


Employment-oriented Industry Studies

Innovation in Resource-based Technology Clusters: Investigating the Lateral Migration Thesis

Knowledge Intensification in Resource-based Economies, Technological Learning & Industrial Policy

Prof J. Lorentzen

February 2006

HSRC
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employment growth & development initiative
innovative employment strategies

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Jo Lorentzen

Education, Science and Skills Development Research Programme (ESSD)

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science & technology
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Contact: Dr Miriam Altman, Executive Director: EGDI – HSRC

E-mail: maltman@hsrc.ac.za

Tel: +27 12 302 2402

Contents

List of tables

List of figures

1 Introduction

A number of questions that are salient for economic development in South Africa and elsewhere motivate this study.

- Does resource intensity hold back growth?
- Is it possible to reconcile resource intensity with the knowledge economy?
- Which lessons do theory and history hold for economic policy in resource-based economies?

If the answers to these questions were, respectively, "yes", "no", and "none", this study would be bad news indeed. But the answers suggested in this report are no reason for concern. In short, high growth trajectories are possible in countries with intensive resource endowments. In addition, economies can excel contemporaneously in resource extraction and in the creation of the intellectual capital at the heart of the knowledge economy. Finally, new developments in our understanding of the determinants of technological learning, plus what went on in the past in countries as diverse as Argentina, Australia, Costa Rica, the US, or Sweden, do bear lessons for resource-based countries today.

To be sure, resource intensity is not a guarantee for economic development, either. What matters is how resource intensity is being exploited. This study contributes to the discussion in two novel ways. The first is the focus on technological trajectories that start in or around resource-based activities and subsequently become more knowledge intensive. Hence the study traces forward linkages. It thus shows the direct contribution resource-based activities make to the knowledge intensification of the economy at large. In other words, it analyses the co-evolution of resource- and knowledge-intensive modes of production. Much – though not all – of the relevant literature merely looks at the co-existence of the two.

The second is the attempt systematically to compare technological trajectories in an African economy with those in a few Latin American economies. The similarities are obvious. In both regions, the rich natural resource endowments to this day determine what they export. Long episodes in their recent economic history have been marred by low growth in the presence of vast mineral and other riches. Much thinking has gone into probing the reasons for this. But while the Latin American experience has been subject to many comparative case studies, this is much less true for Africa. In addition, many analyses are subject to a didactic bias that contrasts successful examples of catch-up (for example, many East Asian economies in the absence of resource endowments) with failures of underdevelopment (Latin America despite its incredible riches), or resource achievers (for example, Australia or Scandinavia) with resource underachievers (Argentina and Brazil).

By contrast, this study concentrates on countries that are customarily lumped together in the failure category. It analyses examples of technological learning not all of which had necessarily been successful – in terms of their net present value – at the time of writing. Some cases are successful, others are not, and for some it is too early to tell. But they all exemplify technological learning. Since it is possible to learn from mistakes no less than from successes, this study therefore analyses, what works (not), and why, and whether insights from a collection of case studies can inform a broader policy discussion about how best to reconcile the demands of the knowledge economy with intensive resource endowments.

This paper introduces and summarises the study and sets it in context. Section 2 introduces the problems of resource-based development. It briefly surveys the relevant theoretical literature and combines it with select insights from the economic history of resource-based economies. Section 3 presents data that show that South Africa has had problems in reconciling resource exploitation with more knowledge-intensive, higher-growth activities. It also introduces earlier attempts by South African researchers at Mintek and the HSRC to conceptualise what they saw as a feasible way out of a dependency on non-renewables in the form of "lateral migration". Together these two sections thus establish the relevance of this kind of research. Section 4 discusses key tenets of technological learning, the role of foreign technology, linkages and interactions, and industrial policy that inform the analysis. Section 5 introduces six incidences of technological learning from four countries – Brazil, Costa Rica, Peru, and South Africa – and presents the methodology. The analysis follows in Section 6 and Section 7 concludes with suggestions for further research.

2 Resource-based development: an update on the resource curse hypothesis

This section first reviews the crude case against resource-based development. It then introduces a more nuanced view based both on theory and historical examples.

The crude case goes as follows. Countries with abundant natural resources are allegedly afflicted by the "resource curse" which says that sitting atop a mountain of, say, gold spoils one's character and for all sorts of reasons stunts one's growth prospects. Adam Smith, for one, is on record for having warned his contemporaries against sinking their investments down mine shafts (1776, 562). In recent times it was Sachs' and Warner's study that attributed low growth performance to resource intensity (1995). International organisations such as UNIDO profess an explicit bias in favour of the secondary sector because it allegedly offers a higher productivity potential and income elasticities than anything the primary sector produces (2005).

Not everybody agrees with this assessment. Smith found his match in heavyweights such as Douglass North (1955) and Jacob Viner (1952) who disputed that there was anything intrinsically inferior in mining iron ore or growing apples as opposed to making toothbrushes. One critique of the influential study by Sachs and Warner (1995) noted that because its observations fall into a period of debt crisis and structural adjustment that Latin Americans customarily refer to as their "lost decade", it is not obvious that resource intensity was the major culprit of low or negative growth, much less since a comprehensive understanding of what went wrong in Latin America would need to look at political economy issues that have nothing to do with resource intensity as such (Maloney 2002). And newer research (Martin and Mitra 2001) questions the interpretation of the very data that was the basis for Prebisch's (1959) old indictment that secular declines in their terms of trade would militate against the emancipation of Latin America and cement its dependency on the core industrial countries, many of which were – to add insult to injury – former colonial masters. He may have been right for Latin America at that particular historical juncture, but the generalisability of his view to all resource-intensive economies is doubtful.

Whatever people think about the significance of the resource curse, there is agreement that the logic behind it is a combination of bad luck and bad policies. The geological make-up of the earth's land mass and the volatility of commodity prices are a case of bad luck. By definition, bad luck falls outside the ambit of rational policy intervention which is why all one can do is lament destiny's injustice for having been dealt a lousy hand of cards. It is worth pointing out the paradox of associating bad luck with possessing something of value. The resource curse only becomes a valid argument when the lure of, say, gemstones leads to perverse incentives. This brings policy into the picture.

If in reaction to a mineral boom more workers are sent underground to work in the mines and ruin their health instead of using the windfall to invest in education so that their children do not need to follow in their parents' footsteps by pursuing more productive and less hazardous careers, governments can be faulted for having made the wrong decision that favours short-term gains over long-term, sustainable development. Of course, the allure of the rentier economy lies exactly in the luxury of availing oneself of economic policies that in the absence of booming resources would never be sustainable in the first place. To be sure, this is attractive only to the beneficiaries of a predatory state, Mobuto-style, but not to the majority of the population that suffers the consequences of corruption, inequality, and essentially a barren future (Deaton 1999).

Among the better-known facets of the resource curse is the Dutch disease phenomenon. It kicks in when resource booms cause a real exchange rate appreciation that lowers the competitiveness of manufactures and other tradables. If the returns to manufacturing are higher than those available from resource exploitation, or if they could be higher insofar as technological upgrading may cause dynamic efficiencies, then the happy-go-lucky illusion that one can have one's cake and eat it, positively harms development prospects.

Having said this, the resource curse is perplexing for development practice. Surely the solution to the dangers inherent in resource riches cannot be to ignore these endowments, especially if, as in large parts of Africa, they are for the time being the only comparative advantage countries possess (Deaton 1999). The good news is that over the last ten years or so – since Sachs' and Warner's (1995) paper rekindled the debate – theoretical advances and new empirical research significantly improved our understanding of how, and why, resource intensity impacts on economic development.

In short – and this is as intuitive as the resource curse hypothesis was counterintuitive – what counts for growth is not the relative abundance of natural resources in and of itself, but what one does with it (Gylfason 2001b). The often used comparison of resource-rich countries in Africa and Latin America with generally resource-poor but high-growth countries in Asia makes sense insofar as it highlights that countries without natural resources have no choice but to invest in human capital. By contrast, education may seem a waste of time and money in the Lands of Milk and Honey. Hence, resource-rich countries have a larger margin for error for unsustainable economic policies. As countless examples from A(rgentina) to Z(aire) illustrate, this is clearly a blessing in disguise (cf. Gylfason 2001a).

But although the rise in crude prices over the last few years is reason for concern as to whether or not oil-producing countries awash in cash have learnt lessons from history (e.g. Shaxson 2005), it is important to differentiate between success stories and failures. Not all societies with riches under their feet have bitten the dust. It is also important to analyse the transmission channels of the potentially negative effects of resource-based development. For example, natural resources seemingly do contribute positively to growth if one controls for the usual suspects of bad governance, bad policies, and bad institutions (Papyrakis and Gerlagh 2004, see also Neumayer 2004). Put differently, the combination of natural resource abundance, sound macroeconomic policies, and economic policies aimed at generating high savings rates and productive investments, can work very well (Atkinson and Hamilton 2003).

It is certainly easier to explain the uncontroversial successes of resource-based industrialisation with this more open interpretative framework. Thus, the relatively more successful exploitation of mineral resources in the context of economic development in the US compared to Latin America had nothing to do with the quality of those resources that, if anything, were often better in Latin America. The key difference lies in the nature of the learning process that more or less promotes the economic potential of these resources (Wright 2001). What mattered was that the US applied its capabilities from exploration all the way to advanced utilisation in the mineral economy which is why the mineral sector became part of its knowledge economy. Latin America, by contrast, for a long time did not make much of its location-specific knowledge of the resource sector; thus, it was not subject to learning and upgrading (Wright and Czelusta 2004).

A comprehensive analysis of the reasons behind the relative backwardness of many resource-rich economies in different parts of the world would require a historical treatment that is beyond the scope of this study (cf. Landes 1998). A commendable project undertaken by a group of researchers at the World Bank compared the relative failures of Latin American economies with the relative successes of similarly endowed countries such as Australia, Canada, the US, Sweden, and Finland (de Ferranti et al. 2002). In short, it blamed the Spanish and Portuguese colonisers for introducing an anti-progress bias in their dependencies. Hence, initial conditions were anything but ideal. While their contemporaries in other emerging economies were busy building industries, Latin Americans had not yet finished their task of building nations. In addition, the highly unequal distribution of wealth, land, financial capital, and education militated against the establishment of dynamic, innovative societies. Since education was significantly less technically oriented than elsewhere, both active and passive technical capacities were severely compromised. Import-substituting industrialisation thus built on an incomplete and imperfect edifice, and this is an important factor behind many of its spectacular failures (ibid, Chapter 3).

In sum, in the past resource intensity has been less than fortuitously matched with economic development in Latin America than in similarly endowed countries. But a more differentiated picture emerges when looking at the recent history of Latin America. To be sure, the region still has its fair share of basket cases. But it also has very successful examples of economic development across a range of activities that include and go beyond traditional activities: fruits and salmon in Chile, electronics in Costa Rica and Mexico, or tourism in the Caribbean. According to the World Bank report, these experiences have in common that countries exploited their natural resources as well as their locations making use of new technologies and knowledge to improve their production processes. Technology and knowledge may be embodied in foreign direct investment, but it will also be generated by domestic institutions and rely on investments in ICT infrastructure. Ultimately, intelligent policies aided the transformation of natural-resource-based activities into knowledge-intensive assets (ibid, Chapter 4).

Intelligent policies are those that help build the endowments that underlie the knowledge economy – in education and training, support for R&D and innovation, an accessible (ICT) infrastructure, and good institutions more generally (ibid., Chapter 1).

In sum, this brief review of the literature suggests that, first, rich resource endowments may, but need not, slow growth. Hence, for countries with this characteristic, there is no reason to sulk. Second, like other (developing) countries, resource-rich economies must diversify their economies in order to obtain higher and sustainable growth. In this endeavour they face many of the same obstacles that bedevil resource-poor countries, namely the inherent risks and uncertainties of investments in innovative activities that are behind restructuring and productivity growth. The rise of the knowledge economy tends to up the ante on risks and uncertainties. In short, technological, information, and coordination externalities militate against the pursuit of diversification through restructuring by lonely entrepreneurs. This insight motivates interest in industrial policy in general (cf. Rodrik 2004) and more specifically has inspired reflections in Latin America how to move from resource intensity to more knowledge intensive activities (De Ferranti et al. 2002, Ramos 1998).

The major difference between the literature reviewed here and the present study lies in the treatment of traditional factor endowments such as resources and new endowments such as human capital. Much of the literature looks at their co-existence. Perhaps it asks how gains from a resource-based activity can be invested to support the emergence of another activity. That is why in the Costa Rican case we hear a lot about electronics but nothing about coffee – obviously there are no direct linkages between these two activities.

But restructuring and diversification in resource-rich economies are likely to take specific forms insofar as they at least in part happen on the back of related and input industries that supply resource-based sectors with goods and services. Although there is a global knowledge base for mining, agri- and aquaculture, or forestry, specific local circumstances will often ask for specific local solutions. This may mean that the local knowledge base around resource exploitation is deeper than in other parts of the economy. For example, a country with an important share of intensive animal husbandry in the economy would benefit from vets that know about how to keep large numbers of pigs relatively healthy even though they live under unnatural conditions, as opposed to vets who specialise in the psyche of Chihuahuas that do not cope with life in the wrong corner of their owner's couch. Everything else being equal, the depth of knowledge around – upstream and downstream – the resource economy is such that it may spur technological learning that starts in but does stop with a resource-based activity. This insight motivates the interest in the co-evolution of resource- and knowledge-based activities through technological trajectories that link one with the other, and if and how industrial policy may complement it.

3 Resource intensity and knowledge: old and new economy in South Africa

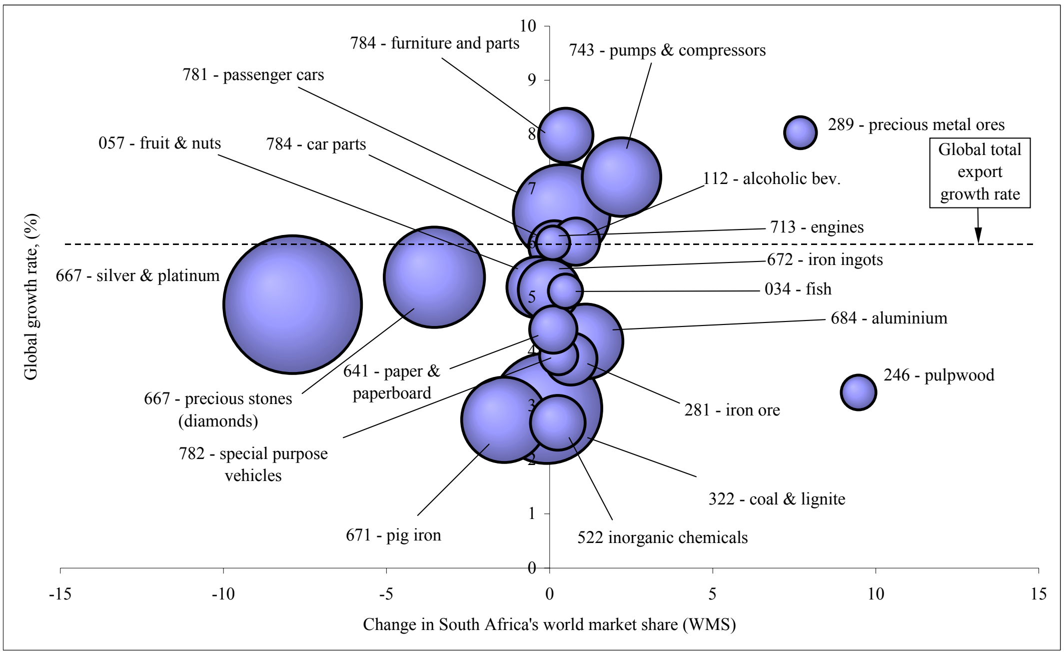
All is not well with South Africa's knowledge economy. The country's export composition is primarily resource-based and diversification into fast growing export sectors is much less visible than in comparable countries. This is a problem insofar the country's total export growth in the 1990s, at two per cent per annum, lagged that of the world and of similarly endowed countries.[1] The main reason for this is the decline

[1] The "resource group" includes 25 economies from Sub-Saharan Africa and Latin America plus Australia, New Zealand, Indonesia, Morocco and Norway.

in exports of primary products. Consequently, South Africa's overall share of world exports fell from 0.89 per cent in 1988 to 0.52 per cent in 2002 (Edwards and Alves 2005). A similar trend holds for aggregate manufacturing where South Africa's annual growth rate trailed that of developing countries in general and resource-intensive economies as well. This was particularly pronounced in high-technology products.

One way to look at the optimal or otherwise positioning of a country's exports in terms of global demand is to compare its share in those products that account for most of the dynamism in world trade. More precisely, a country is well positioned if its world market share in dynamic products is rising. Put differently, an export specialisation in products with a below average growth rate suggests a suboptimal positioning. Figure 1 shows that South Africa exports relatively few products in which its world market share is rising and which simultaneously record above-average growth. In fact, the top right quadrant is relatively sparsely populated, accounting for only 13 per cent of total exports. By contrast, most exports – 43 per cent of the total – take place in product groups for which world demand is falling (ibid.).

Figure 1 - The market positioning of South Africa's top 20 exports, 2002



Note: Dotted line is world growth for all products. WMS changes are expressed as percentage points.

Source: Edwards and Alves (2005, 19)

South Africa is in good company with this not so good performance. The resource group fared similarly (see Figure 2). East Asia's performance, by contrast, is very different (see Figure 3). This analysis does not resuscitate the resource-curse hypothesis in its crude form. But it does show that a high concentration of exports in primary and natural resource-based products was associated with a below-average export growth rate in the 1990s. This is surely one of the reasons that motivated this study in the first place.

The other reason is promoted by analysts associated with South Africa's Mineral Technology Research Council, Mintek, and the Human Sciences Research Council (HSRC). It has found its way into policy discussions, albeit not into the literature. In a nutshell, the argument goes as follows.

Many natural resources are finite. Therefore activities such as mining are ultimately unsustainable. For this reason resource-based economies need to think about a way out, lest they lose their own sustainability. One possibility suggested by the Mintek and HSRC analysts is to exploit the frequently deep knowledge base associated with sophisticated resource sectors such as mining in South Africa. The knowledge base resides not just in mining proper but also in the capital goods and services sector that developed around it. When these knowledge assets are applied in other sectors that are not linked to resource exploitation, new development trajectories become feasible. The Mintek and HSRC experts named this process "lateral migration".

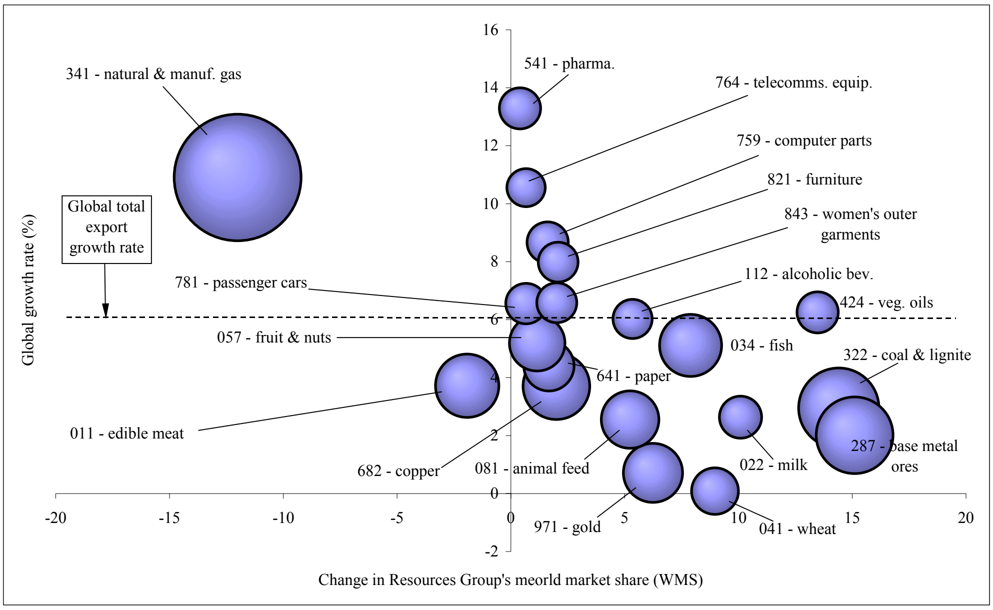
The derivation of the idea of lateral migration is problematic but the concept is nonetheless very interesting. It is problematic because it treats natural resources as a factor fixed by nature. While this is true in the very long run, it is of course not correct that natural wealth is fully exogenous. How much economically useful coal or oil a country has is itself a function of its ability to search for and then extract reserves.

This ability, in turn, depends on the technological capability of the country and especially the concerned sectors. Put differently, what you have depends not just on what lies underground but on how smartly you go about looking for and extracting value from it.

But this should not detract from the important insight associated with lateral migration, namely that resource-based and knowledge-intensive activities may co-evolve. To underline the point, if a country taxes certain old economic activities and provides incentives for perceived new economic activities, resource- and knowledge-intensity may co-exist, but there would be no linkages between the two. Although historical experience shows that select countries have indeed succeeded to create certain competences ex novo, it is obviously easier to think about – and steer – economic development in an evolutionary fashion whereby the accumulation of knowledge is gradual and continuous, and where the challenge hence consists in creating and sustaining linkages that build bridges between the resource and the knowledge economy.

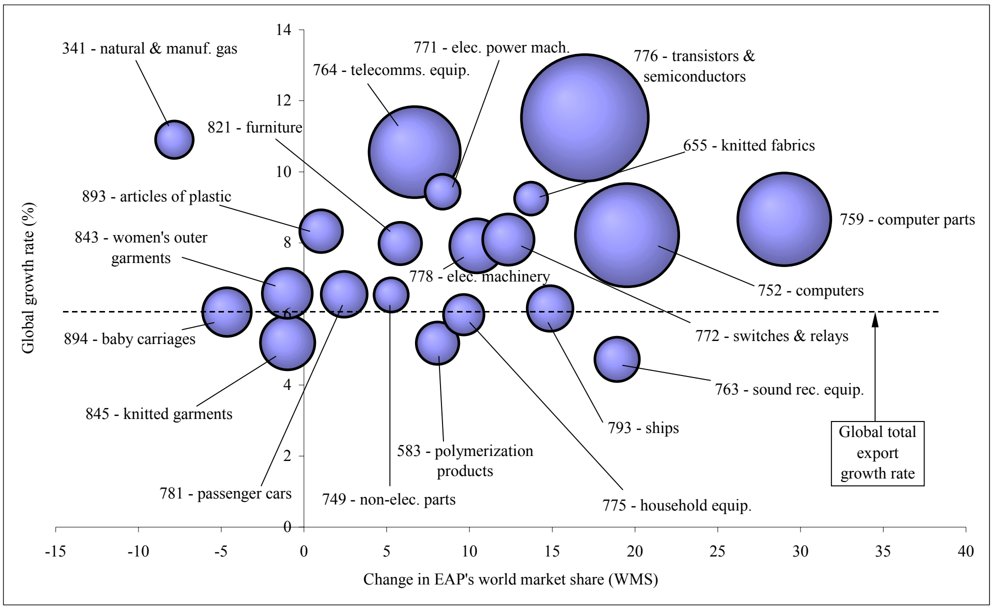
Not all case studies in this report are examples of lateral migration. Some illustrate downstream beneficiation, and others more or less stop with the development of input industries. Not all cases are successful, either, in the sense of fully commercialised technologies; a few are ongoing activities with relatively uncertain outcomes. But they all exemplify co-evolution through linkages. By the same token, they demonstrate how the resource economy can be part of the knowledge economy and vice versa. The strength of the linkages and the relative success of the technological trajectories depend on a series of factors that need systematic analysis. The next section prepares the ground for this.

Figure 2 - Market positioning of the resource group's top 20 exports, 2002



Note and source: see Figure 1.

Figure 3 - Market positioning of East Asia's top 20 exports, 2002



Note and source: see Figure 1.

4 The determinants of knowledge intensification of resource-based activities

The literature on resource-based growth essentially draws on two different but complementary sources. The first is economic history. It explained, for example, how comprehensive mining innovation systems in the US or Australia led to vibrant manufacturing industries. The second is a growing body of economic theory that explains growth and development as a function of a country's ability to learn and build up capabilities through investments in human capital, good institutions, and infrastructure. The best work combines the two in theoretically informed, comparative historical analyses.

This study looks at instances of technology development, both failed and successful, and tries to draw out what made them tick. This leads to insights in their own right and contributes to the literature on knowledge industries based on natural resource-based activities. But insofar this literature is still emerging this study is also partially inductive. It formulates propositions that can be put to further scrutiny in future work. It is the combination of the two that allows making recommendations regarding what policy might do and what it should avoid in contributing to economic diversification based on, but moving away from resource sectors.

In addition to the literature on the resource curse referred to above, four related bodies of knowledge inform this study – absorptive capacities or learning, technology transfer and diffusion, systems of innovation, and industrial policy. First, firms engaged in technological upgrading learn insofar they make use of external knowledge to modify existing or create new technologies. In both cases investments in R&D are important because they help generate new information and because they promote learning. In this perspective, learning is not by-doing but the outcome of a purposeful search for external knowledge to be selected, internalised, and exploited (Cohen and Levinthal 1989, 1990).

Spending on R&D will tend to relate to the characteristics of industry-specific technological and scientific knowledge. The more difficult to assimilate this knowledge, the more firms will spend on R&D. Likewise, the less overlap between a firm's needs and outside knowledge, the more R&D is needed to compensate for the gap through in-house efforts.

Absorptive capacities result not only from R&D (both current and the prior accumulated stock of knowledge) but also as a by-product of manufacturing operations (in the sense that involvement in the latter allows firms to recognise and exploit new information relevant to a product market). They also result from advanced technical training.

Absorptive capacities also influence the level of aspiration of an organisation. Thus, firms with deep absorptive capacities are more likely to recognise emerging technological opportunities. When the knowledge to be exploited is closely related to the firm's existing knowledge base, absorptive capacities can be a by-product of routine activity. By contrast, when that is not the case, it must be created. Finally, absorptive capacities only become "realised" when the assimilated knowledge is commercialised – until then they are merely "potential" (Zahra and George 2002).

Second, insofar the relevant external knowledge is of foreign origin, the key question is how and to what extent technology import and indigenous investments complemented each other (Blomström and Kokko 1998, Lall 1993, Pack and Saggi 1997). On the one hand, with more capable buyers foreign firms have less need to internalise technology transfer through FDI. On the other hand, higher buyer capability also translates into a stronger competitive threat, thus increasing the need for control, especially over the foreign firm's advanced technological assets. It is important to understand if the local firm had the option among a series of technology imports (e.g. license, JV, equity), and if and why it exercised its choice.

Third, learning is embedded in a knowledge infrastructure and takes place in interaction with consumers and producers of knowledge in the private and public sector, including those from outside the country (e.g. Bell and Pavitt 1993, Lall 1993). Thus, once the absorptive capacity of the firm from which the lateral migration technology originates and the nature of the external (foreign) technology input are understood, the focus turns to linkages between case firms and all other actors that matter, in industry, government, academia, and perhaps civil society. The study thus shares with the literature of the national systems of innovation (NSI) a recognition of systemic dynamics and attention to linkages and interactions. But since this study moves from micro to macro, there is no need to describe all institutions that make up the national innovation system (cf. Edquist 1996, Lundvall 1992, Nelson 1993). Instead the focus is on those that matter directly or indirectly (i.e. through skill provision) to the technology at hand.

Finally, innovative activities are subject to externalities that governments may or may not alleviate (e.g. Rodrik 2004, UNIDO 2002). In this instance this refers to specific combinations of investments in science, technology, and innovation on the one hand and requisite policy frameworks on the other that drive innovation and the adoption of technologies.

The reason for drawing on a wide range of literature is not to advance a hotchpotch of theoretical eclecticism. But in order to investigate if there is a pattern to the knowledge intensification of resource-based industries, it is important to understand what internal resources and external knowledge firms draw on, regardless of the purposeful or accidental nature of their technological enquiry. We must also understand the nature and the weight of the contribution of other actors and institutions of the system of innovation to which the firms belong. And finally, we must understand how they individually or collectively overcame disincentives to innovation associated with market failures in technology, information, and coordination. Finally, the analysis of the attendant processes must be embedded in a description of the resource base – including the possible negative impacts it has – from which they took off.

5 Methodology and data

The research is based on six case studies from the two most resource-intensive developing regions in the world, namely Latin America and Africa. Field work took place in the second half of 2005. Each case study team was asked to address a core set of questions in semi-structured interviews (see Table 1). These questions derive from the literature discussed in Section 4 and provide a common framework that allows for systematic comparability.

In the interest of analytical clarity it is important to weigh these groups of questions carefully. A morphological account ending in a conclusion whereby everything is related to everything else does not serve the ultimate aim of this study which is to figure out if there are lessons from these experiences that suggest where and how government might harness the positive aspects while minimising those that are negative. At a minimum, this calls for the differentiation of principal and marginal factors. It was important for case study researchers to construct counterfactual scenarios and have them assessed and triangulated by interviewees with different biases and perspectives on the question at hand.

The case studies are profiled in Table 2. Three originate in agriculture and three in mining. All involve a private-sector firm and many count firms and academic or scientific institutions among their key entities. Some are of rather recent vintage; others go back more than 30 years. Most projects have reached their narrower research objectives but only half have managed to produce commercially viable goods or services. This does not imply that all others are failures; some projects are ongoing and may yet manage to commercialise the object of their endeavours.

The remainder of this section briefly summarises key features of the six cases. It also charts the underlying technological trajectories using the terminology developed by Mintek and the HSRC.

5.1 Sugar-based plastic in Brazil

Brazil is the world's largest producer and exporter of sugar. In response to rising crude prices in the 1970s, Brazil started producing alcohol from its sugar cane for use as a blend in car fuels. Since that time the country has also run a R&D programme aimed at finding alternative sources of alcohol and increasing the efficiency of sugar production, building up substantial expertise in this area. From the late 1990s, a drop in world sugar prices combined with a lower ethanol demand due to lower crude prices plus a gradual liberalisation of the Brazilian economy led to much idle capacity in the industry. This provided the context within which the idea of producing biopolymers was first discussed. Biopolymers help reduce reliance on fossil fuels and also diminish the production of industrial and household waste. They thus have a series of desirable features. Initial discussions involved the Technology Center (CTC) of the sugar and alcohol industry association in the State of São Paolo, COPERSUCAR, the Institute for Technological Research (IPT), a state government-funded research institute, and the Institute of Biomedical Sciences of the University of São Paolo. The partners had previously collaborated in sugar-related research (see Chapter 2 by Velho and Velho, in this report).

Table 1 - Questions for semi-structured interviews

Perspective	Questions
Absorptive capacities or firm learning	▪ Nature of the technology and the resource base from which it originated ▪ Nature of the new application and industry into which the technology migrated ▪ Determinants of cumulative and present absorptive capacities (role of R&D spending, share of R&D spending in turnover over time, advanced technical skills, manufacturing operations (if applicable) ▪ Origin of the LM technology (blue sky, reverse engineering, licensing, involvement in global knowledge flows through scientific or other forms of cooperation, etc.) ▪ Problems with any of the above: nature and cause
The role of foreign technology	Did foreign technology inflows ▪ enhance incentives for innovation ▪ diminish them because they obviated the need for indigenous generation of technology ▪ mattered only in terms of content or also with respect to the transfer mode ▪ benefit from strong/weak IPRs?
Linkages and interactions	▪ What is the nature of the embeddedness of the innovating firm in a system of innovation (suppliers and customers, education and training providers, science institutes, sector associations, public authorities, standard bodies, etc.)? ▪ Which interactions with other firms and with the knowledge infrastructure mattered, and why?
Industrial policy	▪ What sort of market failures did the innovating firm encounter, and how did it (or not) overcome them? ▪ What was the role of industrial policy?

Source: see text.

Funding was available partly through a World Bank loan from its Science and Technology Reform Support Program. The partners agreed to exploit biotechnology in order to produce biodegradable plastics (i.e. polyhydroxyalcanoates) from sugar cane, and registered a patent on the process. Following successful trials, an established sugar mill, Usina da Pedra, agreed to build and run an intermediate-scale pilot unit in an existing mill, and to underwrite the risk of failure. The upshot was total reimbursement of its costs and priority rights to the license for five years should the project succeed.

In 2004, Usina da Pedra opened a commercial plant with an annual capacity of 2000 tons. The product has been tested for a variety of applications, from injection and extrusion technologies to packing materials, cups for seedlings, and medical devices. New specialised research partners joined the consortium, including the Department of Materials of the Federal University of São Carlos, while the bioplastic is given to anyone who wants to test it, including multinational companies such as BASF. Although the consortium managed to produce what can be considered a consistent product with a relatively stable technical specification, bioplastics production is still not cost effective.

Knowledge intensification in this case refers to the diversification in the use of an agricultural commodity toward a variety of industrial applications outside of the food processing chain by way of downstream beneficiation. Thanks to a long tradition in researching alternative uses for sugar, this includes promising applications that move away from the environmentally undesirable use of fossil fuels.

5.2 Biodegradable plastics from maize starch in South Africa

A number of institutes and private companies pursued research on biopolymers in South Africa in the 1990s. This was in part a continuation of work on polymer technology more generally and in part a response to emerging waste management problems due to the ever increasing quantity of plastic bags. In addition, a manufacturer of maize starch was interested in exploring new downstream uses of its products. In the late 1990s these players came together and formed a loose consortium that managed to get government funding from 2002. The research objective was to develop and commercialise a starch-based plastic without the use of significant amounts of synthetic polymers. This case is thus similar to the Brazilian case describe above (see Chapter 3 by Walker and Farisani, in this report).

The consortium reached approximately 80 per cent of its milestones in the third and final year of public co-funding of the project. Although it had failed widely to commercialise a suitable biodegradable plastic from maize starch at an acceptable price, it managed to turn out two products – seedling trays and golf tees – that are commercially available.

This is a case of knowledge intensification because it diversifies the use of an agricultural commodity – from maize for mielies to starch for environmentally friendly plastics – toward a wide range of industrial and household applications, using expertise accumulated from the downstream beneficiation of another commodity, namely oil.

Table 2 - Profile of case studies

Country	Resource base	Lateral migration	Key entities	Period	Results
Brazil	Agriculture	Sugar bagasse ➔ biodegradable plastics	Institute of Technological Research (IPT); Institute of Biomedical Sciences (ICB); Technology Center (CTC) of COPERSUCAR; PHB Industrial S.A. (PHBISA); Department of Materials (DEMa)	1991 – ongoing	PHB production plant within traditional sugar mill; functional but costly biodegradable thermoplastic
Costa Rica	Agriculture	Coffee beans ➔ specialised machinery for sorting by colour of coffee, grains, and seeds	Xeltron; AETEC	1974 – ongoing	Sophisticated machinery using laser technology and artificial intelligence
Peru	Mining	Bioleaching for metal recovery ➔ bioremediation	Minera Lizandro Proaño S.A. (MLPSA); Repadre International Corporation (RIC); Global Environment Emerging Markets Fund (GEEMF); TECSUP; FIMA; Glencor; École de Mines d'Ales; Universidad Particular Cayetano Heredia	1997 – ongoing	Successful conversion of zinc and lead to gold mine but eventual commercial failure; (advanced) research in bioremediation
South Africa	Agriculture	Maize starch ➔ biodegradable plastics	Centre for Polymer Technology, CSIR; Institute of Applied Materials, University of Pretoria; African Products (PTY) Ltd; Xyris Technology CC	2002 – ongoing	Prototypes for future commercialisation: seedling trays and golf tees
South Africa	Mining	Hydro-hydraulic technologies in mining ➔ other sectors ➔ services	Chamber of Mines Research Organisation (COMRO); mining houses	Early 1980s – early 1990s	Hydro-hydraulic technologies used for a variety of applications other than gold and platinum mining; establishment of international consultancies
South Africa	Mining	Coal ➔ medicines	Central Energy Fund (CEF); Enerkom; Department of Pharmacology, University of Pretoria; National Research Foundation (NRF); Secomet; Pfeinsmith	1980s – ongoing	Process patent, product patent on medicinal use of fulvic acid for a variety of applications

Notes to Table 2 -

AETEC is a subsidiary of a US multinational.
COMRO is part of the Chamber of Mines of South Africa (COMSA).
COPERSUCAR is the Cooperative of Sugar and Alcohol producers of the State of São Paolo, the world's largest exporter of sugar.
CSIR = Council for Scientific and Industrial Research, one of South Africa's eight statutory science councils.
DEMa is part of the Federal University of São Carlos.
Enerkom is the research arm of CEF, South Africa's parastatal responsible for managing its fossil resources.
FIMA is an equipment producer.
ICB hosts the Laboratory of Genetics of Microorganisms and Biotechnology and is part of the University of São Paolo Brazil's most prestigious university.
IPT is a public research institute of the State of São Paolo.
MLPSA is a family-owned mining firm.
PHBISA is a partnership between two of Brazil's strongest groups in the sugar and alcohol industry.
RIC and GEEMF are Canadian investment funds.
TECSUP is a mining training centre.

5.3 Bioleaching and bioremediation in Peru

Peru is rich in mineral resources. Together with its Andean Pact neighbours the country was involved in attempts to use bacterial leaching to recover copper in the 1970s. Although successful, these attempts became victims of a deep crisis afflicting the mining sector in the 1980s. Following privatisation and liberalisation of the economy and subsequent inward direct investment by US mining houses, bioleaching took off again in the 1990s. This study describes the technologically successful but commercially unsuccessful indigenous development of a hydro-metallurgic method of gold leaching. A small, family-owned mining firm, Minera Lizandro Proaño S.A. (MLPSA) managed to get private international funding for a project to transform a lead and zinc mine into a gold mine. From 1999, gold was recovered through a cyanide-based technology in connection with the use of bacteria. Two other local actors were involved. A mining training centre (TECSUP) explored the feasibility of using the bacterial leaching technique to treat mining tailings. A domestic equipment producer (FIMA S.A.) was primarily responsible for the construction of the project (see Chapter 4 by Kuramoto and Sagasti, in this report).

The technology was essentially re-engineered from a process owned by South African mining house Gencor which the latter agreed to license albeit at a price too high for the Peruvians. Bottlenecks in mining output meant that the plant's demand of minerals could not be met and saw to it that it had to be closed only a few years after it opened. However, the process of gold and silver extraction per se was successful.

The scientists most closely associated with the experience used the insights gained about the behaviour of bacteria in metal extraction to develop research in the use of bacteria for remediation. Contaminated soils can be remediated using bacteria either by extracting the toxic substances or by reducing their toxicity.

Knowledge intensification thus took place in an input industry; a technology external to Peru was first adapted to local circumstances in mining (bioleaching) and then pursued further for applications that extend beyond mining (bioremediation). Since bioremediation can be applied outside of mining, this case therefore harbours the potential of lateral migration.

5.4 Hydraulic technologies in South Africa's mining sector

Historically South Africa has been a highly resource-intensive economy, particularly with respect to mineral deposits. Mining houses were interested in hydraulic technologies to increase labour productivity in the face of (artificial) labour scarcity and increasingly deep and thus more costly mining operations from the mid-twentieth century. After a long tradition of research in emulsion hydraulic technologies, the research arm of the Chamber of Mines, COMRO, in the early 1980s started research into combined hydraulic power and cooling systems. Hydraulic power systems are advantageous because they are more efficient than pneumatic drills and create much less mechanical and exhaust noise. In turn, water (i.e. pure) hydraulic systems are superior to emulsion (i.e. mixed) hydraulic drills among other things because by definition they do not leak oil into the environment. By the early 1990s, a commercially viable hydro-hydraulic technology existed, making South Africa a world leader in this regard (see Chapter 5 by Pogue and Rampa, in this report).

Engineers associated with the now defunct COMRO have formed successful consultancies specialising on drilling and cooling technologies that operate worldwide. In addition, the technology is being explored as water cutters in the food and steel industries and in aircraft rescue, and has found a few applications outside of the mining sector. Knowledge intensification took place primarily around a supplier industry but, similarly to the Peruvian case introduced above, preliminary evidence of lateral migration exists as well.

5.5 Humic substance research in South Africa

South Africa sits on vast reserves of coal which is its main energy feedstock. Liquefaction of coal plays an important role in local oil supply. In the mid-1980s the Central Energy Fund (CEF), South Africa's state oil agency, mandated its research branch, Enerkom, to look into alternative uses for coal. Enerkom focused on humic substances. They are naturally occurring acids that are good fertilisers and have been used as folk medicine, especially in Asia. Enerkom developed and patented a process by which it extracted humic acid through oxidisation of coal. But the resulting product was too expensive for use in agriculture. Hence it concentrated on researching the medicinal properties in collaboration with the University of Pretoria (see Chapter 6 by Lorentzen, in this report).

The research found that humic acids have anti-microbial, anti-inflammatory, and anti-viral effects. Due to their anti-viral effects, humic substances were used in clinical trials of HIV-positive patients in Tanzania. For a number of reasons, these trials were extremely controversial. The negative publicity they attracted led to the sale of the state-owned company that had been at the forefront of humic substance research, including its intellectual property rights, to an overseas firm. Although some medicinal applications of humic substances have been thoroughly researched, tested, and approved for sale, a twenty-year old research tradition was essentially cut short through the sale of the South African property rights.

In this case the dynamics of the technological trajectory are overshadowed by the complicated politics of HIV/AIDS in South Africa. Nevertheless, lateral migration took place insofar the search for alternative uses of coal gave rise to a research tradition into the medicinal properties of humic substances that eventually substituted a plant-based carbohydrate as the source for the acid.

5.6 Specialised sorting machinery in Costa Rica

Xeltron is a small, specialised machinery manufacturer located in an export-processing zone between San José and Cartago. Xeltron designs and produces machinery that by colour sort coffee, rice, beans, nuts, and seeds in general. Almost all of Xeltron's output is exported. The beginning of the company dates back to the mid-1970s. At that time coffee-sorting machinery was imported, and only maintenance and repair was locally done. Xeltron's founders introduced a number of technological innovations over the years. They first improved on existing colorimetric techniques by employing optical analysers that allowed for much more precise measuring of colour. Subsequent technological upgrades included the use of microprocessors and semiconductors and, finally, artificial intelligence. Xeltron holds five international patents on its innovations (see Chapter 7 by Giuliani, in this report).

This is the only pure case of successful lateral migration. For the country as a whole, it occurred because Xeltron's machinery design took its point of departure in coffee crops, one of Costa Rica's traditional mainstays. For the company, lateral migration moved machinery strictly developed for the sorting of coffee beans to other grains, and finally even the sorting of plastics and emerald products.

5.7 Overview

Altogether the data consist of two cases of downstream beneficiation; two cases of development of input industries each of which is involved in some lateral migration; and two cases of lateral migration proper where the original resource – coal in one case and coffee in the other – is no longer necessary for the application of the technology. Figure 4 provides an overview.

Since the study does not employ a proper measure of knowledge intensity, the relative positioning of the six cases is merely an approximation. Comparisons are possible along either the vertical or the horizontal axis, but not both. Thus, it is evident from the research that the Brazilian endeavour at sugar beneficiation was more knowledge intensive than the South African. Likewise, the South African drill experience led to more lateral migration than the leaching experiment in Peru.

Figure 4 - Knowledge intensification and technological trajectories in the six cases

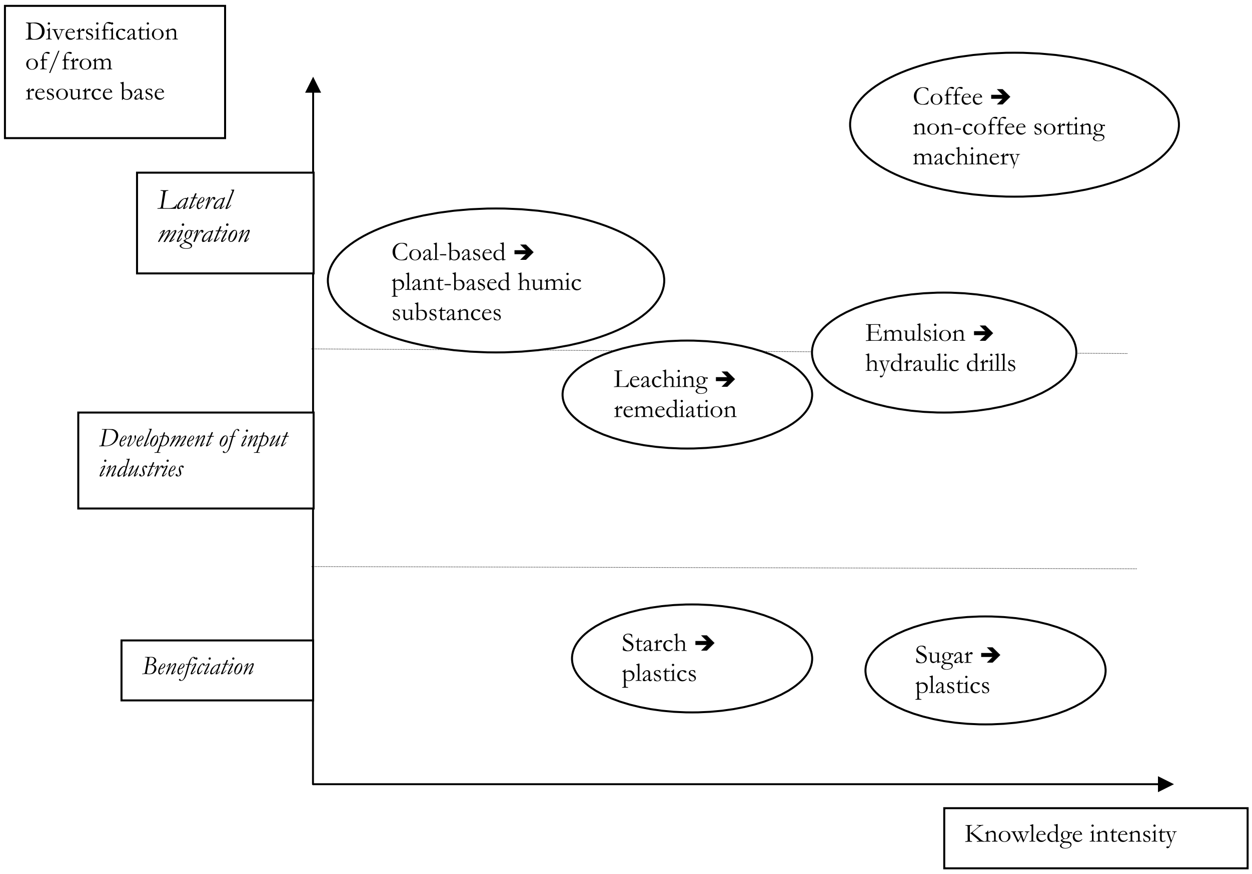


Table 3 - Determinants of lateral migration in six case studies

	Brazil: bioplastics	Costa Rica: sorting machinery	Peru: bioleaching and -remediation	South Africa: biopolymers	South Africa: hydro-hydraulic power and ventilation	South Africa: humic substances
Absorptive capacities	High and rising thanks to consistently high public/private investment in R&D.	High and rising thanks to consistently high R&D investment and internal skill upgrading by firm.	Fragmented and discreet because of inconsistent investment in R&D.	High because of strong tradition in polymer research. Rising thanks to strategic search by science, university, and private sector. Skill upgrading through training in university.	High because of dedicated, long-term research programme. Potentially diminishing because of termination of main research vehicle.	High because of dedicated, long-term research programme and training through university. Potentially diminishing due to interruption in funding.
Foreign technology	None.	Technical expertise enhanced incentives for innovation. IP protection not important for market leadership.	Imports of capital equipment through development assistance enhanced incentives for innovation.	Technical expertise enhanced incentives for innovation. Reliance on license initially positive but then withdrawn.	JVs and other partnerships with MNCs enhanced incentives for innovation. Control of potential abuse of IP protection important for technology diffusion.	None.
Linkages	Intensive interaction between universities, technology centres, and industry.	Poor with domestic suppliers, customers, education institutions. Critical interaction with MNC subsidiary.	Poor, especially with engineering departments in universities.	Intense linkages between science sector, university, and private firms.	Strong linkages within sector between research organisation and private firms.	Strong but isolated linkages between research arm of parastatal and university department, and between university department and private firm.
Industrial policy	Govt. funding key for ethanol-from-sugar and later for channelling World Bank funds to bioplastics consortium.	Mkt failures in infrastructure. Gov. support poor in R&D, trade, marketing. EPZ very bureaucratic.	Andean Pact initiatives in 1970s set up but did not sustain research programme. Strong financial constraints on further research.	Public co-funding relatively bureaucratic to access and small scale.	Mission-oriented research historically important.	Time-inconsistent investment in technological exploration.

Source: see text.

6 Analysis

The case evidence shows the following (see Table 3). In five out of six cases the involved entities had high absorptive capacities thanks to competences accumulated over time. In three cases absorptive capacities were rising due to investment in R&D and the upgrading of advanced technical skills. In the remainder, diminishing or uncertain investments in R&D meant that absorptive capacities might fall. In this respect, bioleaching and bioremediation in Peru appears to be the case where learning is most difficult and technological upgrading perhaps least likely.

Foreign knowledge played no explicit role in two cases and increased incentives for innovation in four. There is no evidence that it was ever perceived as obviating the need for the indigenous generation of knowledge. Hence, foreign technology and local knowledge appear to be complementary.

Linkages and interactions between firms, science institutes, and universities – or a subset thereof – mattered greatly in four cases. Not surprisingly, systemic dynamics are important for knowledge intensification. The exception is Costa Rica where an individual firm managed to compensate for positive dynamics with respect to linkages with the training system or with capable domestic suppliers, respectively, though in-house training and the use of external suppliers. By contrast, neither an individual mining company nor the mining sector as a whole in Peru can overcome the negative consequences of an absence of linkages with the university sector. Likewise, when in South Africa sectoral systemic dynamics were interrupted following the merger of the very focused mining research organisation into a science council with a broader orientation, it would appear that capacity was lost for good. This suggests that linkages are important, and that in their absence individual firms might be able to compensate for the resulting shortcomings in highly specific niches, but entire sectors are unlikely to do so where issues of scale are key.

Industrial policy does not appear to be of great importance in these cases in terms of overcoming information failures. Where firms perceived opportunities, they invested even in the face of relatively high risks. Much more important are the long-term financial constraints that bedevil even promising and partially successful research and development, especially when things do not go exactly according to plan. It appears as though the potential technological merit of those technologies that have not yet been commercialised exceeds the capital available to make this happen. This is a problem. In the Peruvian case, coordination failures seem to be a problem. That, too, could be addressed by interventions aimed at setting up the dynamics of a national system of innovation.

This is not to say that industrial policy played little role in the cases under consideration here. A more nuanced interpretation would distinguish between massive, targeted interventions such as those that brought about Brazil's move into ethanol production from sugar cane, and much smaller subsidies in favour of, for example, research cooperation between science and industry for the development of biopolymers in Brazil or South Africa.

What stands in the way of successful commercialisation in both the latter cases is the relatively high production cost of bioplastics as opposed to synthetic polymers. If either government priced waste management costs into conventional packaging made from synthetic polymers, it would contribute to levelling the playing field between the rival technologies, possibly giving rise to substantially new technological solutions, or knowledge intensification writ large.

The importance of industrial policy may also be related to levels of development. In the middle-income countries under investigation here – Brazil, Costa Rica, and South Africa – absorptive capacities seem the single most important determinant of lateral migration followed by linkages and foreign technologies. In other words, things happen even in the absence of strong industrial policy interventions because firms and research institutes have the wherewithal to internalise external knowledge, often in interaction with other economic actors. However, in Peru where the competences of firms are less strongly developed and where systemic interactions are few and far between, industrial policy might be necessary in order to address the weaknesses that hinder a more fortuitous technological trajectory, namely a deeper commitment to firm learning and the creation of linkages between the productive and the training sector.

7 Conclusions

This study analysed six cases of knowledge intensification in resource-based activities. It relates to and builds on a sizeable body of work on resource-based growth. It tried making an original contribution by accompanying its analysis of firm learning with attention to linkages between what many see as almost separate entities, namely the "old" factor-based economy and the "new" competence-based knowledge industries. For developing countries in particular it is clearly more realistic to make use of prior accumulated knowledge to promote new competences, as opposed to going for blue-sky applications. Hence bridges between old and new are important or, put differently, it is primarily in the co-evolution of human capital, scientific pursuit, technological development, and concomitant infrastructure investment around the linkages that resource-based economic activities can become more knowledge intensive and thus lead to higher growth.

The study confirms that knowledge intensification is a possible answer to the resource curse potentially bedevilling resource-intensive economies. It also shows that such a strategy is not easy. Much has been learned from comparing experiences with resource-based growth from around the world and in different periods of time. Most comparative studies took their lead from success stories and formulated recommendations accordingly. This research took a more agnostic view and compared successful with not so successful cases. Reality is more nuanced than a simple dichotomy of success and failure, and in any event learning can be based on insights of why failures occurred as much as on those from luckier tales.

The crude version of the resource-curse hypothesis has been convincingly rebutted. This was the merit of comparative historical analyses of, say, Australia and Argentina. With determinism off the table, the challenge lies now in systematically linking historical and theoretical insights – namely the potential of resource-based growth and the importance of created assets such as human capital and knowledge infrastructure – to the empirical differentiation of indigenous capabilities across developing countries in the present period. The case analysis undertaken here suggests important differences between a relatively poorer country, Peru, with more advanced economies such as Brazil. This warrants further study. Similarly, much like the process of knowledge intensification is different from sector to sector, perhaps the rather more general attention to, say, R&D subsidies must be analysed with the specifics of what drives innovative activities across different sectors in mind. For example, there are likely important differences in agriculture and mining from which this study abstracted. In sum, a better understanding of the conditions under which knowledge intensification could be a successful strategy of industrial diversification requires a larger sample of cases from a more diverse set of developing countries.

Much heuristic mileage could be gained by raising the systematic requirements of the comparisons. For example, if knowledge intensity were properly measured both in terms of inputs (e.g. R&D investments) and outputs (knowledge assets embodied in the new technology), it would be possible better to understand the efficiency and effectiveness of public policy in support of knowledge industries that originate in or otherwise relate to resource-based activities.

Propositions worth testing include the following. This list is by no means exhaustive. First, absorptive capacities (of the relevant R&D entities) are the single most important determinant of lateral migration. Second, knowledge intensification can take place in the absence of foreign technology and with weak systemic interactions, but only from a certain level of economic development (in other word there is a threshold value of absorptive capacities). Third, the import of industrial policy is proportional to the level of development and the level of ambition behind promoting knowledge industries. Ceteris paribus, at lower levels of economic development (of countries) or technological maturity (of sectors), industrial policy is needed to bring about a minimum degree of absorptive capacities. In addition it may have to secure access to external knowledge and incentivate linkages and interactions. Likewise, the higher the ambition behind the policy, the more necessary it becomes to align the R&D endeavour with the requisite regulatory changes to facilitate the emergence of technological opportunities.

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