

TABLE 2. CORRELATION BETWEEN EXPY AND GDP PER CAP. BY INCOME GROUP, 2003.

For low income countries it would appear that EXPY is not as influential a factor although it would take at least one growth regression to determine the validity of this. A measure of natural resource intensity of exports to define an "is resource abundant" dummy {=1 for resource export intensity>0.01, = 0 otherwise} is used in an interaction between resource abundance and a dummy for low income. This results in a dummy for low income, resource abundant countries which, when interacted with EXPY yields the marginal effect of resource dependence (RESX) on the explanatory power of EXPY on the level of income. Again it appears that the explanatory power of EXPY is reduced when controlling for resource abundant, low income countries.

Table 3: Cross national income regression

	Dependent Variable: Log GDP per capita (PPP)	
	OLS	OLS
Log EXPY (PPP)	1.9	1.99
	(.1219473)***	(.1191502)***
RESX	-0.031	
	(0.012274)*	
Constant	-11.17	-12.24
	(-1.340225)***	(1.305608)***
Observations	110	110
Adjusted R^2	0.7331	0.7194

* significant at 15% level

** significant at 10% level

*** significant at 1% level

Variation in the explanatory power of EXPY

The pattern of trade which emerges between countries might only reveal the relative capital intensity. Resource abundant countries will export primary resources and capital abundant countries will export high technology capital goods. For high income countries, relative capital intensity usually exceeds relative resource abundance. It is not surprising, then, that a measure of the sophistication of products exported is a good proxy for the structure of the broader economy in capital abundant countries. On the other hand, even fast growing low income countries might be imbued with enough resource wealth that their export baskets reflect only simple commodities. The relative abundance of natural resources can be an indication of a scarcity of capital and retardation in development such as in the case of Nigeria, where the large population is so impoverished that the high levels of oil exports make up a significant portion of the underdeveloped economy[6]. At the other extreme, relative resource abundance might reflect a highly productive mining and natural resource infrastructure such as in Sweden and Norway where more than 40% of exports are in primary products such as timber[7]. Thus EXPY correctly predicts Nigerian underdevelopment while it might understate Australian and Scandinavian productivity. The higher the relative share of resources in exports the greater this understatement might appear which would explain the coefficient of RESX in regression 2 from table3 since low income resource dependent countries can experience resource intensity of exports of up to 80% of GDP. Therefore, taking resource exporters as a single group points to resource abundance reducing income and growth since countries in the former group have higher shares of primary exports and make up the majority of resource exporters.

Growth Hypothesis

The cross sectional growth relationship for the period 1992-2003 and 1994-2003 is a regression of the effect of EXPY at the beginning of the period on cumulative GDP PPP growth. In Hausmann et al (2007), human capital is controlled for and initial GDP is introduced to capture income convergence. Several attempts at replicating these results were made and the tightest fit is show in Table 4 and Table 5, the difference between the 2 being the measure of human capital[8]. It is important to note that the results are very sensitive to the choice of data used, alluding to the possibility of model misspecification.

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[6] At the time of writing the population of Nigeria exceeded Japan's population, yet it had a lower GDP than Egypt (IMF, 2009).

[7] Timber is not strictly a point resource nor is it renewable but the time it takes to regenerate and the volume of wood per tree means that it shares many of the economic constraints typically associated with point resources.

[8] In Table 4 the measurement of human capital is the proportion of the school age population enrolled in secondary schools whereas in Table 5 it is the proportion of the adult population with post-secondary schooling qualifications

The resource curse literature often cites the natural resource sector as a drain on human capital (Sachs and Warner, 1997). Using the model developed in part 1 it was shown that human capital in the resource sector can benefit the broader economy. Bravo-Otega and de Gregorio (2007) shows that for low levels of human capital, resource abundance has a negative effect on growth. However, beyond a certain threshold resource abundance has a significantly positive effect on growth. Therefore

Table 4: Cross national growth regression (1994-2003)

Dependent Variable: Cumulative growth in GDP per capita (PPP) over 1994 - 2003	OLS	OLS
Log Initial GDP per capita	-.20	-.08
	(.494189581)	(.1382249)
Log EXPY (PPP)	.63	.36
	(.2285877)**	(.2823539)
Human Capital		.00028
		(.0055611)
Constant	-5.6	-3.26
	(2.13016)**	(2.744522)
Observations	72	59
Adjusted R^2	0.0803	-0.0093

* significant at 15% level
** significant at 10% level
*** significant at 1% level

Table 5: Cross national growth regression (1994-2003)

Dependent Variable: Cumulative growth in GDP per capita (PPP) over 1994 - 2003	OLS	OLS
Log Initial GDP per capita	.16	-.21
	(.1631811)	(.1958775)
Log EXPY (PPP)	-.06	.33
	(.3345179)	(.4001218)
Human Capital		.0039
		(.0078805)
Constant	-.05	-1.53
	(3.11213)**	(3.889244)
Observations	70	59
Adjusted R^2	-0.0013	-0.0093

* significant at 15% level
** significant at 10% level
*** significant at 1% level

human capital is one possible measure of whether a resource abundant country is on the path to prosperity or not. Instead of controlling for human capital, 2 variables are constructed which are based on the level of human capital. LOWHCX is a dummy for resource abundant countries with low levels of human capital, interacted with the natural log of the initial value of EXPY. HIHCX is a dummy for resource abundant countries with high levels of human capital, interacted with the natural log of the initial value of EXPY[9]. The functional form of the main growth regression is

$$D\ln Y_E = \beta_0 + \beta_1 \ln(Y_0) + \beta_2 \ln(X_0) + \beta_3 L + \beta_4 H \qquad (1).$$

where

> $D\ln Y_E$ = The difference in the logs of GDP per capita (PPP) at the beginning and end of the period,
>
> X = EXPY,
>
> L = LOWHCX,
>
> H = HIHCX,

Subscript 0 denotes the beginning of the period. The main regression in Hausmann et al (2007) excludes the last 2 variables. We expect β_1 to be negative (convergence). β_2 is the effect of EXPY on growth for resource poor countries, regardless of human capital levels. β_3 captures the marginal effect of EXPY in low human capital countries which are resource abundant and β_4 is the marginal effect of EXPY on high human capital, resource abundant countries. The variable L represents countries such as Nigeria, the DRC and Mozambique. The variable H is for countries such as Australia, Sweden, Chile and Brazil. In the former we expect, ex ante, that EXPY correctly predicts underdevelopment whereas EXPY understates income levels in the latter case. The main hypothesis being tested is:

$$H_0 : \beta_1 < 0, \beta_2 > 0, B_3 \geq 0, \beta_4 < 0$$

Table 6 shows growth regressions for the base years 1992 and 1994. The results lend support for the main hypothesis to the extent that the signs are correct but the significance varies greatly depending on both the source of human capital and income

[9] Details on the construction of LOWHCX and HIHCX can be found in the Appendix to this section.

data. The appendix contains a summary of various permutations of this regression as well as the list of countries in the specification contained in Table 6.

Table 6: Growth regressions with differentials for resource abundant countries

	OLS(dependent variable: GDP per capita(PPP) over 1994-2003)	OLS(dependent variable: GDP per capita(PPP) over 1992-2003)
Log Initial GDP per capita	-.15	.18
	(.1019543)	(.1626292)
Log EXPY (PPP)	.46	-.15
	.2139369	(.3402198)
LOWHCX	.02	.02
	(.0078614)***	(.0138134)
HIHCX	-.03	-.01
	(.0191622)**	(.0459715)
Constant	-3.8	.81
	(2.004105)**	(3.219789)
Observations	72	70
Adjusted R^2	0.2321	0.0135

* significant at 15% level

** significant at 10% level

*** significant at 1% level

Discussion on Growth results and data availability

The findings of Hausmann et al (2007) are surprisingly sensitive to the choice of human capital data. The availability of human capital data is also strongly correlated with income, depending on the chosen definition. The most representative data set in this analysis was the measure of completed secondary schooling from the WDI database (WDI). Nonetheless, the non-reporting on all forms of human capital in many countries (as well as GDP per capita PPP in a few) severely restricts the analysis further especially since the outcomes of low income countries is central to the hypothesis[10]. While there is plenty of detailed and anecdotal evidence of individual cases of resource oriented knowledge intensification (see Lorentzen, 2008; Wright and Czelusta 2007; Blomström and Kokko, 2007; Maloney, 2002; Atkinson and Hamilton ,2003, Papyrakis and Gerlagh, 2002), a far more representative survey which does not suffer from this selection bias is needed before robust relationships can be tested.

Tellingly, the results of the growth regressions were more robust under the altered specification which separated resource abundant countries into 2 groups than for the default Hausmann et al (2007) specification. Better data are needed to confirm this finding. For now the hypothesis cannot be rejected but the data is also far too income-biased to be able to draw robust conclusions. Future research is needed with emphasis on obtaining a representative set of data for all levels of income and from that a useful proxy for human capital.

[10] See the Appendix for a brief discussion on the problems with measuring human capital.

Conclusion

Contemporary resource curse literature tends to group primary commodity producing countries into one camp of overdependence and sclerosis. This works empirically, partly because the successful resource abundant countries constitute a minority, but it also risks amplifying developmental bias against resource dependence. What this paper has shown firstly is that capital intensity of exports is a poor proxy for overall capital intensity and that the primary/secondary production paradigm is inappropriate for nations which invest significant resources in the extraction and exploration of primary resources which are exported as final goods in an elaborate mineral-industrial value chain.

Growth regressions illustrating the negative impact of resource abundance are therefore made more robust when the successful resource abundant countries are separated out as a group. Although the quality of the data is compromised by the fact that reporting is correlated with income, the results of the above analysis tentatively suggest that resource abundant countries are in fact comprised of two distinct groups, one low income, low growth characterised by all the symptoms of the resource curse such as the Dutch Disease; and the other, vibrant and dynamic, demonstrating that resource intensity of production is at the core of industrial and innovative strategy. The key theoretical conclusion for innovation policy is that resource abundant countries characterised by sclerotic growth may not suffer from suboptimal levels of innovation driven by commodity market failures. Instead the key market failure may in fact arise from secondary sector oriented industrial policy which distorts the allocation of human capital across the primary and secondary sectors. Policy makers which choose the secondary sector over the primary sector as an ameliorative strategy to the resource curse may in fact be compounding the symptoms of the curse.

References

1. Atkinson, G. and K. Hamilton. 2003. "Savings, Growth and the Resource Curse Hypothesis", World Development Vol 31, No. 11, pp. 1793-1807, www.elsevier.com/locate/worlddev

2. Blomström , M. and A. Kokko. 2007. "From Natural Resources to High-Tech Production: The Evolution of Industrial Competitiveness in Sweden and Finland", ", *Natural Resources: Neither Curse Nor destiny, pp. 183-212, The International Bank for Reconstruction and Development / The World Bank, 2007.*

3. Claudio Bravo-Ortega, C. and de Gregorio, José. 2007. "The Relative Richness of the Poor? Natural Resources, Human Capital, and Economic Growth, *Natural Resources: Neither Curse Nor destiny, pp. 183-212, The International Bank for Reconstruction and Development / The World Bank, 2007.*

4. Hausmann. R, J. Hwang and D, Rodrik. 2007. "What you export matters.", Journal of Economics: Growth (2007) pp. 12:1–25, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA

5. Hidalgo, C.A., B. Klinger, A.L. Barabasim R. Hausmann. 2007. "The Product Space Conditions for the Development of Nations.", *Science 317, 482, vol. 317. American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005*

6. IMF. 2009. "Nigeria: 2009 Article IV Consultation-Staff Report; Staff Supplement; Public Information Notice on the Executive Board Discussion; Statement by the IMF Staff Representative; and Statement by the Executive Director for Nigeria", *International Monetary Fund, Publication Services 700 19th Street, N.W. Washington, D.C. 20431 Telephone: (202) 623-7430 Telefax: (202) 623-7201 E-mail: publications@imf.org Internet: http://www.imf.org*

7. Lorentzen, J. 2008. "Knowledge intensification in resource-based economies". Resource Intensity, Knowledge and Development Insights from Africa and South America.
8. Maloney, William. 2002. .Innovation and Growth in Resource Rich Economies. Mimeographed. Office of the Chief Economist for Latin America and the Caribbean, The World Bank, Washington, DC.

9. Penn World tables, Centre for International Comparisons at the University of Pennsylvania, University of Pennsylvania 3718 Locust Walk Philadelphia, PA 19104-6297 (215) 898-7624

10. Smith, A (1776). "The Wealth of Nations". Oxford. Clarendon Press, 1976.

11. WDI. World Development Indicators. *World Bank, http://data.worldbank.org/data-catalog/world-development-indicators*

12. Wright, G. and J. Czelusta. 2007. "Resource based growth: past and present", *Natural Resources: Neither Curse Nor destiny, pp. 183-212, The International Bank for Reconstruction and Development / The World Bank, 2007.*

Appendix

Construction of PRODY

Let goods be indexed by *i* and countries by *j*. Then the relative weight by value of good *i* in country *k*'s export basket can be denoted by r_{ij} . Let the total level of exports and the per capita GDP in country *j* be denoted by X_j and Y_j respectively. For a given product, the level of implied productivity can be given by

$$\mathrm{PRODY_i} = \sum_j \frac{r_{ij}}{\sum_j r_{ij}} Y_j \,.$$

This relative weight of a particular good is weighted by its relative size internationally. That is, for a country *j* with a higher proportion of a particular product in its export basket than country *k* (*k≠j*), good *i* will be weighted more strongly by country *j's* income than by country k, regardless of the relative size of each country's economy. PRODY will thus provide an index measure for goods according to the weighted relative income of the countries which export it. PRODY can be used to calculate the overall implied productivity of the export basket for country *j*.

$$\mathrm{EXPY_j} = \sum_i [(\frac{x_{ij}}{X_j})\mathrm{PRODY}_i] \,.$$

where x_{ij} is the value of exports of good *i* in country *j*. The PRODY for each good in a country's export basket is weighted by its relative share in total exports. The sum of these weighted PRODY's gives the weighted implied productivity of the export basket, EXPY.

Table A1: The significance of explanatory variables in the main growth regression

	|P|>t				R^2
	Log(initial GDP per capita PPP)	Log(initial EXPY)	HIHCX	LOWHCX	
High school Complete	0.1	0.01	(dropped)	0.02	0.1751
High school Complete	0.124	0.035	0.001	0.071	0.2754
High school Complete	0.086	0.025	0.06	0.16	0.1767
Enrollment in high school	0.101	0.013	0.007	0.901	0.2012
Tertiary	0.109	0.017	0	0.905	0.2605
Tertiary	0.092	0.016	0.001	0.719	0.2583

The difficulties of measuring human capital

Typical measures of human capital make use of national education statistics. This is known as the input approach as it does not reflect productivity in any way since both the educational standards of countries vary and the productivity of different classes of skilled workers vary from one country to the next. In some countries such as Austria, relative levels of tertiary educated workers are similar to that of developing countries, yet Austria has very high income levels. This discrepancy is explained by the system of vocational training which is very prevalent in Austria and Germany but which does not show up in tertiary statistics.

Calculation of HIHCX and LOWHCX

The first step is to calculate RESX a measure of natural resource intensity of exports. This was calculated as the total value of primary commodities excluding agriculture and fishing as a ratio of GDP.

Secondly, a dummy for resource abundance was constructed where RESX>0.01 (or resource exports comprised more than 1% of the entire economy). Let the dummy be denoted by D_R. Finally, human capital dummies were constructed for high and low human capital endowed countries. The thresholds chosen varied depending on the definition. These dummies were H_c and L_c for high and low human capital countries respectively. Then,

$$H_{cx} = H_c D_R X$$

and

$$L_{cx} = L_c D_R X$$

where H_{cx} represents HIHCX and L_{cx} represents LOWHCX. X represents EXPY.

<u>List of Countries in the cross national growth regression in Table 6 of section 3 in part 2.</u>

1	Albania
2	Argentina
3	Australia
4	Austria
5	Bangladesh
6	Barbados
7	Belgium
8	Belize
9	Benin
10	Bolivia
11	Bosnia and Herzegovina
12	Botswana
13	Brazil
14	Bulgaria
15	Burkina Faso

16	Burundi
17	Cambodia
18	Cameroon
19	Canada
20	Central African Republic
21	Chile
22	China
23	Colombia
24	Costa Rica
25	Croatia
26	Cuba
27	Cyprus
28	Czech Republic
29	Denmark
30	Dominica
31	Dominican Republic
32	Ecuador
33	El Salvador
34	Estonia
35	Fiji
36	Finland
37	France
38	Gabon
39	Georgia
40	Germany

41	Ghana
42	Greece
43	Guatemala
44	Guyana
45	Honduras
46	Hungary
47	Iceland
48	India
49	Indonesia
50	Ireland
51	Israel
52	Italy
53	Jamaica
54	Japan
55	Jordan
56	Kenya
57	Latvia
58	Lebanon
59	Lesotho
60	Lithuania
61	Luxembourg
62	Madagascar
63	Malawi
64	Malaysia
65	Mali

66	Malta
67	Mauritius
68	Mexico
69	Moldova
70	Mongolia
71	Morocco
72	Mozambique
73	Namibia
74	Netherlands
75	New Zealand
76	Nicaragua
77	Niger
78	Pakistan
79	Panama
80	Paraguay
81	Peru
82	Philippines
83	Poland
84	Portugal
85	Romania
86	Samoa
87	Sao Tome and Principe
88	Senegal
89	Seychelles
90	Slovak Republic

91	Slovenia
92	South Africa
93	Spain
94	Sri Lanka
95	St. Lucia
96	Suriname
97	Swaziland
98	Sweden
99	Switzerland
100	Tanzania
101	Thailand
102	Togo
103	Tunisia
104	Turkey
105	Uganda
106	Ukraine
107	United Kingdom
108	United States
109	Uruguay
110	Zambia