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Thematic Review

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Foreword

Globelics is a worldwide community of scholars who place learning, innovation and competence building at the heart of the development process. Over the years, Globelics has been a forum for cross-fertilising the two rather different traditions of innovation studies and development studies. While these in themselves are both interdisciplinary and broad, their intellectual traditions are quite separate and they have hitherto tended to unfold in separate communities. The policy circles with which they have engaged have often been disparate.

Although the Globelics community incorporates a range of social science disciplines and approaches, the focus on learning, innovation and competence-building systems is a defining element of their analyses of a wide range of economic and social development processes and problems. The objective of the Globelics Thematic Reviews is to communicate insights relevant to policy from the community to policy circles and development donor organisations. Each review focuses on a separate theme, in a format that aims at making it relevant and accessible to users outside academic circles. It gives an overview of research outcomes as well as reflections on policy implications.

The present review was produced by Allan Dahl Andersen, Björn Johnson, Anabel Marin, Dave Kaplan, Lilia Stubrin, Bengt-Åke Lundvall, and Raphael Kaplinsky. Substantial input was drawn from a 2-day Globelics seminar entitled 'Natural Resources, Innovation and Development' in Copenhagen, March 2014, and from a subsequent special session of the Globelics Annual Conference in Addis Ababa in October 2014. We thank all of the participants for their valuable inputs and comments. The review reflects the insights from papers on Natural Resources, Innovation and Development at Globelics conferences in general and the meetings in Copenhagen and Addis Ababa in particular. We are furthermore grateful that colleagues invested some of their scarce time to comment on earlier versions of this review. Those colleagues are: Tilman Altenburg, Michiko Iizuka, Keith Smith, and Max Rolfstam. However, responsibility for the final review lies

with author team and the secretariat. The editors are also thankful to Nina Kotschenreuther for editorial support and to Shagufta Haneef for extensive support in editing references and helping with various bibliometric analyses.

The purpose of the Thematic Review is to inspire future Globelics research and to influence policy. However, there is no intention of giving specific advice to donor and development organisations about the conduct of development aid and design of development strategies in the field of natural resources and development. The intention is merely to offer practitioners insight into an innovation perspective on development on the basis of natural resources. We hope that this review may inspire the design and development of new and effective policies for innovation systems and strategies for development.

Globelics Secretariat

Preface by Bengt-Åke Lundvall

The rise in global demand for natural resources in the new millennium made it possible for countries highly specialised in the export of natural resources to reach high growth rates. This development renewed doubts about the proposition that there is a 'natural resource curse'. This review relates to the ensuing debate and asks the question: Does a strong presence of natural resource intensive sectors constitute a hindrance for economic and social development? The answer reached on the basis of a combination of historical evidence and current observations is negative.

The review shows that some of the richest countries in the world (including the Nordic countries and the US) have grown rich on the basis of natural resources. Some rich countries such as Australia and Norway remain highly specialised in the export of products with a strong content of natural resources. The review also refers to a series of cases illustrating how developing countries in Latin America and Africa succeed in transforming natural resource industries through the use of advanced knowledge and through innovation. While it is recognised that several less developed countries with rich access to natural resources have shown little progress in terms of job creation and social inclusion this, it is argued, has more to do with the way the society is organised and not least with weak 'innovation systems' than with the access to natural resources per se.

But the report also indicates that it is not possible to create sufficient jobs and better the living conditions for the majority of the population if the economy remains dependent on just a few specific export commodities. Economic development requires a process of diversification where new industries producing new products for the home market and for exports emerge. Monoculture implies vulnerability and instability. Therefore, the key issue for the countries now specialised in the production and export of natural resource commodities is to engage in an economic transformation where a diversified economy is built upon the natural resource base.

The report argues that the fundamental response to this challenge is to establish competence and building linkages between natural resource intensive activities and other activities. Backward linkages through the demand for means of production and other inputs to the natural resource sector may stimulate sectors producing machinery and service sectors, including demand for science and skills involving knowledge institutions such as universities and schools as suppliers. Forward linkages involve the establishment of production that adds value to the natural resource commodity. New enterprises for refining oil, ore, diamonds, coffee and rubber and transforming agricultural products into processed food are examples of such forward linkages. Also, in this case, the knowledge base and the knowledge infrastructure will be of great importance for what can be achieved.

Both when it comes to backward and forward linkages, the question of how natural resource activity is embedded in the international division of labour is crucial for the transformation of the economy towards a more diverse and knowledge-based economy. With foreign ownership of export oriented natural resource intensive industries, local linkages may still develop, but only if the competence gap between domestic suppliers and foreign extractive industries is not too wide. Therefore, investment in the specific knowledge base relevant for natural resource intensive industry is one way to promote the formation of competence building linkages and economic transformation. Public programs supporting specialised research and training in engineering and design may, for instance, be necessary to support this process.

Another way to stimulate the formation of domestic linkages is to regulate the access for multinational corporations (MNCs) to domestic natural resources. Local content rules or requirements specifying that foreign firms should procure some of the inputs from domestic firms may be combined with requirements that MNCs engage in knowledge sharing and training of domestic workers and managers. This kind of regulation makes it more attractive for foreign firms to link up with domestic firms and knowledge institutions. A combination of innovation, trade and industrial policy may thus help to establish forward and backward linkages by reducing the barriers for domestic firms that try to enter into development blocks around the production of natural resource commodities.

This report offers lessons for policy makers in developing countries and for donor organisations in the developed countries. Below, I have listed five of the most important:

1. Context matters when defining and choosing adequate policy instruments. 'Natural resources' is a quite heterogeneous category and there are major differences between hard commodities such as oil and minerals and soft commodities such as those emanating from agriculture and fishery. While at least part of agriculture and fishery are small scale and labour intensive, the production of hard commodities is more often scale and capital intensive and therefore more attractive for foreign investors. But the two fields have in common that there is a

potential for building competence by enhancing backwards and forward linkages. A second distinction is between policies to promote the on-going production on the basis of natural resources and policies in connection with the opening up of new sources.

2. For many countries, especially for countries in Africa, the second perspective is important. Natural resources are not 'natural' in the sense of being given once and for all. Which elements of nature that become part of the resource base will depend on the current state of knowledge and technology. A first step is therefore to map what nature offers in terms of 'potential resources' in the country. A second step is to assess the technological capacity to exploit these potential resources. A third step is to assess the broader costs and benefits for society as a whole of opening up a new source. In some cases, a narrow economic perspective may result in serious environmental consequences at the local, national and global level. A fourth step is to consider how to organise the further exploration and exploitation of the research in terms of engagement of foreign expertise and ownership. A fifth step is to negotiate with domestic and foreign private and public partners aiming at agreements that create competence-enhancing backwards and forward linkages. A sixth step is to return to an assessment of domestic knowledge and skills and to design a strategy aiming at establishing education and research in relevant fields. Enhancing the analytical and managerial capabilities to pursue these steps in poor countries is a very important element in capacity building.

3. When it comes to the upgrading of ongoing production in local firms and to the diversification of the economy, a first step would be to locate the production of commodities based upon natural resources in the wider setting of the national innovation system as well as its integration in international trade. A first step would be to take the view of an open input-output system and to see how commodities flow between sectors. A second step would be to define 'key sectors'. These may be defined both on the basis of their quantitative contribution to the economy and on the basis of filling a crucial function for the transformation of the bigger sectors. A third step would consist in getting an overview of the most important actors in those key sectors. A fourth step would be to enter into negotiated partnerships with those actors with the explicit aim to upgrade activities through competence building linkages. A fifth step would be to identify the most important barriers that make it difficult for upstream and downstream domestic firms to emerge, expand and link up with the natural resource development blocks. As a sixth step, a sector specific policy aiming at reducing barriers and building relevant competences should be designed.

4. As indicated in the first part of the introduction, the role of natural resources in overall economic and social development will depend upon the quality of national 'institutions'. Easy access to income from taxing exports of hard commodities may be used to bolster regimes that neglect the need to diversify the economy and make the economic development sustainable and inclusive. On the other hand, they may be used to upgrade the activities within the natural resource intensive sectors and to stimulate the formation of domestic upstream and downstream activities. Increased transparency and democratic control may help to reduce corruption and the siphoning off of income into private accounts abroad. It needs to be combined with a long term perspective where development takes into account the needs of future generations. Donor organisations may play a role in promoting both democratic control and the development of long term plans aiming at making the economy more diverse, more inclusive (job creation is a key factor in this context) and more sustainable (low carbon solutions in the context of transport, energy and urbanisation are key factors).

5. The review gives an overview of recent research on the role of natural resources in economic and social development. It is clear from this overview that research based knowledge is still limited and many questions remain to be answered before we may give qualified specific policy advice. Why do some low-income countries succeed in transforming themselves from being dependent on exports of natural resources into middle-income countries with a diversified economic structure while others fail? How should developing countries with the ambition to escape the low-income trap that depend heavily upon the export of natural resource commodities insert themselves in the global economy? Does domestic ownership matter? Do the current rules of the game for trade, FDI and intellectual property give sufficient room for action for national governments to intervene? On the background of the review, one basic rule might be that national strategies aiming at economic transformation should combine openness and autonomy in such a way that it strengthens the knowledge base of the economy as a whole. The most important factor when it comes to valorising potential natural resources is knowledge.

This report reflects research efforts within the global network of scholars, Globelics. Within this network there are of course different views on all controversial topics including the role of natural resources in economic development. This report builds on and summarizes available research on natural resource, innovation and development, and concludes that natural resources are, under proper management, more of a blessing than a curse for poor countries. Although the topic of natural resources and development is particularly contested, scholars within our network would share the view that development must build upon what is already there. Therefore they would also agree on the main policy implications as outlined in the report. Diversifying the economy and promoting competence building through domestic and international forward and backward linkages to the natural resource intensive sectors is what OECD and other international think-tanks refer to as 'no-regret policy'.

Contents

Figures

Tables

Boxes

1. Natural resources, innovation and development

In this Globelics Thematic Review, the author team presents and discusses recent research on the relationships between natural resources[1], innovation and development in developing countries, and suggests some implications of this body of knowledge for policy makers.

1.1 Natural resources: why and how?

Natural resources are indispensable for the functioning of modern economies and for achieving economic development in all countries. Natural resources are the primary inputs to most production processes and they supply the energy for transport, light and heat around the world. In many ways, the manner in which the world manages natural resources will be a crucial factor in determining the scope for sustainable development in the world economy. In fact, as the world is confronted with climate change, natural resource management becomes an urgent issue to address.

Supply and demand of natural resources are most often unevenly distributed between countries, which create ample opportunities for trade. In consequence, we often see that countries rich in natural resources become highly specialised in, or dependent on, production and export related to such resources (WTO, 2010).

Structural changes in the world economy – particularly due to the high growth rates of China and India – have during the last two decades generated rapidly rising demand for and production of natural resources (see figure 1). This expansion was furthermore associated with unprecedented price increases for resources (Gruss, 2014). Although price increase has decelerated recently most analysts believe that price levels will remain high in the foreseeable future (Farooki & Kaplinsky, 2012; IMF, 2014). This natural resource boom contributed – although far from uniformly – to GDP growth in several developing countries rich in natural resources and may continue to offer opportunities for development.

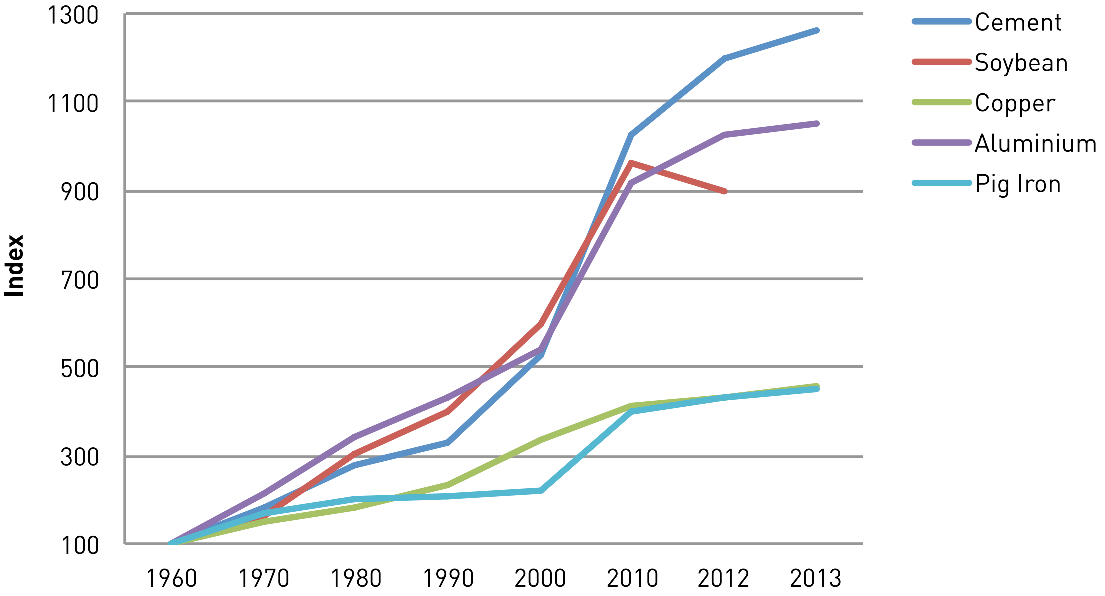
However, it may be problematic for countries to be overly specialised in natural resources. First, being economically dependent on exporting only a few products makes countries vulnerable to changes in demand for these products. Second, economic development is intimately associated with diversification of the economy. Countries should therefore add diverse productive activities to their resource activities. Third, several researchers argue that natural resource dependence may directly inhibit growth and development.

Recently, several reports have argued that although the recent natural resource boom contributed to growth in several Latin American and African countries this has – especially in Africa – failed to translate into the expected employment growth and improvement of socio-economic indicators (AEO, 2013; UNCTAD, 2013; UNECA, 2013). Progress is recorded in both public expenditure on and outcomes in areas such as poverty reduction, nutrition, education, and health, but it has been slower than anticipated (UNCTAD, 2013; UNECA, 2013) . As a result, calls for a more inclusive form of growth have been made in order to improve the link between growth and poverty reduction. A modification to this picture is that many of the resource rich developing countries are actually net importers of food and energy. These countries, thus, have not unequivocally benefitted from the rising prices of natural resources (UNCTAD, 2013). In addition, the resource boom has had limited structural impact on natural resource rich developing countries, something which may foreshadow an unsustainable growth path for the longer run due to lacking diversification (UNCTAD, 2013).

There are, thus, major doubts in policy circles about (i) to what extent it is currently possible for a country to develop on the basis of natural resources, and, if so, (ii) what the main underlying mechanisms of resource intensive development paths are, and lastly, (iii) how such mechanisms can be supported politically. It is the goal of this Globelics review to explore these three interlinked questions with a focus on innovation and industry dynamics. Regardless of the answers, it is important to improve the performance and development impact of resource production, and thus that analysts and policy makers learn from recent obstacles as well as from countries that in the past have succeeded in transforming their natural resource wealth into development. In consequence, this Globelics review considers a range of contemporary and historical studies and diverse theoretical positions.

We approach the set of questions from the point of view that development is a process of structural change which builds on interactive learning and innovation and which considers the building of Learning, Innovation and Competence building Systems (LICS) a central part of a viable development strategy. There are at least two reasons for this broad and multifaceted approach. First, the sources of learning are numerous and innovation includes minor as well as major changes of vastly different technical sophistication rooted in all types of activities and sectors. Second, evidence shows that innovation is widespread and common in developing countries and leads to productivity increases in about the same ways as in high-income countries

Figure 1: Global natural resource production



Source: US Geological Survey.

(Fagerberg et al., 2010). We apply a broad 'system of innovation' perspective in which economic production is understood as a process which draws on a mix of diverse inputs (materials, energy, labour, capital, etc.) whose interaction via different forms of linkages is coordinated by the, at any given time, available stock of knowledge (Boulding, 1981). The coordinating role of knowledge implies that its accumulation via human learning and innovation is at the heart of economic development (Nelson, 2008). For example, the material resource inputs required to produce an iPhone were present on the planet 1000 years ago, but human knowledge to produce it was not.

The Oxford dictionary of Economics defines natural resources as factors of production provided by nature. They belong to what is traditionally referred to as the primary sector of the economy, which also encompasses the secondary (manufacturing) and tertiary (service) sectors. Sachs and Warner (1997) delimit the primary sector to 'fuels' and 'non-fuel primary products'.[2] We refer to the industries in the primary sector as 'natural resource intensive industries (NRIIs)'.[3] Furthermore, we refer to economies whose industrial structure is dominated by NRIIs as 'natural resource intensive economies (NRIEs)', and we denote economies with large value shares of natural resources in total export as 'natural resource dependent economies (NRDEs)'.[4] The notion of natural resource based development has been evoked to describe development associated with the expansion of NRIIs (OECD, 2014). Due to the centrality of knowledge accumulation and innovation in development it is, however, more accurate to speak of *Innovation based Natural Resource Intensive Development* (INRID). The latter refers to a process of structural change where the expansion of NRIIs is associated with processes of learning, innovation and competence building within (in producers), around (in suppliers and users), and beyond (inter-industry spillovers) production activities to the benefit of the national economy. A central challenge for resource intensive developing countries is, thus, to move towards a more knowledge intensive and innovation-driven mode of producing natural resources. A main element in INRID must thus be to build Learning, Innovation and Competence building Systems (LICS) around natural resource deposits and activities.

We have to keep in mind that there is a huge diversity in technological and economic properties across and within NRIIs. Recently, researchers have proposed to distinguish between soft, hard, and energy natural resources (Farooki & Kaplinsky, 2012).[5] The argument is that the differences across NRIIs have important implications for their potential contribution to development. Soft resources include agriculture, forestry, tobacco, beverages and fisheries. Hard resources include minerals and metals, and energy resources cover oil, gas, coal, nuclear, and renewable energy. Soft resources, it is argued, tend to be small-scale, have low technological content, be labour-intensive and rely on distributed infrastructure useful for many other activities. Hard resources are large-scale and capital-intensive projects that require complex technologies and concentrated transport infrastructure. Energy resources tend to be even more capital-intensive, large-scale, technologically complex, and rely on specialised infrastructure (such as pipes) with little externalities for other activities. Although this taxonomy veils vast diversity within each resource group (we return to this point in section 1.2.3) it is, for now, helpful for structuring our knowledge about natural resources and development.

1.2 What do we know about natural resources and development?

The possibility that NRIIs may stimulate beneficial structural change and development has in recent years been contested by political scientists and economists under a discourse known as the *curse of natural resources* (see e.g. Ross, 1999; Sachs & Warner, 1995). The main message is that an expansion of NRIIs is most likely detrimental to development. However, as we will see below, the resource curse draws on a wider and older set of academic literatures arguing that natural resources are not necessarily good for development. In combination, these bodies of research have broadly installed the idea that countries with a significant weight of NRIIs in their economic structure will struggle to develop. The policy recommendations for NRIEs have, accordingly, been to move away from or ignore natural resources. We argue that albeit resource curse research has its merits, it ignores important innovation and industry aspects of NRIIs and thus constitutes an incomplete and, at times, misleading guide for the countries in question.

The broader literature sceptical of the development potential of natural resources identifies a number of different challenges for development. These mainly include macroeconomic challenges, institutional challenges, and innovation and industry challenges. We briefly consider each of these below. In this Review, we predominantly focus on the industry and innovation dimensions of the natural resources and development nexus.

1.2.1 Macroeconomic challenges

Deteriorating terms of trade

Both Prebisch (1950) and Singer (1950) noted that the terms of trade of developing countries (specialised in natural resources) was deteriorating vis-à-vis the high-income countries (specialised in manufacture). They saw this as a main obstacle to economic development in Latin America. The premise for the argument is that in the primary sector prices will not increase as much as in the secondary (manufacturing) sector due to four factors. First, in high-income countries unions are strong. In developing countries, they are weak and the labour market is characterised by an unlimited pool of labour. The latter prevents rises in and stickiness of wages (Hadass & Williamson, 2003). Second, the 'fact' that productivity growth, positive externalities and innovation are stronger in the secondary sector (Palma, 2008b) implies that primary producers' exchange relations worsen over time. Third, markets for primary products are characterised by perfect competition because the products are easy to imitate, and thus substitute. In the secondary sector, competition is imperfect because products are not easy to imitate, so prices can easier increase. Here competition takes place on the basis of innovation. Fourth, according to Engel's Law, the share of a household's income allocated to food purchases decreases as income rises. The structure of demand thus also negatively affects terms of trade.

The empirical evidence on the Prebisch-Singer hypothesis is inconclusive. The conclusion that one might reach depends very much on what time period one is looking at (Baffes & Haniotis, 2010; Frankel, 2012). Moreover, recently it has been the terms of trade for manufacturing that have been declining (Ferranti, Perry et al. 2002). The latter reflects an increasing 'commodification' of manufacturing (Marín et al., 2009) and the price growth in natural resources. The ambiguous empirical results reflect that the proposed characteristics of natural resources are heavily influenced by contextual factors such as labour market institutions and regulation of competition.

The Dutch Disease

The Dutch Disease is really neither a disease nor Dutch. It is, according to Gylfason (2008), rather a recurring phenomenon that involves a reallocation of resources – for example from high-tech, skill-intensive service and manufacturing industries to low-tech, low-skill primary production – with lasting harmful effects on economic growth and diversification. The Dutch-disease model describes a situation where an economy receives windfall earnings from an unexpected discovery of natural resources – it is named after the Dutch discovery of natural gas in the North Sea in the 1960s. A gas export boom led to an appreciation of the Dutch Guilder, and subsequently total exports from the Netherlands decreased. The causality of the argument goes as this: (i) an export boom (of natural resources) leads to appreciation of the exchange rate which gives worse terms for manufacture to export; (ii) the export boom will draw capital and labour from manufacturing sectors. This reallocation of resources will increase the cost of labour and materials (because initially the economy was in equilibrium) and thus increase cost for all sectors, which will increase the general price level; (iii) because of the latter, and because of currency appreciation, export of manufacture decreases and the price of non-tradable rises; (iv) foreign income from natural-resource export will in turn be used to import now cheaper foreign manufactured goods (spending effect). So, as the NRII grows, it attracts key labour inputs from the rest of the economy, which benefits the NRII and the non-tradable sector.

If we, for now, ignore the crucial assumption that manufacturing is superior to NRIIs (see section 1.2.3), the Dutch Disease narrative has been criticised for not adequately reflecting the reality of most developing countries by assuming ex ante full employment and the existence of an internationally competitive manufacturing sector. Moreover, the empirical evidence does not support the argument that the Dutch Disease is a major transmission channel between natural resource wealth and poor economic growth in developing countries (Torres et al., 2013). In fact, during the recent natural resource boom, there does not seem to be any Dutch Disease effects in NRDEs. The real exchange rates were stagnant owing to build-ups of foreign financial assets and declining liabilities (UNCTAD, 2013). Actually, it seems that the strong attention paid to the challenge of Dutch Disease among analysts and policy makers has, during this recent natural resource boom, made resource-dependent developing countries first and foremost strengthen their financial position as a fundamental part of development policies. These countries not only used natural resource income to build reserves, they also actively sought foreign direct investment (FDI) inflows to feed further expansion of NRIIs. Still, this accumulation comes with the opportunity cost of bypassing investments in the real economy in terms of infrastructure and capabilities (UNCTAD, 2013).

Income volatility

Markets for natural resources tend to be more volatile than other markets, which, in worst case, can make a country more vulnerable and instable. Volatility arises from changes in demand (buyer preferences) and in supply (often victim of ecological changes as floods and diseases). In addition, natural resources are often highly financialised products that are traded in futures markets. Speculation in such markets may increase volatility, but the overall effect of this is contested (Black, Hashimzade, & Myles, 2002; Ross, 1999). Still, the recent decade has seen a further increased financialisation of the world economy, including natural resources, which is believed to have enhanced the volatility of resource income (UNCTAD, 2013). Although some of these challenges emerge in the international financial architecture, individual countries have a range of macroeconomic instruments to counteract different forms of volatility (Ploeg, 2011).

Treatment is possible

In conclusion, we may say that having abundant natural resources can be a double-edged sword. Such resources carry with them a certain risk of damaging the economy. Still, the macroeconomic challenges related to natural resources can be addressed with appropriate policies and are thus not – as the term 'curse' indicates – intrinsic to NRIIs (Frankel, 2012). The literature does not reach a consensus about how an abundance of natural resources impacts economic growth. Researchers find positive, negative, and sometimes no correlation between resource wealth and growth. A major reason why different studies come to opposite conclusions is measurement problems (see Text Box 1).

There is, thus, not a direct relationship between growth and natural resources. Instead, several researchers have found an indirect relationship via how natural resources impact institutional quality. Institutions have received increasing attention as the deeper causes of growth and development (Rodrik et al., 2004), and they are also widely seen as the link between economic performance and natural resources (Torres et al., 2013).

1.2.2 Institutional challenges

The institutional challenges related to natural resources are a collection of arguments about why policy makers are not able to or disincentivised to avoid the Dutch Disease, regulate labour markets, manage volatility, build linkages and diversify the productive structure. They are what Ross (1999) calls 'political explanations' of the resource curse that complement the economic and innovation explanations. At the core of them lies the argument that natural resource richness enhances myopia, rent-seeking and corruption among private and public decision makers.

It is argued that NRIIs are especially prone to political capture because profits are disproportionally large (vis-à-vis other sectors), and easy to control (by negotiating tax payments with a few foreign firms) and protect (by being geographically concentrated). Therefore different forms of extractive regimes combine uncomfortably well with growth based on the expansion of some NRIIs (Acemoglu & Robinson, 2012; Altenburg & Melia, 2014). The main transmission channel is denoted the 'rentier effect' where non-democratic incumbents use resource income to stay in power and consolidate their position. Moreover, rulers with continuous access to large resource rents tend to change values over time towards spending more on regime-preserving activities – a corruption effect, so to speak (Ross, 2014). Thus, the basic argument is that natural resource richness will give you 'poor' institutions.

Still, others argue that 'poor' institutions are causes, and not results, of natural resource richness. When natural resource richness is measured as the value share of export from the primary sector in GDP, the denominator in this ratio is the size of the economy, and both the size of the economy and export specialisation are affected by past policy and institutions. This implies that the measure is endogenous. Brunnschweiler and Bulte (2008) add institutional indicators to the analysis and find a strong negative correlation between institutional quality and natural resource intensity of economy (which is equal to absence of manufacturing exports). They conclude that countries with poor institutions are unlikely to develop non-primary sector export goods. Thus, their finding contradicts the notion of a resource curse. Also, when controlling for institutions there is no (negative) correlation between natural resource richness and growth (Brunnschweiler & Bulte, 2008; Mehlum et al., 2006).

Despite these findings, there is still disagreement on the direction of causality and many observers are perplexed by how researchers continue to arrive at conflicting conclusions. The main explanation is to be found in problems of measurement and operationalisation (see Text Box 1). In his review of the field, Ross (2014: p. 13) states:

> "…the relationship between resource wealth and institutional quality is exceptionally hard to disentangle: institutions are often ambiguously defined and poorly measured, and they could simultaneously affect, and be affected by, resource wealth".

Hence, the empirical evidence is rather inconclusive on the link between NRIIs in general and institutional quality.[6] However, the literature does report clear findings on the negative impact of oil and gas wealth on democracy, institutional quality, and conflict. These are, however, not valid for other energy resources or soft and hard resources.

Oil wealth (value of production per capita) is shown to have a strong negative effect on transitions to democracy. Different forms of authoritarian regimes tend to persist much longer in oil rich countries. Research also shows that access to oil resources tends to make authoritarian regimes further authoritarian (for example in reducing freedom of speech). These results have an intriguing historical background. Most oil wealth was nationalised in developing countries in the late 1970s, giving political leaders direct access to oil rents. In the period of 1960-1979, there is no negative effect on democratic transitions, while after 1979 it is pronounced. The effect of oil wealth on existing democracies is less clear and seems to depend on the strength of the democratic institutions. If they are strong ex ante, oil wealth will stabilise democracies, while if they are weak, they tend to be undermined (Ross, 2014).

Similar results are found for institutional quality. If a country has strong institutions when discovering oil and gas, this will strengthen institutional quality while if institutions are weak, the

Text Box 1: Measurement problems

Many observers highlight how the debate around natural resources is haunted by measurement and data problems which tend to paralyse progress (Frankel, 2012; Ross, 2014; Torres et al., 2013). Ross (2014) illustrates the complexity by identifying three main dimensions of measurement.

First, the type of resource. Early studies included all types of NRIIs. Today, however, soft resources – especially agriculture – tend to be excluded from the link to institutions. Still, researchers constantly analyse different resources and combinations of NRIIs. Second, the quality of the resource, which can be measured as quantity of production, value of production, rents generated by production, value of exports, value of reserves, number of workers employed in NRIIs, etc. Third, the normalisation of the quality values, which can be defined as share of GDP, share of export, fraction of government revenue, on per capita basis, etc. The most commonly used proxy for natural resource wealth is the value share of natural resources in exports. This, however, indicates a flow of resources and is thus a poor indicator for resource wealth, which is a stock. Still, it is a suitable indicator for resource dependence (Torres et al., 2013). Add to this the even further complex measurement of institutions.

These dimensions may be combined in different ways. This is good for stimulating creative research but rather inhibiting in comparing results. It goes a long way in explaining how researchers can arrive at conflicting conclusions. Besides different proxies, different empirical approaches yield different conclusions. Over the years, methods have moved from simple cross-section studies towards panel-data analyses. Panel-data studies tend to find a weaker relationship between growth and oil wealth, for example. Using panel-data, Torres et al. (2013) suggest that the negative relationships between growth and natural resources result from poor proxies and inappropriate estimation models. Methodological progress is important, but it also further complicates comparisons between studies.

presence of oil rents (not minerals) can further weaken them with detrimental effects for development outcomes. Furthermore, access to oil and gas rents may impact social conflicts and spur civil war. Rents can finance weapon purchases in areas of armed conflict. This may help incumbent regimes to force out opposition. Also, fighting may prevail in the location of the resource as all parties seek to control it (Ross, 2014).

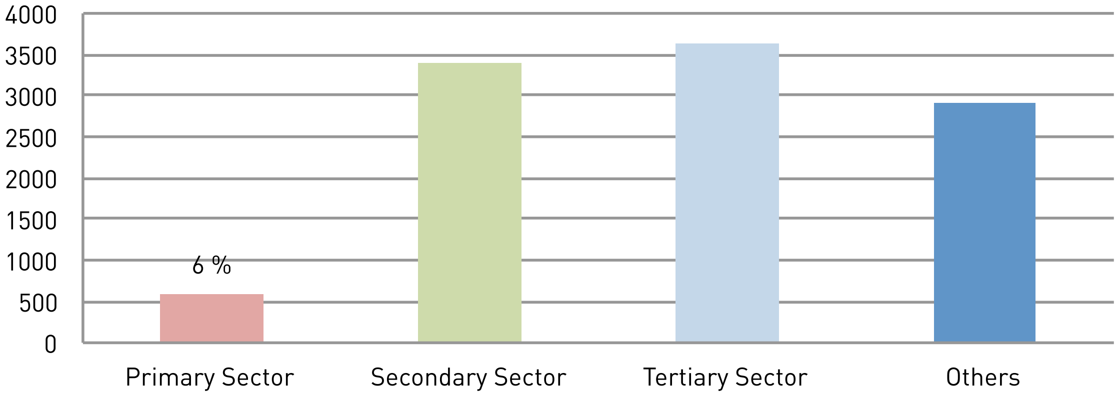
During the last 15 years, research has moved from generating analyses of cross-country averages to studying the differences within samples such as why different natural resources have very different impacts on institutions. This also involves moving towards a sub-national focus to minimise 'noise' in the data. Still, this work is only beginning (Ross, 2014). Currently, there are few indisputable conclusions to draw and analysts continue to disagree about whether the presence of natural resources contribute to the undermining of institutions or whether weak institutions make it difficult to develop advanced manufacturing, thus making countries natural resource exporters by default. Still, it is safe to conclude that the literature is more occupied with discussions about how to contain the harmful effects of natural resources than about which institutions could be directly conducive for innovation based natural resource intensive development. As Frankel (2012) points out, institutions supporting different forms of innovation may be just as useful for developing natural resources as they are for the other sectors of the economy.

1.2.3 Industry and Innovation challenges

In line with much of the resource curse literature, researchers specialised in technology policy and innovation studies have argued that NRIIs are problematic mainly because they create little opportunities for learning and innovation, and because they have few linkages. This branch of research builds on the early ideas by Prebish, Singer and Hirschman (Hirschman, 1958; Prebisch, 1950; Singer, 1975) that have been further developed in the innovation literature. Here, the idea that some industries offer higher potential for innovation, growth and development than others is broadly accepted. In other words, some industries are more technologically dynamic than others. This is because they can benefit more from advances in knowledge bases, in advances from technology suppliers and from feedbacks of knowledge within the same industry (Klevorick, Levin, Nelson, & Winter, 1995; Laursen, 1999; Malerba, 2002; Park & Lee, 2006).

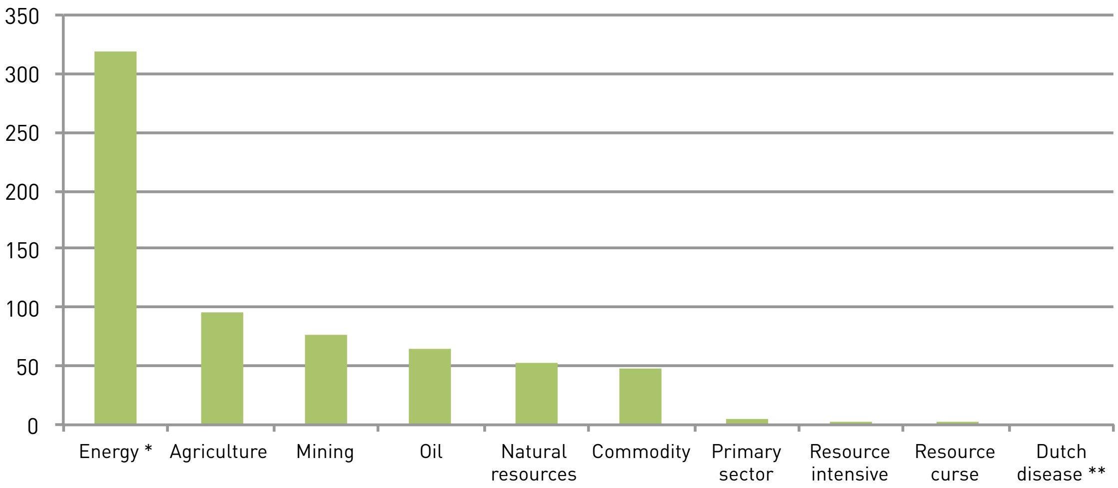
As a consequence of the dismissal of NRIIs, there has been proportionally little interest in exploring how NRIIs behave and perform in different situations (see figures 2-4). Within research focusing on learning and innovation, merely 6% of the existing knowledge stock focuses on the domain of NRIIs, and by far the majority considers these industries from an energy perspective rather than a developmental one. Therefore, we currently know very little about learning and knowledge accumulation in this type of industries. This Globelics review takes a first step in synthesising what we do know.

Figure 2: Number of articles published in Innovation Studies journals, 1994-2013, distributed according to sectoral focus



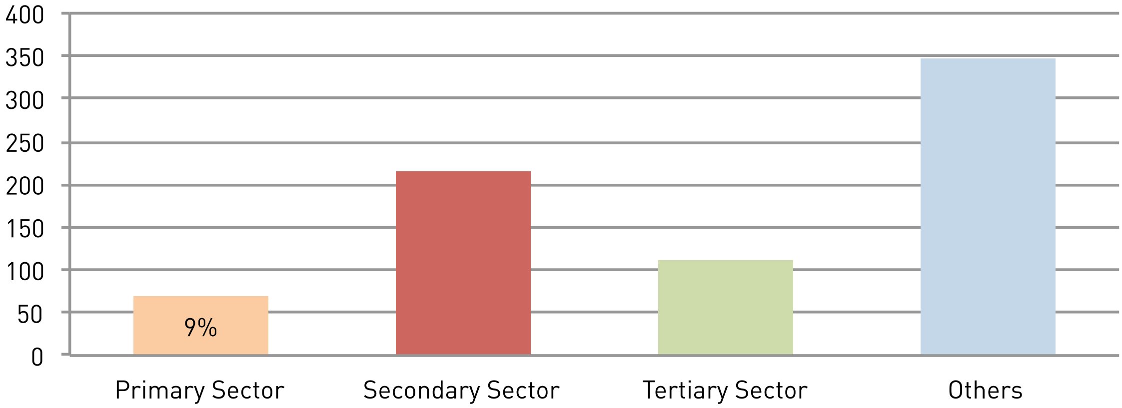
Source: Scopus database.[7]

Figure 3: Number of articles published in Innovation Studies journals, 1994-2013, analysing the primary sector (the 6% in figure 2) distributed on topics analysed



Source: Scopus database.

Figure 4: Number of articles presented at Globelics Conferences (2011-2014), distributed according to sectoral focus, 742 papers.



Source: Based on review of papers presented at Globelics conferences using same methodology as figure 2.

Linkages: Natural resource intensive industries as detached islands

It is often supposed that industries in the primary sector have fewer, or no, linkages to other industries compared to industries in the secondary and tertiary sectors. For example, Humphreys, Sachs and Stiglitz (2007: p. 4) recently argued that:

> "…unlike other sources of wealth, natural resource wealth does not need to be produced. It simply needs to be extracted. Since it is not a result of a production process, the generation of natural resource wealth can occur quite independently of other economic processes that take place in a country; it is in a number of ways, enclaved… without major linkages to other industrial sectors".

In his seminal work on conceptualising development as industrial change via linkage dynamics, Albert Hirschman (1958: p. 109-110) excluded primary production as a source of important linkages:

> "…the lack of interdependencies and linkages is of course one of the most typical characteristics of underdeveloped economies…agriculture in general and subsistence agriculture in particular, are of course characterized by the scarcity of linkages effects. By definition, all primary production should exclude any substantial degree

Text Box 2: Types of linkages

Linkages are in economics generally understood as stable relations between actors. Most often, linkages are seen as channels of transactions for goods. Linkages are important because they are thought to be the basis for inter-industry dynamics, which in turn stimulates structural change and development. We distinguish between (a) production linkages, which can be backward, forward or horizontal, (b) lateral knowledge migration linkages, (c) demand linkages, (d) fiscal linkages, and (e) domestic versus foreign linkages (Hirschman, 1981; Lorentzen, 2006; Watkins, 1963).

(a) 'Vertical production linkages' mainly focus on inter-industrial demand with a distinction between backward and forward linkages. Also, vertical linkages create interdependent investment decisions because linked industries can both hinder and block each other's growth (Richardson, 1990). Horizontal linkages refer to intra-industry relations that may be both of competitive and collaborating nature (Buur et al., 2013).

(b) 'Lateral knowledge migration linkages': the notion of 'lateral migration' of knowledge and competences has been used to describe processes where knowledge developed in relation to NRIIs 'migrates' to other areas of application, which are not linked directly to natural resources (Lorentzen, 2006).

(c) 'Demand linkages' refer to the characteristics of demand regarding a specific production entity. It has two aspects: (i) how do employees in the industry spend their income? (ii) What is the nature of the demand for the industry's output? An often-seen characteristic of natural resources is that production is severely dependent on international demand, which establishes a dependency relation to the international economy, which can generate uncertainty and instability.

(d) 'Fiscal linkages' refer to how the income generated by an industry – resource revenue – is distributed and used – is it for example reinvested in the industry or country? The fiscal linkages can be weak, e.g. in a situation where producers are foreign firms, or if domestic producers have taken up large loans internationally to finance investment in equipment.

(e) Due to the considerations in (c) and (d), it is important for an industry's developmental potential that a significant share of linkages is domestic rather than foreign to avoid that value mainly accrues abroad. This is also true for production linkages as the potential of NRIIs is closely linked to the extent to which countries manage to establish domestic suppliers (backward) and processing industries (forward). Still, foreign linkages are central. They are needed inter alia for sourcing relevant knowledge to fuel local learning processes, for trade, and finance.

In chapters 2 and 3, we further extend the linkage typology to discuss the quantity and quality of linkages with respect to learning and innovation.

> of backward linkage…the case for inferiority of agriculture to manufacturing has most frequently been argued on grounds of comparative productivity. While this case has been shown not to be entirely convincing, agriculture certainly stands convicted on the count of its lack of direct stimulus to setting up new activities through linkage effects: the superiority of manufacture in this respect is crushing. This may yet be the most important reason militating against any complete specialization of underdeveloped countries in primary production".

Thus, the argument is that *backward linkages* are thought to be few because NRII does not demand inputs. The input needed is nature, and nature is just there to be taken, wherefore inputs from science and technology are irrelevant. However, this is only true for the simplest perception possible of agriculture, as for example picking an apple from a wild growing tree. Still, today much agriculture and fruit production is knowledge intensive and innovation plays an important role (Hirsch-Kreinsen et al., 2005). Also, backward linkages to infrastructure and especially transport are important (Watkins, 1963). *Forward linkages* are thought to be few because end products go directly to consumers or are used as input to other industries in the form of raw materials. Raw materials per definition do not need processing – they are grown right out of the earth's crust wherefrom they are easily collected. If they were processed, they would not be primary products. But these are simplifying assumptions rather than facts. As pointed out by Fisher (1952), it is not easy to determine the precise stage in the conversion of milk into butter or cheese when this work ceases to be primary and becomes secondary. The products produced by NRIIs are most often processed, even though it may not be to the same degree as secondary products. Regarding *demand linkages*, Engel's law is not misplaced when we talk of levels of income, but, as pointed out by Marin, Navas-Aleman and Perez (2009), the last four decades of globalisation have been more about incorporating new consumers rather than booming income levels. In conclusion, linkage potential certainly exists in NRIIs. Whether it is exploited is another matter.

The foundation for Hirschman's assessment was a time- and place-specific combination of capital-intensity, weak local capabilities, and foreign ownership which hindered domestic linkages; 'the enclave argument'. With reference to hard natural resources in Latin America, Rollins (1971) gives his account of why linkages do not form in NRIIs. First, creation of employment for locals is limited since NRII is often very capital-intensive. Also, the jobs will most likely be for unskilled labour with low wages. Second, productivity increases will most likely not benefit the local economy. Third, knowledge spillovers via workers are unlikely because national employees perform unskilled work. Fourth, backward linkages will not exist because machinery purchase and service is likely to be imported from abroad, because the host country does not have an advanced secondary sector. Fifth, fiscal linkages are weak because developing countries use low taxes to attract foreign investment, and thus trade the fiscal linkage for demand linkages, which rarely exist. This implies that profits accumulate in the source country, and thus will not benefit the host country. Even though the analysis is based on few specific cases, the points have been supported by other studies (Auty, 2001; Humphreys et al., 2007).

Still, the prevalence of several historical and contemporary cases of extensive linkage dynamics in NRIIs (see chapters 3 and 4) now illustrates that their initial assessment mistakenly transformed context-specific experiences into a general conceptual model for understanding natural resources in which development is equivalent to moving out of NRIIs. The latter understanding tends to ignore that the nature of economic activities tends to differ across time and place, and it tends to dismiss innovation activities in NRIIs. As we will see in chapters 3 and 4, the extent to which linkages unfold is subject to various forms of policy.

Only manufacturing matters?

The Dutch Disease story firmly rests on a perception of manufacturing industries as growth poles. For example, to explain the negative aspects of Dutch Disease, Palma (2008a) states that:

> "…manufacturing is an activity considered by many as the most effective engine of growth – either because it is a crucial driver of outward shifts of the production frontier, or due to its capacity to set in motion processes of cumulative causation based on increasing returns".

Hence, if manufacturing is good, then what is not manufacturing is bad. The Dutch Disease narrative equally rests on a negative perception of NRIIs. For example, Gylfason (2001: p. 856) argues that NRII:

> "…as a rule is less high-skill labor intensive than other industries, and thus confers relatively few external benefits on other industries…primary production and primary exports tend to impede learning by doing, technological advance and economic growth".

Since the starting point for the argument is that there is neither innovation nor linkages in NRIIs, the conclusion that an expansion of NRIIs will inhibit long-term economic development by crowding out manufacturing sectors is not a surprise.

Despite this 'negative' perception of NRIIs, Ferranti, Perry et al. (2002) show that productivity growth in agriculture has outpaced that of manufacturing in both high-income and developing countries during the 20th century. The authors conclude that (p. 4-7):

> "…natural resource-based activities can have high productivity growth, technical spillovers, and forward and backward linkages as much as modern manufacturing…

> the view that manufacturing has something special must be called into question”.

Besides, even though innovation activities may historically have been stronger in manufacturing, it seems peculiar to completely ignore such activities in NRIIs (Frankel, 2012). Moreover, even though innovation research has broadly adopted the rather negative perception of NRIIs, recent research has started to question these ideas, see section 1.3.

Capital-intensity and employment creation

NRIIs are also mostly seen as being less developmental than manufacturing due to their capital intensity, which limits employment creation. For example, UNECA (2013: p. 94) argues that NRIIs are inappropriate for stimulating development in African countries that instead should pursue labour-intensive manufacturing (such as textiles). The proposition echoes the perception of hard and energy resources outlined in the taxonomy presented above. However, several types of hard and energy NRIIs are not particularly capital-intensive, high-tech or large scale. For example, mining activities in developing countries constitute two rather different industries. One that corresponds with the above, and another which is labour-intensive and low-tech and denoted ‘artisanal and small-scale mining’ (including coal) (Hilson & Gatsinzi, 2014). Small-scale mining is found across Asia, Africa and Latin America and is estimated to directly employ about 25 million people worldwide while the livelihoods of up to 170 million people depend on such activities (Gunson & Jian, 2001; Hruschka & Echavarría, 2011). Moreover, while a nuclear power plant fits quite well with the taxonomy outline, several forms of renewable energy technologies do not. Solar PV, hydropower and wind can all be both distributed small-scale and concentrated in large-scale projects with implications for employment opportunities in services and manufacturing inputs. A similar distinction can be found within oil and gas activities. The recent shale gas ‘boom’ in the US has created about 1 million jobs distributed across resource production, manufacturing and services (Bonakdarpour & Larson, 2012; The Economist, 2013). Although textile industries on average surely are more labour-intensive than oil and gas activities in developing countries, we must be aware that simplifying taxonomies can be misleading. This foreshadows the proposition that it may be less important *what* you do than *how* you do it.

Developmental potential across different natural resources: the key issue

It is by now clear that the taxonomy of soft, hard, and energy natural resources presented above is not flawless. The taxonomy has been used by researchers to argue that the developmental potential of NRIIs systematically varies across the three groups with reference to few linkages, little job creation, and no externalities (Farooki & Kaplinsky, 2012; Morris, Kaplinsky, & Kaplan, 2012b). One conclusion arising from this line of thinking is that resource intensive developing countries should primarily pursue expansion of soft resources.

Still, in many places of the world, including in developing countries, agriculture, forestry and fisheries are very capital-intensive and technologically complex operations (see for example chapter 4). Moreover, as we saw above, hard and energy resources may also differ significantly from the taxonomy. This is because development processes are always concrete, rooted in time and place. Hence, the taxonomy is not universal but mirrors a specific snapshot of reality.

Although the taxonomy may reflect a relevant part of the picture, we argue that in order to understand the development impact, there is a more fundamental distinction to be made. The key issue is that we should be more concerned about whether the expansion of NRIIs is associated with innovation-driven knowledge intensification of production activities and beyond to enhance productivity, employment and diversification, rather than about the type of resource produced. We are, in other words, interested in *processes* rather than *structures*.

Summing up: A dynamic perspective on resources and their production

Most of the theoretical arguments critical of natural resources implicitly presume that natural resources are not an outcome of production processes but are extracted, which requires minimal effort. It follows that learning and related spillover effects are negligible. This line of thinking is, however, flawed. It rests on the assumption that nature, which is freely available, equals natural resources (extracted products) (Andersen, 2012).

Nature is the topic of natural science and concerned with the physical universe. Social science, however, is concerned with the meaning of nature for society, with that ever-changing portion of nature that is known to man and affects his existence. That portion – which we here refer to as 'natural resources' – is both expanding and contracting. It expands in response to increases in knowledge. In other words, nature reveals herself gradually to man, but no faster than he can learn (Zimmermann, 1972).

In the interface between nature and natural resources, there are ongoing processes of resource creation, obsolescing and extension, which are guided by the available stock of knowledge. This dynamic perspective implies that natural resources are not freely available, but instead they are created via advances in our knowledge of the material world, search, exploration, and production processes. It explains how resource deposits continue to grow and how new resources are discovered as we learn (see for example AEO, 2013: p. 136).

The main implication, however, is that the production of natural resources requires inputs from services and manufacturing activities of varying knowledge sophistication. These categories of economic activities are thus complementary.

In fact, this complementarity receives wide global attention in the case of renewable energy such as solar and wind power industries that, in essence, transform nature into natural resources by use of manufactured capital goods and services. These industries are considered major growth opportunities due to the fact that they are, supposedly, manufacturing industries (Mathews & Reinert, 2014). We argue that renewable energy industries are not more manufacturing-intensive than are oil and gas, mining or soybean industries. All are natural resource production processes involving elements from all three main sectors; primary, secondary and tertiary. Our perspective implies that rather than merely being a source of financial capital, NRIIs can, given the right institutions and policies, be drivers of skill creation, job growth, innovation activities and industrial diversification processes with impacts on the wider economy.

1.3 Towards a new approach to natural resources and development

There have been different reactions to the dominance of the resource curse thinking. Among the more compelling, Wright and Czelusta (2002, 2004a, 2007) along with David and Wright (1997) argue that natural resources should be seen as endogenous (with linkages) to the economy and as contingent on the stock of knowledge. On the basis of a range of historical case studies, Wright and Czelusta argue that NRIIs have been central to economic development in the United States. In principle, they argue that knowledge accumulation increased the natural resource richness of the country, and that it is possible for NRIIs to lead economic development for extended periods of time. They further suggest that these NRIIs in the US were instrumental for being part of the more recent knowledge economy. Similar observations regarding the linkages between science and natural resources in Brazil led Bound (2008) to describe the Brazilian economy as a 'natural knowledge economy'.

More recently, different kinds of studies have demonstrated that NRIIs can be sources of important innovations and technological opportunities and have generated significant and knowledge–intensive linkages to other parts of the economy. The studies include high-income economies such as the US, Norway and Australia (David & Wright, 1997; Smith, 2007; Ville & Wicken, 2012), middle income developing countries such as Chile, Argentina and Brazil (Andersen, 2015; Dantas, 2011; Iizuka & Katz, 2010; Marín & Petralia, 2015; Marín & Smith, 2011) and low-income countries in Sub-Saharan Africa (Morris et al., 2012a; Ovadia, 2014; Teka, 2011; UNIDO, 2012). Combined, these studies constitute the beginning of a new wave of thinking about NRIIs in relation to learning, innovation and competence building – and about the possibilities for innovation based natural resource intensive development.

This branch of research does not reject the insights from the resource curse debate. Sound management of macroeconomic fundamentals, careful exchange rate policy, institutional quality and 'good governance' are important factors in a development strategy. Also, there has historically been a tendency for NRIIs to be enclave industries in developing countries. But as the review above illustrated, this is not necessarily an inherent property of NRII. The question then becomes, not whether, but how natural resource rich developing countries should seek to transform their natural resource deposits into national wealth.

Furthermore, a number of major international organisations have recently published policy reports on the development potential of NRIIs, see inter alia (AEO, 2013; Buur et al., 2013; UNCTAD, 2013; UNECA, 2013; UNIDO, 2012). Most of these reports highlight lacking domestic knowledge and competences in both the public and private sectors as a central barrier for potentially virtuous circles of development around natural resources. We know from decades of innovation research that such broad-based competence building involves collective, systemic and context-dependent learning processes that can be adequately conceptualised and analysed by use of the innovation system framework. The present Review adds to these recent reports by exploring how LICS building can support development led by the expansion of NRIIs.

1.4 A new context for natural resource intensive industries

Besides strong growth in the demand for natural resources, other changes in the world economy have been radically transforming some of the conditions under which all sectors operate. There is tendency that several manufacturing industries, which were dynamic and high-tech in the past, are now experiencing becoming standardised commodities with low technology content and market dynamism (e.g. some electronic goods, textiles, parts of the automotive industry, etc.). At the same time many NRIIs, which were low-tech and with low dynamism in the past, are now dynamic (Marín et al., 2015; Pérez, 2010). Key examples are the agricultural, oil and mining industries that have all become high-tech on the basis of massive investments in knowledge by different types of actors. The literature has identified four sets of changes that are creating new opportunities for innovation, dynamism and linkages for NRIIs in general: changes in the volumes of demand, changes in demand requirements, changes in knowledge bases, and changes in institutions and the global market context (see chapter 4 for elaboration).

Moreover, other tendencies could be conducive for enhancing the domestic dimension of the often global NRIIs. First, 'resource nationalism' is increasing in both African and Latin American countries (Bremmer & Johnston, 2009). This generates new requirements on foreign investors that may counteract the formation of enclave industries. Policy instruments include nationalisation of natural resource deposits, expropriation or disinvestment requirements, local content and linkage requirements, as well as increases in taxes and royalties (Buur et al., 2013).

Second, multinational corporations (MNCs) in NRIIs are increasingly outsourcing non-core functions locally and, due to new competition and resource nationalism, applying Corporate Social Responsibility measures to enhance transparency and engagement with local communities. Combined, these factors create a new opportunity space for domestic linkage building (Morris et al., 2012b).

Third, traditional MNCs in NRIIs (mainly from the United States and Europe) are more and more being challenged by new, increasingly competent state-supported 'national champions' from both Asia, Africa and Latin America (Buur et al., 2013; Morris et al., 2012b). This implies that local governments have a better bargaining position to negotiate the extent and nature of local linkages with competing MNCs.

Fourth, unlike previous natural resource booms, many developing countries now possess significant technological capabilities and diversified local firms. This is part of a broader geographical redistribution of innovation power and capabilities and growing South-South technology interaction (Dantas et al., 2013). Better competences in developing countries have incited MNCs to increasingly employ local companies (Buur et al., 2013). This facilitates building not only more linkages (quantity) but also more knowledge-intensive linkages (quality of linkage).

In addition to the opportunities of development on the basis of NRIIs, researchers have noted that the low-wage, labour-intensive, simple manufacturing development path (the 'East Asian Miracle' model) is now congested if not blocked by Asian countries. Moreover, the historical examples of innovation based natural resource intensive development in Europe and North America relied heavily on natural barriers such as transport costs. This has now changed with the technical development and globalisation. Also, current trade liberalisation policies are tougher than in the past albeit import-substitution-industrialisation policies were important for both Asian and 'Western' economies (Chang, 2002; Morris et al., 2012b). This implies that low-tech manufacturing-export based development is now, albeit not impossible, even more difficult to achieve than in the past. This makes the possibility of a development path based on the expansion of NRIIs further alluring. The latter also suggests that natural resource rich developing countries must now identify and follow a different kind of development model than has been the dominant benchmark during recent decades. A 'following the natural resources' development strategy can and should not replace a manufacturing development strategy. Such strategies need not be in conflict but rather have a large potential for development synergies, as we will see later in this review.

New opportunities, however, also raise new challenges. The increasing world demand for resources is putting significant pressure on the long term sustainability of these resources and on the environment from which these resources are extracted, by increasing levels of pollution, water contamination and scarcity, the threatening of species diversity, etc. (see chapter 5). The commoditisation and privatisation of resources in areas where the natural resources were before in the hands of local communities is creating conflicts over access to income and decision-making processes in these communities (for example, in the Amazonia in Brazil).

Furthermore, the intensification of technology and knowledge in the exploitation of resources is creating issues of property rights when this technology is proprietary and owned by a few companies that introduce barriers to the use of this knowledge. Thus, whether community rules of interaction are respected and local institutions are able to secure an efficient and socially equitable exploitation of the resources becomes central to the possibility of innovation based natural resource intensive development (Katz, 2014). One implication of this is that the LICS building involved should be both inclusive and sustainability-oriented.

1.5 Structure of the Thematic Review

Chapter 2 is about the importance of thinking in terms of processes vs. structure when analysing the possibilities of development based on NRIIs. Our main argument is that artificially separating primary, secondary and tertiary sectors does not help to analyse possibilities of change. NRIIs (or primary sectors) typically demand new knowledge and innovation to solve their problems. Entire new activities and enterprises could be developed to satisfy these requirements. We highlight the need to look at the complementarities and necessary linkages between the different types of sectors, and analyse them jointly to grasp the possibilities of structural change. Here, the importance of adopting a systemic approach, with innovation at the centre, becomes clear.

Chapter 3 discusses more in detail the possibilities for linkages and diversification between 'recipient' NRIIs and enabling industries based on what existing studies have shown. One of the main arguments of the chapter is that opportunities for linkages are very high in NRIIs due to the complexity of the activities often involved in the production of natural resources and due to local specificities. However, very often, important existing knowledge gaps make it difficult to take advantage of these opportunities. We argue that the development of local innovation systems oriented to fill these gaps appear to be crucial.

Chapter 4 discusses a new opportunity for structural change and development related to NRIIs. It is argued that some NRIIs are becoming themselves enabling industries, which enlarges the opportunities of transformation in association with them. We then discuss, in the context of these changes, how the processes of linkages creation and innovation should be examined in a particular case, in order to develop policies oriented towards taking advantage of the boom in natural resource demand. It becomes evident in the analysis that some important challenges have appeared, as well, together with the new opportunities for change in association with NRIIs, and if these are not addressed, new opportunities might be missed.

Chapter 5 discusses the main sustainability challenges emerging from expanding NRIIs. It asserts that sustainability problems associated with NRIIs, though significant, are not very different to the ones emerging in association with other economic activities. It reviews the more urgent challenges and proposes different ways to address them with policies.

In chapter 6, we outline some policy implications for national governments, the international community and donor agencies and NGOs.

We end the Globelics Thematic Review with a postscript by Raphael Kaplinsky who has done extensive work on the importance of global value chains (GVCs) for development and innovation. In this postscript he reflects on the Thematic Review with a focus on how GVCs may take different forms in NRIIs as compared to other industries. He further contemplates what the implications of the latter for research and policy might be.

2. Natural resource intensive industries and structural change

A key issue underlying and motivating this review is, as Hirschman (1958) formulated it, "how one thing leads to another", which epitomises a linkage and process approach to development. Linkages between actors convey impulses for change whose ultimate outcome is conditioned by the environment in which they take place. Linkages take distinct forms across levels of analysis. At the level of companies, the issue is how the activities of one company facilitates the establishment of another firm by delivering inputs, processing outputs, or by entering its market to compete. At the level of industries, the question is how one branch of economic activities stimulates the emergence of other economic activities. At the national level, structural change is about changes over time in the sector composition of the economy. The latter is often portrayed as changing specialisation patterns from primary production (NRIIs) to secondary production (manufacturing) and towards tertiary production (services) – a perspective we refer to as 'the tripartite model'. The question of how one thing leads to another is thus inherently one of industrial dynamics. Prominent evolutionary scholars have made seminal contributions to our understanding of industrial dynamics (e.g. Jospeh Schumpeter, Simon Kuznets, Erik Dahmèn, and Richard Nelson). From them we know that industries tend to grow in clusters, that the locus of change moves over time via emergence of new industries, that the latter is intimately linked to the transformation of existing industries, and that innovation is a core enabler for the unfolding of these industrial dynamics. When considering this heritage, we come to understand that the tripartite model of structural change is rather misleading because the industry clusters that grow over time evidently crosses these boundaries via different forms of relatedness and linkages. In this chapter, we outline how natural resource intensive industries can contribute to structural change via linkage dynamics.

2.1 Structural change and Innovation

Economic development is, in the longer run, associated with a process of structural change of the economy where its composition of industries (types and sizes) changes. There are, however, different interpretations of the mechanisms underpinning such transformations. In the New Palgrave Dictionary of Economics, Matsuyama (2008) defines structural change as:

> "a complex, intertwined phenomenon, not only because economic growth brings about complementary changes in various aspects of the economy, such as the sector compositions of output and employment, the organisation of industry, the financial system, income and wealth distribution, demography, political institutions, and even the society's value system, but also because these changes can in turn affect the growth processes".

Early work on structural change sought to identify generic patterns of development. The overall conclusion was that as the economy grows, the production shifts from the primary to the secondary to the tertiary sector (Matsuyama, 2008).

This perception of structural change is also supported by the findings of Kuznets (1971) who searched for characteristics of economic growth in the period between 1850 and 1950 in now high-income countries. Kuznets categorises production in three sectors: (A) agriculture and related industries like fisheries, forestry and hunting; (I) mining, manufacturing, construction, electric power, gas and water, transportation, storage and communication; (S) trade, finance, insurance and real estate, income from dwellings, and a variety of personal, professional, recreational, educational and governmental services.[8] As can be seen from the table below the shares of (A) and (I) changed significantly during the period.

Table 1: Structural change in now high-income countries

Sector	Share of GDP 1850/1900	Share of GDP 1950
A	More than 40%	Less than 10%
I	22-25%	40-50%
S	No general trend besides a modest increase, especially in governmental services.	

Source: Kuznets (1971).

The majority of the increase in (I) was accounted for by manufacture (around 70%). Within manufacturing, the metal fabricating and chemical-petroleum branches rose conspicuously while industries in decline were textile and clothing, along with wood and leather. In terms of employment, the (A) sector went from employing 50-60% of the workforce in 1850 to employing 10-20% in the early 1960s. The share of the work force employed in sector (I) grew less than the fall in sector (A), hence sector (S) employed still more people. Focusing on sector (I) in the United States (1880-1948), Kuznets found strong diversity in growth rates between different groups of manufacturing activities attributable to technological change. He concludes that economic growth is strongest in the industries with most innovation. It thus seems obvious to infer that innovation is the driver of growth, and that large parts of what we have defined as NRIIs do not innovate, and therefore become less important in modern economic growth.

This picture of history indicates that economic development is, in fact, equivalent to moving out of and away from NRIIs. Still, there is not a complete consensus on what lies behind these patterns of structural change and what, if any, the role of NRIIs have been in the process. For example Cohen & Zysman (1987) argue that the dominance of the outlined model of structural change and development is problematic. This is so because even though it is only a hypothesis, it helps coordinate the way economists think. In other words, it reflects:

> "…a popular understanding of how an economy works and ought to work: it is simply clear as a bell that a country that does brain surgery and computer programming is, in a fundamental way, ahead of a country that does not and cannot. But it is a slippery path from that hard truth to a model of development — and worse, a policy for development — based on those categories which now become analytical categories though they embody no real theory, though they do not square with the realities of economic organisation and linkages, and which, like the Brand X candies in the M&M's ads, melt in your hand when you try to use them" (p. 9).

Hence, although intuitively persuasive, the tripartite explanation of long-run structural change has surprisingly little to say about the characteristics of the underlying processes. To this point, Kuznets argued that the observable structural change was driven by clusters of 'growth industries' fuelled by innovation activities. Focusing on sector (I) in the United States, Kuznets found that in 1948 over a third of the value of manufacturing production was accounted for by economic activities that did not exist in 1880, or had such a limited size that they in total only produced 3.2% of the total manufacturing output. On this basis, he concludes that (1) growth rates differ across industries; (2) 'growth industries' grow in groups of related industries; (3) 'growth industries' change over time; (4) economic development is associated with shifts in economic structure; (5) the source of these shifts is predominantly innovation activities.

Kuznets also argues that even if innovation may be the main source of structural change, there are at least two other important sources as well. First, differences in income elasticity between product groups lead to shifts in the structure of demand as a result of economic growth. Second, global economic growth will change the international division of labour, which will change the level and composition of export and import and, hence, the structure of every open economy. In a period like the present, when fast economic growth in China and a few other countries lead to increased demand for natural resources internationally, the sector composition in natural resource producing countries will change too.

These propositions indicate that one should focus less on whether an industrial structure is characterised by primary, secondary or tertiary production, and focus more on understanding shifts in the structure. Groups of growth industries tend to cross the tripartite classification. Actually, Kuznets himself argued that the growth and development of several now high-income economies has been based primarily on the commercialisation and technological modernisation of agriculture rather than on industry per se. It is, accordingly, a mistake to universally identify 'modern growth' with expansion of manufacturing (Easterlin, 2008). The perspective emanating from this work is that innovation and inter-industry linkages are historically central for structural shifts and development.

2.2. Innovation and linkages

Schumpeter (1934) focused on horizontal linkage dynamics (intra-industry) and innovation via the notion of competition-driven creative destruction. However, Schumpeter, as Kuznets, observed that innovations tend to cluster via vertical linkages (inter-industry) in certain industries, time periods and locations, and that the locus of change moves over time. The latter phenomenon has been described as 'development blocks' on the basis of research on the Swedish economy in the early 20th century, which at that time was very natural resource intensive (Dahmén, 1950).

The basic idea behind the notion of a development block is that complementarity exists among technological, economical and related factors across industries. Due to complementarity, growth or bottlenecks in one industry tends to interact with and affect growth in other industries via linkages between actors that convey flows or impulses of different types. Innovation is often important for setting in motion impulses and overcoming bottlenecks. The effects of innovation are thus likely to spread throughout the economic system across related industries (Carlsson & Henriksson, 1991).

Hirschman (1958) evaluated an industry's 'development potential' by its number of vertical linkages. Using evidence from high-income countries' input-output tables, he inferred that linkages are strong in manufacturing and weak in NRIIs.[9] However, this perspective says little about the *processes* of structural change. The problem that becomes visible is that such input-output analyses tend to neglect the role of innovation in structural change, and instead focus on obtaining the 'right' industrial structure based on a context-dependent and static image (Andersen & Johnson, 2014).

Instead, we need to understand the dynamics and content of vertical linkages to understand structural change (Pasinetti, 1993). As a micro-level interpretation of the latter, Lundvall (1985, 1992) proposes that learning, innovation and competence building activities emerge in or from vertical linkages between users and producers of goods and services. Innovation is seen as a cumulative process that materialises from a confrontation of user needs with technological opportunities. This situation entails interdependence in innovation endeavours between users and producers via linkages. The latter extends the linkage concept from being only about market-based transactions to also containing exchange of information, knowledge and more qualitative items. It is thus meaningful to distinguish between the quantity and quality of linkages. Quantity refers to the number of linkages. Quality refers to the content of linkages. We will refer to linkages that stimulate learning, innovation and competence building activities as 'high quality linkages' and linkages that mainly contain arm's length transactions as 'low quality'. Enhancing the quality of linkages is equivalent to deepening the knowledge intensity of linkages.

Such a user-producer linkage approach has several implications for the understanding of structural change and economic development: (i) innovation and economic performance changes from being seen as exclusively individual to being seen as predominantly collective and distributed; (ii) the approach suggests that innovative activities will be related to prevailing economic structures; (iii) communication skills and the ability to identify problems and possibilities on behalf of both users and producers become very important. The input-output method for identifying linkage potential contains valuable insights, but it focuses mainly on the quantity of linkages. It is too static and must be complemented with attention to both the quality of linkages and the processes of change in linkages over time.

2.3 The Demand for knowledge

A consequence of the interdependence between users and producers in innovation is that the competence of users (quality of demand) may be just as important as competences of producers. This has important implications for how we understand both innovation and structural change. Pol, Carroll et al. (2002) and Robertson, Pol et al. (2003) propose to view industries as either 'receptive industries' or 'enabling industries' in order to better understand inter-industrial dynamics. A firm is part of enabling industries if outcomes of learning and innovation are exported to and applied in other industries. Firms in recipient industries innovate less, only use it within own industry, and tend to buy 'efficiency-enhancing' products or processes from enablers. Enabling industries tend to have high growth rates, be new, small in size and 'high-tech' while recipient industries tend to be large, 'traditional', 'low-tech' and have moderate growth rates.[10] Companies in NRIIs predominantly belong to the category of recipient firms while their supplier industries are often enabling companies.

Again, it is tempting to conclude that enabling industries make up the 'growth industries', but they often innovate in collaboration with and on the request of recipient industries. Actually, demand from recipient industries is often needed in order to make investments in innovation profitable. In other words, it is often mature, low-tech industries that via their demand for complex goods influence the direction and intensity of innovative activities in enabling industries. Demand from incumbent industries (recipient) are thus not only shaping but also driving the development of 'high-tech' (enabling) industries to some extent (Sandven et al., 2005). We may think of an enabling industry as consisting of networks of supplier companies that in natural resource intensive industry dynamics play an important role in overcoming the knowledge barriers for linkage formation and deepening. Dietrichs (1995) suggests that the transformation of incumbent industries and the creation of new industries are often two distinct, but interacting, mechanisms in structural change. Thus, shifts in industrial structure can partly be ascribed to high-quality linkages between firms from distinct, but related, industries that make up development blocks crossing the tripartite classification.

The quality of demand is partly determined by firm competences in NRIIs. Laestadius (1998, 2000) observes that Swedish firms in pulp and paper industry spend significant resources on competence building to interact with external technology suppliers, to adapt technology, and to identify, articulate and communicate experiences and demands/needs precisely for equipment suppliers. Such user competences can be seen as co-determinants of the quality of linkages.

This linkage approach to structural change implies that new growth industries, products and processes are very rarely isolated islands, but part of and often emerging from an existing system of production. Thus, for example, some manufacturing industries could not have grown as they did unless there were a strong demand for new knowledge from inter alia the primary sector in form of, e.g. mechanisation, packaging, transport, and conservation.

Acknowledging that new knowledge is central to the underlying mechanisms of structural change moves focus from interaction between users and producers of *products* to users and producers of *knowledge and information*. For example, linkages between firms, universities, R&D organisations or other entities affecting learning, innovation and competence building become important, too. Both actors and linkages are embedded in a wider social system that may be more or less supportive. Hence, in order to grasp how linkages between actors change, along with the interaction of the latter with a wider context, we need to apply a LICS perspective.

2.4 Are some industries better than others? Towards a systems approach

Some define an industry's 'development potential' by its number of linkages, others by the size of its growth rate or technological intensity. To understand the role of NRIIs in development, we need to lift our gaze from individual companies to interconnected networks of production and interactive learning related to the production of natural resources that cross and break the tripartite classification.

Emergence of linkages from a 'recipient' (natural resource intensive) industry to an 'enabling' input supplier of capital goods, or a firm that processes the natural resource further, is equivalent to establishing a new firm or form of production – often in competition with foreign companies. In a given context, actors must overcome a 'knowledge gap' to establish this linkage. Once established, the knowledge intensity of it may be deepened by moving towards more complex problem-solving activities, which involve overcoming a sequence of knowledge gaps. A firm or individual's propensity to learn, innovate and build competence is influenced by a variety of factors that differ across contexts. Industries' propensity to innovate differs, for a number of reasons, across location, industry type, and time.

First, capabilities to produce and to learn, embodied in individuals and firms, are unequally distributed, wherefore actors learn at different rates (Dosi, 1988). In addition, to which extent firms and other organisations pursue learning, innovation and competence building depends on their respective strategies, which, in turn, greatly depends on the kind of incentive structure they face. Thus, even if knowledge bases and demand structures were identical across industries, firm diversity would ensure different innovation outcomes.

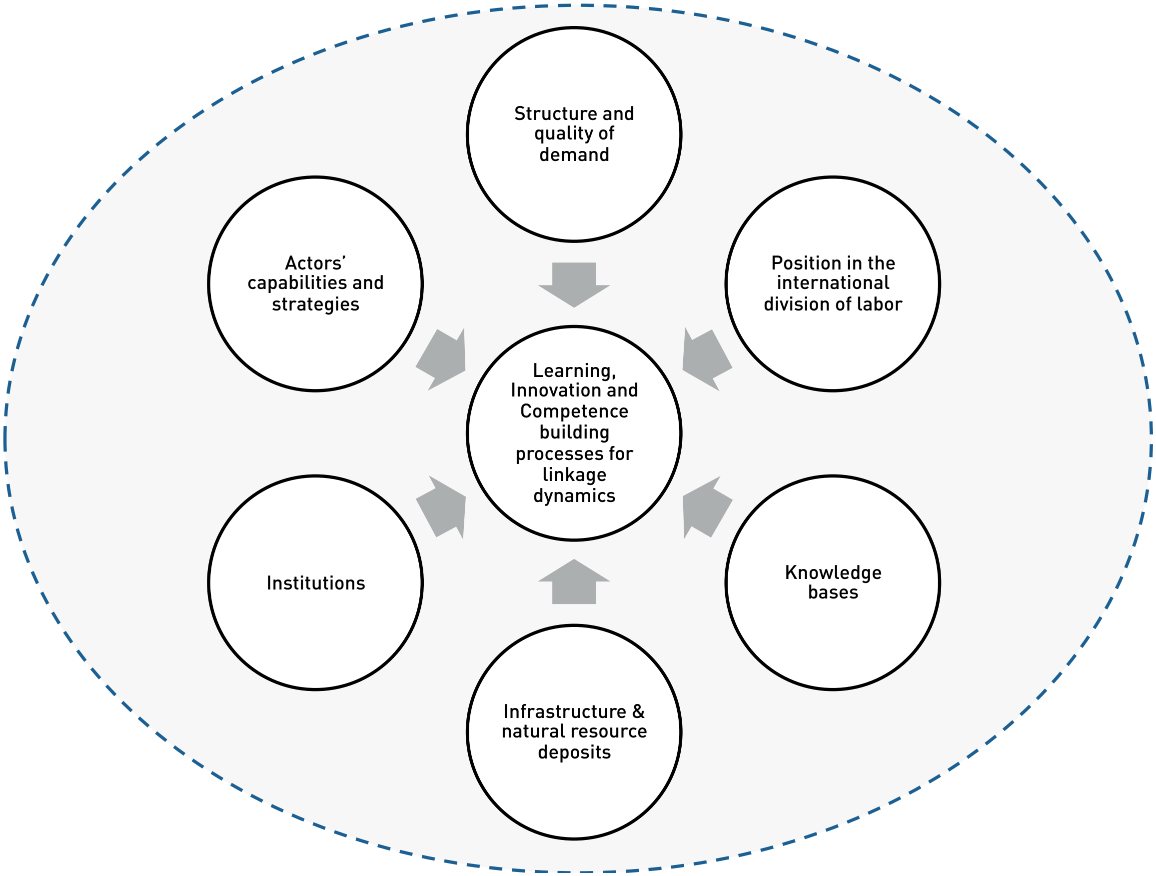
Second, industries differ in technologies used and they therefore rely on different knowledge bases (Dosi, 1988). Connecting to (or advances in) *knowledge bases* fundamental to a given industry may rejuvenate even mature industries. In addition, firms' and countries' capacity to connect to, absorb, utilise, and reproduce (often international) knowledge bases differ widely. Hence, the 'technological opportunity space' favours some industries over others at any moment in time.

Third, even if knowledge bases and capabilities were identical across industries, the intensity of innovation activities would differ due to differences in demand growth, which often induces innovation activity. Income elasticity varies across product groups so some products will always constitute a diminishing part of consumption and others an increasing part.

The interactions between these factors are embedded in a context made up of institutions[11], infrastructure, and natural resource endowments, which within the context of the international division of labour shape the intensity and direction of learning activities in industries and, over time, structural change in the wider economy. Taken together, these elements and the relationships between them constitute an analytical framework for analysing how domestic firms in developing countries fare in overcoming knowledge barriers to linkage formation and deepening (see figure 5). This framework is also useful for identifying systemic weaknesses and to inform system-wide policy interventions.

Figure 5 gives us a framework for evaluating how different types of industries contribute to develop-

Figure 5: A Learning, Innovation, and Competence building System (LICS) framework for analysing the extent and nature of linkage dynamics.



Source: Developed by authors

ment by stimulating learning activities. The fact that industries differ along several dimensions is relevant for the discussion of structural change. According to the broadly accepted tripartite model of structural change, industries in the primary sector are inferior in terms of development potential vis-à-vis manufacturing and services. Still, industry differences should be assessed in terms of learning, innovation and competence building activities rather than in terms of categorisation within the tripartite model.

Development block dynamics are most likely to emerge from industries with most innovation opportunities. This implies that at any point in time some individual industries are growing more and innovating more than others, and they can therefore be characterised as 'better' for development than others. It thus seems possible to establish a hierarchy of industries for any given moment in time. This can be interpreted as a claim that a development strategy should focus on building those growth industries. Still, the take-off of these growth industries often relies on an existing strong competence base, existence of demand growth, and presence of competent customers to take advantage of opportunities emerging from changes in knowledge bases. New enabling growth industries with high innovation potential very often innovate (with input from science and new technologies) as a response to 'needs' or 'potential' rooted in the existing production structure – in recipient industries. Thus, new industries often emerge as linkage formation where one single firm supplies a larger incumbent customer.

Firms in NRIIs can serve as competent customers to enabling innovative firms. Without these firms, enabling industries would be less innovative. The role in development that this gives domestic NRIIs is further enhanced by mechanisms explained in the home market argument. A dynamic home market often serves as a springboard towards export markets because communication and interaction between firms is often easier when they operate in the same country (Krugman, 1980; Linder, 1961). In some situations, however, the simple dichotomy between home markets and export markets is not very helpful. When the NRII firm is part of a global value chain, it may come to serve as user for enabling firms in other countries rather than the home country – where its developmental role is reduced accordingly. The increasing importance of global value chains makes it even more difficult to identify a best developmental specialization structure for a country. To join such a chain may lead to opportunities for a firm to upgrade its product- and process technologies in different ways. However, upgrading is not guaranteed and the firm may, on the contrary, be locked in to a passive role in a chain where most learning and innovation are located in lead firms in other countries. The possibilities for the government to pursue an active policy for structural change may also be decreased by global value chains.

It is misleading to focus solely on the creation of new industries and to neglect the transformation of existing industries, and the interaction between these mechanisms, because it overlooks the importance of user-producer interaction, and thus the systemic performance of connected industries. By only focusing on new and immature industries, one blurs the understanding of the process of innovation, the complementarity between industries, and ultimately the sources of development. It is of course undeniable that at any *point in time* some individual industries are growing more and innovating more than others. In the short run, these industries can, for a specific 'region', be understood as being 'more promising' than others. But it is not possible to establish a universal hierarchy due to the systemic performance of blocks of related industries.

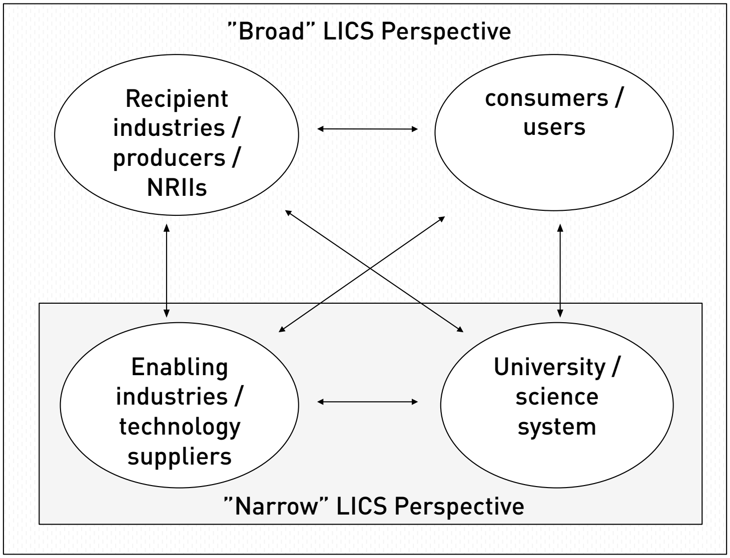
2.5 A Broad LICS Perspective

Innovation Systems research has, almost from the beginning, encompassed two different perspectives; a narrow one primarily linking innovation directly to science, and a broader one comprising, more broadly, learning, innovation and competence building in the economy (Lundvall, 2007). The notion of a LICS is meant to emphasise the latter perspective by explicating the broad set of factors that influence innovation. Our discussion of linkages, innovation and structural change connects with the differences between perspectives. The narrow approach aims at mapping indicators of national specialisation and performance with respect to innovation, R&D and science and technology organisations. In contrast, the broader LICS approach aims at taking into account social institutions, macroeconomic regulation, financial systems, education and communication infrastructures and market conditions as far as these have impact on learning and competence building processes (Lundvall et al., 2009). The broad approach has mainly been developed on the basis of the experiences of small, open – often natural resource intensive – economies (Scandinavian countries) for which the international competitiveness of its firms is crucial.[12] Such economies have a handicap in the 'high-tech' industries because limited investment resources, indivisibilities and scale advantages in R&D make it difficult for them to compete in these areas. Partly as a consequence of this, the diffusion of innovation and absorption of external innovations have been more important for their economic welfare than development of 'science-based' innovations. The mechanisms of diffusion and absorption broaden the innovation system approach, because it now involves the whole population of firms, and not just the firms excelling in patents and R&D expenditure.

In the optic of an interactive learning approach to economics, the difference between a broad and narrow approach is basically about which types of linkages are seen as important. In the narrow one, it is mainly linkages between science and (enabling) technology firms, while linkages between users and producers in production are seen as less important. Furthermore, in the broad approach linkages between domestic and foreign firms within as well as outside global value chains are important. As developing countries are rarely characterised by innovation activities in the 'narrow' sense and since they get most of their new knowledge from abroad, the broad LICS approach is better suited in this context (Arocena & Sutz, 2000b).

Above, we have argued that learning, innovation, and competence building (including R&D) are rarely isolated activities but, rather, tied to production in different ways. For example, in firms with R&D departments, new products are often developed in close cooperation between the research and production departments (Cohen & Zysman, 1987). Furthermore, innovation investments are more effective when tied to production, because of user-producer interaction (Fagerberg et al., 2009; Lundvall, 1985). These arguments point to an important role for existing production structure in innovation, and to most firms being only indirectly related to the science system via enabling industries. Thus, applying a narrow innovation system approach would practically exclude the role of demand from recipient industries (both quality and quantity).

Figure 6: Broad-Narrow LICS perspectives and natural resource intensive industries



Source: Developed by authors

The simple sketch in figure 6 illustrates the differences between the narrow and the broad approach. In it, all linkages (indicated by 2-way arrows) are equally important for learning and innovation in the economic system. It is obvious that a narrow approach will underestimate or ignore the role played by NRIIs (recipient industries). The narrow approach would miss the fact that the initiating factor of innovation might be competent demand from a recipient industry. This implies that a broad approach is better suited for capturing inter-industry dynamics in general and especially in contexts where NRIIs are dominant.

It must be emphasized that innovation systems are always more or less open. This is an important aspect of the broad perspective. To build LICS as part of a development strategy has to take on board the importance of different kinds of linkages between domestic and foreign entities(firms, organizations, government offices, NGOs, etc.).

As learning, innovation and competence building are rarely detached islands, developing countries must necessarily start with a knowledge intensification of the industry structure they already have – whether natural resource intensive or not. In the perspective of the model presented here, the latter would involve competence upgrading for problem identification and articulation in producing natural resources, and creating an environment supportive of interactive learning spaces between recipient and enabling industries. Creating such an environment can be conceptualised as building a strong learning, innovation and competence building system around and beyond NRIIs. The latter is central for facilitating linkage building and overcoming knowledge gaps.

2.5 A natural resource knowledge economy

We have argued that a country's industrial structure at a given moment in time is less important for development than the by institutions sustained interdependency and interaction between the different types of industries over time, and the way in which such interaction is managed or coordinated.

Linkage building is enabled or blocked by development, diffusion and use of new knowledge and capabilities within and around the natural resource activities. It is therefore meaningful to conceptualise the challenge of innovation based natural resource intensive development as that of creating and supporting the institutions and organisations that generate, diffuse and use new knowledge and capabilities in the production and use of natural resources. In other words, we can think about this as building a natural resource LICS.

It is obviously not enough to have access to abundant natural resources. But if you can build an institutional framework for the utilisation of specific natural resources, which supports development of new knowledge and competences, which may again be applied in a range of different activities, INRID may be possible. Therefore, the resource curse is not really about natural resources, but about learning – or the absence of it. Natural resources do not make countries poor, but weak innovation systems do.

The perspective presented implies that we should move away from thinking in terms of secondary being better than primary sectors, and instead focus on industries' contribution to learning, innovation and competence building activities. It also implies that we, when analysing NRIIs, should broaden our focus, from looking at companies producing natural resources to including the networks of users and producers of products, services and knowledge that make up blocks of development across the tripartite classification.

As a further reflection on the implicit value premises that we ascribe to industry classifications, we want to avoid narrow definitions of the knowledge economy. A recent report from the World Bank, for example, pictures a knowledge sector that is somewhat decoupled from the production of goods and services and defines a knowledge economy as:

> "…distinct from agrarian, resource-based, or traditional industrial economies, a knowledge economy is essentially driven by the creation, distribution, and use of knowledge and information. In this respect, it reflects the latest stage of development in the evolution of modern economies, often characterized by an increased use of ICT, globalization, active networking, and various forms of innovation" (Halme et al., 2014).

We know now that all forms of economic production draw on diverse factors of production (capital, natural resources, labour) to varying degrees and that the process is coordinated by our stock of knowledge. This implies that productivity and quality of production comes down to knowledge accumulation via the learning, innovation and competence building processes that unfold in interactive learning networks. The notion of a knowledge economy is thus not necessarily different from a natural resource intensive economy. In the perspective outlined here, the core challenge is to enable knowledge intensification of all sorts of production via LICS building.

The possibility of development on the basis of NRIIs in both the short and longer run should be seen as complementary to, rather than in competition with, development strategies addressing other aspects of the economy, such as manufacturing and services unrelated to natural resources. Innovation based natural resource intensive development should be seen primarily as a sometimes important element of economic development and not as a development strategy for the national economy as a whole.

Lastly, it must be noted that much of the discussion of linkage effects in this chapter has been formulated in terms of a closed economy, in the sense that the importance of high-quality linkages in broad systems of innovation has been discussed regardless of the effect national borders. This is a useful approach if one wants to escape the narrow and static thinking about the role of NRIIs in development connected to the tripartite model. However, since every system of innovation is open to the international economy and since big multinational firms play an increasingly important role in international innovation networks and global value chains, every discussion of a development policy and/or strategy in which NRIIs play a role have to take on board the present and potential position of these firms in the international economy.

3. Linkage dynamics, diversification and natural resources

In this chapter, we build on what was presented in chapter 2 and we elaborate on how linkage dynamics are central to innovation based natural resource intensive development (INRID). First, we connect our considerations about INRID with perspectives on diversification and development. This illustrates the central role of linkages in structural change. Second, we make a general assessment of linkage dynamics related to structural change and job creation during the recent natural resource boom, with special attention to Africa. Third, we review recent research on the potential of, barriers to, and determinants of linkage dynamics. We focus on backward, forward, and lateral knowledge migration linkages. We argue in this chapter that NRIIs have the potential to stimulate structural changes that promote long term economic development and diversification of the economy.

3.1 Linkages and Diversification

The extent to which expansion and potential knowledge intensification of NRIIs (NRIIs) in developing countries today can promote development over longer periods of time and more broadly in the economy is closely connected to whether such an expansion and knowledge intensification is associated with diversification of the national economy. As we saw in chapter 2, development economics has historically emphasised the importance of structural change and economic diversification towards industries with higher value added and productivity – in particular moving from a structure dominated by NRIIs towards one with larger shares of 'modern' manufacturing (Lewis, 1954; Rosenstain-Rodan, 1943). The mechanisms underlying the relationships between diversification and development, however, has received less attention (Frenken et al., 2007).

3.1.1 Diversity, Diversification and Development

Historically, there has been an intimate relation between economic development and increasing diversity and complexity of economies associated with an increasing division of labour. Thus, wealth and development are related to rising complexity that emerges from the interactions between an increasing number of activities and 'capabilities' in the economic system (Hidalgo et al., 2007). Hidalgo and Hausmann (2009) find that cross-country differences in complexity of economies is correlated with cross-country differences in income. They also note that a country's diversity of capabilities tend to influence its ability to develop new capabilities, and the speed with which this process unfolds. Thus, an economy with low diversity – as is the case with many developing countries – will, ceteris paribus, have larger challenges in diversifying further and initiating longer term growth.

It is well-known that innovation most often arises from new combinations of existing items of knowledge (Schumpeter, 1934; Utterback, 1994) and that this in turn generates novelty and increased diversity. Thus, diversity strengthens innovation potential. When seen from a linkages perspective, the more diversity an economy contains, the larger is the potential for the emergence of new linkages and for innovation.

Diversification is often advanced as a countermeasure directed against the perceived resource curse. Diversification, it is argued, improves the productivity of the economy, thus counterbalancing the detrimental impacts on productivity offset by the Dutch Disease in particular. The focus is most often on diversification of the bundle of export products (Hesse, 2008; Wiig & Kolstad, 2012). The latter has a positive 'portfolio effect' because this insulates the economy from external shocks. This is important because many natural resource intensive economies have historically been unable to respond to changes in international markets by diversifying into new traded products (Marín & Benavent, 2011). In addition, diversifying the export bundle ideally allows countries to tap into fast-growing and/or high-value added segments of global markets (UNECA, 2007).

Export diversity most often reflects industrial diversity in the domestic economy. Industrial diversity is, in turn, strongly related to the level and depth of technological diversity of the economy, which to a large extent reflects the strength and specialisation of the National Innovation System and particularly in the business sector. Export diversification thus begins with learning and capability building at home. In this regard, having access to a home market that can serve as a 'learning arena' via local user-producer interaction can be an important factor for successful diversification (Fagerberg, 1992).

In essence, the notion of diversification gives us another way of approaching the issue of what drives structural change and what shapes its direction. At the heart of export and industrial diversification processes, we find diversification of technology, knowledge and competencies that constitute a set of factors that can enable or block the former processes.

3.1.2 Building on related capabilities

Technological diversification does not follow random patterns. Countries' technological specialisation is cumulative and tends not to leapfrog, but rather to change incrementally, building on pre-existing capabilities. This suggests that future technological diversification is constrained, though not determined, by past technological achievements (Cantwell & Vertova, 2004). Diversification – as structural change – is thus a path-dependent process (David, 1985). This means that diversification to some extent must build on and be compatible with existing capabilities, knowledge bases and technology, economic conditions, infrastructure, and institutions (Dosi, 1988). The latter analytical categories are, in fact, dimensions of 'relatedness'. Over time, these dimensions interact to create techno-economic paths resulting in industrial specialisation patterns at both the level of firms and national economies.

Within the dimensions of relatedness, technological relatedness has been promoted as the main enabling factor in both path dependency and path creation. Each economy has a set of knowledge bases distributed across a number of actors (Robertson & Smith, 2008). Combined, these existing knowledge bases constitute a selection environment for new firms and technologies. In addition, incumbent firms will diversify – which they mostly do only unwillingly – in the least demanding directions; that is, where firm routines and competences are most readily applicable with modest adaptations (Boschma & Frenken, 2009). As a consequence, new industrial activities that are related to, or can benefit from, the existing knowledge bases are both more likely to emerge and to grow over time (Neffke et al., 2011).

This perspective implies that diversity per se is not necessarily good for innovation or development. Novelty introduced into the economy ought to be different from, but also related to, existing knowledge bases in order to both add diversity to the economy and to reap benefits of knowledge spillovers. One implication is that the best and proven way to stimulate diversity of an economy is to partly build on what you already have in place. This resonates well with the interactive learning approach outlined in chapter 2. That is, new industries and R&D projects are rarely detached islands, but are related to, and often emerge from, the existing system of production.

Furthermore, although technology is seen as the central enabling dimension of relatedness, it cannot stand alone as explanatory factor for the direction of diversification. As we saw in chapter 2, the emergence of new industrial activities and associated linkage dynamics is shaped by the interactions between inter alia domestic capabilities, structure and quality of demand, knowledge bases, and a range of other factors such as institutions, infrastructure, and natural resource deposits. Hence, relatedness should be understood as a multi-dimensional concept that connects certain economic activities.

In conclusion, the literature suggests that diversification is central to development and that diversification processes are most likely to unfold between incumbent industries and new ones via linkage dynamics. This also signifies that technological diversity can increase significantly even though large, low-tech, and recipient industries continue to dominate GDP and the export bundle as production becomes more knowledge intensive.

3.1.2 The quantity and quality of linkages

As we have argued continuously throughout this Review, a central issue in embarking on a path of 'innovation based natural resource intensive development' (INRID) is the emergence of domestic supplier and/or processing industries around the NRII. To understand how such industries emerge in terms of linkage dynamics, we return to and extend the discussion on the quantity and quality of linkages.

The quantity (or volume) of domestic linkages between the, often foreign, operating firms in NRIIs and domestic firms is important. It is to be expected that a feature of INRID is that the importance of domestic linkages increase over time.

As innovation often emerges in linkages between suppliers, producers and users, the quantity of linkages across the entire economy should, ceteris paribus, be raised to realise the innovation potential of the economy. These can, and often should, be both domestic and foreign linkages. Connecting domestic and foreign firms can, if pursued in the right manner, be a central element of the former's learning strategy to pursue linkage deepening and diversification (Lema & Lema, 2012).

Inter-industry linkages most often consist of rudimentary transactions in stable patterns. INRID involves knowledge intensification, innovation and upgrading in domestic companies enabling them to move from producing simple goods towards more technologically complex and higher value-added products and services. This often also involves establishing interactive learning linkages to different types of research centres and/or multinational corporations (MNCs). As a consequence, the content of linkages is of cardinal importance. The quality of a linkage is high if it stimulates learning, innovation and competence building in the actors it connects. It is of low quality if its contents are rudimentary transactions. Another central feature of INRID and an objective of development policy is therefore that the quality of linkages should increase over time. We refer to this as 'linkage deepening'.

Fourth, diversity grows out of the current industrial structure inter alia in the form of new organisations. It is therefore insufficient to only focus on the quantity and quality of linkages between existing actors. The formation of new linkages should include also the emergence of new firms conducting new economic activities.

INRID involves enhancing the quantity and the quality of linkages to stimulate diversification, emergence and upgrading of domestic 'enabling' industry. Such enhancement is to a large extent determined by the strength of the supporting LICS.

3.2 Natural resources and recent structural change

The relative drop in manufacturing value added to GDP, the rising share of services in African economies, and disappointing employment creation associated with the resource boom have been presented

Text Box 3: Natural resources and development in pre-World War II Norway

Traditionally, Norway has specialised in NRIIs. During the 19th century, Norway responded to demands from the leading economy of the time, England, by increasing export of salted/dried fish and timber. The increasing transport of natural resources from Norway to England stimulated the development of shipping and shipbuilding industries as a backward linkage – by the 1880s, Norway had the world's third largest shipping fleet. As a response to the growing NRIIs, several linkages to what we can call manufacturing appeared. Shipbuilding technology improved significantly, and production of intermediate products related to ship transport took off. Also, saw mills improved their equipment and implemented stream-driven saws in the 1870s. Norway actually started to export pulp and paper machinery in the 1890s. With respect to the fishing industry, whaling and canning took hold. In the 20th century, new NRIIs appeared due to access to cheap energy. Development in chemical and electronic engineering enabled Norway to exploit waterfalls for production of hydroelectricity which attracted foreign investments in energy-intensive products as zinc, artificial fertilisers and aluminium (forward linkage) (Cappelen & Mjøset, 2009).

Foreign capital played an important role during the 19th century, and foreigners had a strong presence in many areas. After independence from Sweden in 1905, Norway nationalised many sectors of the economy that were dominated by foreigners. Politicians implemented 'concession laws' that gave Norwegian authorities control over the relevant water resources. Still, the changes in law allowed for joint ventures between national and foreign enterprises, which according to Cappelen and Mjøset (2009) was aimed at developing a Norwegian knowledge base for the relevant engineering supply industries. Subsequently, manufacturing of turbines and machinery for power production became significant backward linkages through hydropower. Additionally, after World War II, production of components for automobiles developed as a forward linkage from the production of aluminium.

as evidence of NRIIs being a constraint on diversification and development.

A recent and important example of this thinking is that of McMillan and Rodrik (2011). They argue that natural resource intensive economies are at a disadvantage in affecting the structural changes that underpin development – structural change being defined as the movement of labour from low to high productivity activities.

> "…economies with a revealed comparative advantage in primary products are at a disadvantage. The larger the share of natural resources in exports, the smaller the

> scope of productivity-enhancing structural change. The key here is that minerals and natural resources do not generate much employment, unlike manufacturing industries and related services. Even though these "enclave" sectors typically operate at very high productivity, they cannot absorb the surplus labor from agriculture." (McMillan & Rodrik, 2011: p. 3).

Still, this argument begs the question of how so many of the presently developed countries historically entered their industrialisation process while at the same time being heavily dependent on resource exports – the Scandinavian countries, Canada and even the US, for example (see text boxes 3-5). Enhanced access to raw materials can spur manufacturing even in high-income countries – the fillip given to US manufacturing through other countries' access to now cheaper oil and gas is illustrative. The expansion of shale gas in the United States has had a major direct impact on supplier industries such as steel and chemicals and a direct impact on industries that use natural gas liquid as a feedstock, particularly petrochemical plants. The overall increase in US employment resulting from the expansion of shale oil has been estimated to be at least 1 million permanent jobs (Bonakdarpour & Larson, 2012). A major study found that gains in GDP 2008 – 2035 are likely to be of the order of 2.2% and the gain in employment 2.9% as compared with no expansion in shale (Taheripour et al., 2013). Clearly, a large share of natural resources in exports is not an absolute bar to emergence of vibrant manufacturing industries and accompanying productivity enhancing structural change. The outcomes are not given. They are institutionally and policy mediated.

As the quote above illustrates, McMillan and Rodrik (2011) appear to see NRIIs as 'enclave' industries. By contrast, in many countries that have a comparative advantage in natural resources, linkages between NRIIs and the rest of the economy, including domestic manufacturing, are often significant.

In South Africa, important sections of high productivity manufacturing and services sectors are deeply integrated with the mining sector. As and when mining booms, so do these activities. At the height of the natural resources boom, when South Africa enjoyed growth rates above 5%, and when the share of natural resources in exports was consequently rising as a result of higher prices, employment in manufacturing grew – i.e. there was movement of labour into higher productivity occupations, including modern manufacturing. Indeed, it was *only* in this period, 2006-2007, when natural resource prices rose and South Africa enjoyed a natural resource led boom and a consequent rise in the share of natural resource intensive exports, that employment in manufacturing grew and that South Africa experienced positive structural change. Mining in South Africa can thus hardly be termed 'enclave'.

But even in countries with a much less developed mining sector, there are often considerable linkages

Text Box 4: Minerals and oil in the US

By 1913, the US was the acknowledged world's dominant producer in almost every one of the major industrial minerals (David & Wright, 1997; Wright & Czelusta, 2004b, 2007). This was not because the US possessed the richest mineral deposits – indeed many deposits were significantly poorer than those found in other countries. What gave the US the edge was the acquisition of skills and technical know-how. Between 1900 and 1914, the US produced 10 times more copper than Chile even though Chile had, and has, a much larger geological endowment. The US mineral industries advanced in 1870s and 1880s due to huge capital investments, but the major breakthroughs were technological - in areas such as metallurgy and improved conversion processes such as the Bessemer process. Institutional innovations resulting in a liberal and 'softly' enforced legal environment, investments in related infrastructure and knowledge bases such as the geological surveys, and investments in education and research in mining, minerals, geology and metallurgy combined to result in a highly innovative and productive sector.

Moreover, the enhanced production of minerals provided a major impetus to manufacturing:

> "...there is reason to believe that the condition of abundant resources was a significant factor in shaping if not propelling the US path to world leadership in manufacturing…Nearly all major US manufactured goods were closely linked to the resource economy in 'one way or another': petroleum products, primary copper, meat packing and poultry, steel works and rolling mills, coal mining, vegetable oils, grain mill products, sawmill products, and so on...These observations by no means diminish the country's industrial achievement, but they confirm that American industrialisation was built upon natural resources" (Wright & Czelusta, 2002: p. 4-5).

The coefficient of relative mineral intensity in US manufacturing exports actually increased sharply between 1879 and 1914 – precisely the period in which the US assumed global dominance in manufacturing.

with domestic manufacturing. Mining is not necessarily an enclave activity. As mining output has expanded, so has the output of domestic manufactured goods and services for the mining sector. Ghana is a good example (Bloch & Owusu, 2012).

In Africa more broadly, there are clear indications that positive structural change is enhanced when natural resource prices increase and the share of NRIIs in output and exports consequently increases. The recent African Economic Outlook draws attention to what it terms 'Africa's remarkable turnaround'. Between 1990 and1999, structural change made a negative contribution to productivity as workers moved out of higher productivity activities. However, in the period 2000-2005, structural change made a positive contribution, as employment shifted from NRIIs to manufacturing and services. Structural change accounted for nearly half of Africa's overall productivity growth (AEO, 2013: p. 115-16).

As Africa's primary sector has performed better, and as its share of output and exports has risen, partly because of higher prices and partly because of increasing productivity, it has provided a positive spur to employment growth in manufacturing and services and so enhancing structural change. As the African Economic Outlook report succinctly expressed it:

> "What has been holding back Africa is not the large share of its primary sector in itself, but the poor performance of this sector" (p. 135).

Better performance of the primary sector in the recent period has had widespread beneficial impacts on the domestic economy and on processed exports.

> "The recent boom in commodity prices has brought the expected growth effects, but (natural resource) exploration has also expanded much beyond previous efforts, largely driven by demand from emerging partners in the East and the South" (p. 135).

It is misleading to focus only on the relative share of manufacturing in GDP. As natural resource prices rise, both the relative share of NRIIs in GDP and the absolute output of manufacturing increase.

Although exports of processed products have grown at a slightly slower pace than those of NRIIs, they have by no means been crowded out but gained significantly on the back of the trade boom in natural resources (AEO, 2013). In the period 2000-2011 Africa's exports of natural resources rose from $160billion to $350billion (2010 prices). Exports of processed goods rose from $110billion to $180billion. The share of processed goods declined, but there was no crowding out. Growth in processed manufactures increased side by side with growth of natural resource exports[13] (AEO, 2013).

An earlier study of the impact of natural resource prices on economic growth in Africa found a positive correlation:

Text Box 5: Minerals in Australia

Compared to the US, countries like Chile, Russia, Canada and Australia started very late with their natural resource exploitation. Australia is a special case. It was a British colony and part of the British Empire in the same sense as the US in terms of institutions, but it was lacking behind most developed countries in income, education and technology. In USA, people had a 'true entrepreneurship spirit' to go out and create, take risks and look for fame and fortune. In Australia, there was a largely pessimistic feeling about the size and value of natural resources which lasted up until the 1950s. At one point Australian politicians even put export limits on minerals in order to save some for the future. Due to changes in policy and 'attitude', exploration and exploitation of minerals took off and led to many new discoveries after 1960. Canada has a similar story. In 1966, Canada was not seen as a country rich in natural resources (Wright & Czelusta, 2007). This shows us that informal institutions and knowledge are important for perceiving value of nature. It also illustrates that natural resources should be partly understood as a dynamic, endogenous concept.

During the 1990s, the Australian mineral industry increased capital stock and production while the deposits of known resources have grown as a result of more and better exploration. These activities have according to Wright and Czelusta (2007: p. 201) stimulated other economic activities:

> "The surge in production of mineral inputs has carried a number of new and old industries along in its wake. In the decades following the onset of Australia's most recent minerals boom, leading manufacturing industries had obvious connections to minerals: metal and steel products, autos, industrial equipment, petroleum products, ships, and chemicals".

Also, Australian firms are world leaders in mining software systems and, in general, mining firms export services and equipment. Also, based on experience in mining activities, Australian firms have built capabilities in cleaning up air, water and soil, recycling waste and eliminating pollution. These capabilities have proven increasingly relevant as environmental concerns increase.

According to Smith (2007), linkages need not be made directly into related manufacturing industries, but can also lead to service sector development. In Australia, the major financial markets in Sydney are heavily focused on specialised finance for the natural resource sector. Mining involves major risks, and the investment banking and equity markets in Australia are heavily involved in managing the risk spreading portfolio problems of the industry. This has over time led to Sydney evolving into one of the major financial centres of the world, which is partly owed to its background in NRIIs (which continues to be one of its major specialisations). The Australian example also illustrates that there can be important linkages between primary, secondary and tertiary sectors. Here, the importance of research and related learning was seen, too.

> "…there is no obvious sign that high commodity prices are more of a curse than a blessing. African economies remain heavily dependent on exports of natural resources and, as one might have expected from first principles, those economies do better when the prices of natural resources are rising than when they are falling" (Deaton, 1999: p. 38).

The African Economic Outlook conveys further interesting data on employment generation in African NRIIs. Greenfield foreign direct investment (FDI) created about 600.000 jobs in NRIIs between 2003 and 2012 with about 400.000 of these in mining. Using an (conservative) employment multiplier of 2, the African Economic Outlook estimates that a total of 800.000 FDI related-jobs were created in mining. This is in addition to the about 6 million artisanal and small scale miners in Africa that also benefitted from higher prices (AEO, 2013: p. 141-42).

Referring to accumulated household surveys, the African Economy Outlook also records that in African countries, labour force participation for both men and women increased between 2001 and 2007. Moreover, there was an overall shift in employment from agriculture to services and manufacturing (AEO, 2013: p. 116-17). At the same time, the working age population in Africa increased with approximately 65 million persons (ILO, 2007). Hence, as the resource boom unfolded, employment grew both in relative shares and absolute numbers (UNECA, 2013). That employment also grew in services and manufacturing indicates that the expanding NRIIs do have linkages to these activities. The strength of these linkages might have been greater and the associated GDP growth and job creation stronger. Growth might have been more inclusive, in other words. It is a task for future research to explore this issue further and for policy to address it.

Although all sectors in these economies expanded in absolute terms during this period of growth, the NRIIs expanded more than services, with manufacturing expanding the least. Hence, the shares in GDP of services did not change while that of manufacture declined. Still, this might be expected because structural change is a much slower process than responses to price increases (expanding what you already know how to do). It need thus not be a problem for longer-term development that NRIIs dominate, as long as there is a flow of revenue from natural resources that serves to stimulate diversification for the longer run. UNCTAD (2013: p. 111) shows that such mechanisms are in place for the wealthier NRIEs where there is a positive correlation between higher resource income, growth and investment. This, however, may not be the case for the poorest NRIEs. On the basis of available data, it may be too early to conclude definitively what the structural change effects of the recent natural resource boom are, because this is a long-term process. The African Economic Outlook concludes that, albeit slow, development-enhancing structural change is taking place in Africa. A key challenge is to accelerate this process and make it more inclusive (AEO, 2013). Such acceleration can be achieved by enhancing the quantity and quality of linkages around the NRIIs to, for example, advance in global value chains (AEO, 2014).

While, overall, the collection of studies are admittedly patchy and many other factors are at play, the evidence does suggest that rising global natural resource prices and a consequent rise in the share of natural resources in output and particularly exports is positive for growth and for structural transformation measured by output, employment and exports in manufacturing and services. In the following, we explore linkage dynamics in more detail.

3.3 Backward linkages

It is important to have in mind that empirical work on mapping and exploring linkage and innovation dynamics related to NRIIs is relatively scarce and much of it is anecdotal. According to a recent report from UNIDO (2012), there have only been a few systematic studies of linkages around NRIIs in developing countries. The report further argues that research has concentrated on fiscal linkages, which mainly interests macroeconomists. Within the work that does exist – including both historical and contemporary studies – focus has predominantly been on backward production linkages – i.e. the emergence of domestic input supplier industries in a context dominated by Multi-National Corporations (MNCs). In this section, we will briefly summarise what we have learned from these studies, with a focus on work on different mining industries in a set of African countries. We rely particularly on the recent work of Morris, Kaplinsky and Kaplan (see Morris, Kaplinsky, & Kaplan, 2012a, 2012b). We supplement the latter with historical case studies.

In general, mining firms have recently enhanced their domestic linkages. They are increasingly focusing on their core competencies and outsourcing other activities to domestic firms who specialise in these activities and are hence able to supply at lower prices than the mining companies could produce in-house. Moreover, contrary to the common view of mining industries as intrinsically enclave activities, mining companies have currently a considerable interest in procuring from domestic suppliers. This is especially so where transport and logistics are poorly developed and where, consequently, imported inputs are costly and subject to considerable delays and uncertainties.

Despite such linkage enhancement via procurement activities, the overall situation is that linkages are limited and that those that do exist are of low quality. The latter is particularly true for NRIIs in Angola, Botswana and Tanzania. On the other hand, South Africa's mining industry has linkages of both significant quantity and quality. The studies further found that NRIIs in Gabon, Ghana, Nigeria, and Zambia lie in between the latter two groups. On this empirical basis, a number of important factors that influence linkage dynamics are identified (Morris et al., 2012a, 2012b).

3.3.1 Capabilities and strategies of actors

The capabilities and strategies of actors – both domestic and foreign – are influential. The fact that lean and just-in-time production has come to characterise large multinational mining corporations as much as manufacturing firms tends to favour suppliers located in close proximity. As a consequence, procurement strategies of such companies can give openings to domestic suppliers. The major barrier for domestic actors, in turn, is that often significant 'knowledge gaps' persist between what they can deliver and what the MNCs expect (also see AEO, 2013: p. 169).

3.3.2 Demand

Second, the sustained *demand* growth for natural resources on global markets has been a fundamental driver behind the expansion of NRIIs, and thereby also for creating domestic linkage dynamics. We may add that the latter global demand for natural resources has been translated into domestic demand for goods and services through a combination of private procurement strategies and its interaction with public regulation (such as local content requirement policies).

3.3.3. Natural resource knowledge idiosyncrasy

A key issue that emerges from recent research is that NRIIs very often face specific geological and agro-ecological conditions, which vary from context to context. Therefore knowledge produced in a specific location might not always be useful to every other location (Andersen & Wicken, 2013; Kaplan, 2012) We refer to this feature as 'natural resource knowledge idiosyncrasy'. There is an important difference between the manufacturing industries and NRIIs on 'local specificity' of knowledge required. While manufacturing activities can produce homogeneous output given the same input and production process regardless of geographical location, this is not possible in NRIIs.

This aspect of NRIIs questions the usefulness of the conventional model of technological upgrading of firms in developing countries for understanding development on the basis of NRIIs. The conventional model conceptualises learning and technological upgrading in firms as a sequence that starts with the copy and replication of existing technologies developed by firms in advanced countries, followed by creative imitation, when incremental improvements are made to the original technology, and finished by innovation when, and if, firms from emerging economies are able to create completely new things. This conventional model, developed mostly on the basis of the experience of manufacturing industries, particularly high-tech (such as electronics, automotive, and capital goods) of South East Asian countries, suppose that existing technologies are available to solve domestic problems (Amsden & Tschang, 2003; Hobday et al., 2004; Kim, 1991; Lall, 1987; Lee, 2013; Mathews, 2002). However, this is not always the case if natural resource knowledge idiosyncrasy is involved.

For example, in order to face natural resource knowledge idiosyncrasy, some firms in developing countries have developed different pathways of technological upgrading to those followed by industry leaders from advanced countries. This was because, among other things, the first step – knowledge imitation – on the ladder of upgrading, which worked well in manufacturing, was not available. Figueiredo (2010), for instance, has shown how some Brazilian firms within the pulp and paper industry took advantage of the specific agro-ecological conditions of some areas of Brazil, which were favourable to the fast and efficient growth of eucalyptus, developing a completely new trajectory of pulp and paper production based on this tree. A trajectory that could not be imitated in the rest of the world by world-leading firms to produce pulp and paper. This process involved the development of capabilities to improve eucalyptus-growing technologies, and by developing new processes of pulp and paper production out of eucalyptus, which were not previously available. The importance of natural resource knowledge idiosyncrasy is further exemplified by recent events in the salmon farming industry in Chile (see Text Box 6).

Natural resource knowledge idiosyncrasy can provide an interesting opportunity for developing countries endowed with natural resources by giving leverage for developing countries in negotiating the use of resources with large multinational firms who own generic frontier technology. For instance, Iizuka and Thutupalli (2014) describe how in India, in cotton, local seed firms were able to negotiate better with large multinationals (i.e. Monsanto) due to the fact that they own local varieties.

There are also numerous cases from inter alia agricultural machinery in Brazil (Andersen, 2011), offshore Oil and Gas equipment in Norway (Andersen & Wicken, 2013), and mining equipment in South Africa (Kaplan, 2012) that show how the absence of appropriate natural resource specific technology at the global market created an opportunity – a 'protected space' without competition from MNCs – where domestic linkages and capability building could prosper around the NRIIs.

Another implication of natural resource knowledge idiosyncrasy is identified by Bridge (2008), who argues that due to heterogeneity of oil deposits it is difficult for the O&G technology suppliers to achieve economies of scale. Instead, it is more likely that these firms will pursue economies of scope (diversification) by using their engineering competencies to enter upstream segments of other industries. This feature is likely to characterise most NRIIs. Hence, the markets for technology that is appropriate for natural resource knowledge idiosyncrasy in a given context may be many but each is of limited size. As a consequence, technology suppliers tend to migrate across industries (see section 3.5). Also, where local or domestic technology suppliers are absent, it is likely that inappropriate technological solutions developed elsewhere are applied, resulting in less efficient production. However, the absence of scale economies for suppliers may also work as a disincentive for firms to invest in the generation of natural resource-idiosyncratic knowledge.

Although Globelics researchers working on NRIIs have only recently begun to explore this

Text Box 6: 'Local specificities' of the natural resource intensive industries and knowledge

Salmon farming industry in Chile is currently, after the sanitary crisis in 2008, trying to cope with the environmental sustainability issue of finding a good balance between the given natural conditions and the farming activities at different geographical locations (Iizuka & Katz, 2011, 2015). This industry has grown rapidly since the mid-1980s on the basis of technological transfer from countries such as Japan, USA, Canada and Norway with regard to rearing techniques and specialised production equipment. Up until the crisis in 2008, the industry was considered a remarkable success, becoming the leading exporter of salmon after Norway (Iizuka, 2007; Katz et al., 2011; Katz, 2006; Maggi, 2007; UNCTAD, 2006).

The sanitary crisis in Chilean salmon farming was caused by disequilibrium in two dimensions. First, there was a mismatch between the carrying capacity of the local natural environment and 'exploitative' practices of large firms. Second, these large firms (both domestic and foreign) applied knowledge and equipment for production that was developed elsewhere and thus incapable of taking into account the specificities of local natural resources. Concretely, this concerns different optima in maximum geographical concentration between cultivation sites (Norway had low concentration, Chile, unfortunately, had higher concentration), and in methods of how to deal with fish health (e.g. antibiotics in Chile, and vaccine in Norway).

Experts were called to deal with the problem and soon after aquaculture sites were grouped in accordance to geographical characteristics. These sites are to collaborate in coordinating the farming practices and to report fish mortalities to the National Fishery Service Agency (SERNAPESCA). Through processes of trial and error, experts and the Agency are gradually coming up with certain indicators and patterns to monitor the environmental conditions in different zones of the sea where aquaculture is taking place, to keep their industry in a sustainable manner (Iizuka, 2016; Katz, 2016).

The experience above points to the importance of local specific knowledge with regards to natural resource intensive activity. In this case, the generic knowledge of salmon rearing techniques, production processes, sanitary procedures for processing and equipment are transferred rather rapidly with technological efforts by various stakeholders. However, the development of a scientific understanding of the local biosphere lagged behind. Now, the national research institutions (Institute Fishery Production: Instituto de Formento Pesquero IFOP) as well as universities are involved in establishing regulatory mechanisms for observing the interaction of economic activities with local environments. This part of the salmon LICS was lacking and turned out to pose a danger to the sustainability of production.

issue, it is clear that natural resource knowledge idiosyncrasy sometimes affects linkage and innovation dynamics in these industries.

3.3.4 Technological complexity and scale

The technological complexity and scale of NRIIs is in many cases an important barrier to linkage dynamics. A range of inputs is required and these vary in technological complexity and scale. It is obvious that a major dividing line between historical and contemporary conditions for INRID is the fact that many of the modern technologies that are applied in NRIIs are today already developed and available on the global market. It is true that NRIIs can function with very different types of technologies spanning from use of simple tools as a fishing rod or an axe to the application of complex technological systems – such as advanced fishing trawlers or high-tech agricultural operations (see chapter 4) – that cost billions of dollars. The gaps between foreign and domestic knowledge bases can therefore appear gargantuan. However, this is most likely true for most sectors – including manufacturing and some services. Such gaps are, moreover, likely to be smallest in areas where industrial activities of the type already exist – hence in natural resource intensive activities. Although the challenges for reducing these gaps are immense, it does not mean that they cannot be reduced. Much can be done. We know that closing knowledge gaps – through learning and capability building by domestic actors – is a process that involves a number of different agents (public-private, domestic-foreign, supplier-producer-user, etc.) that must engage in processes of collective action. Hence, closing these gaps is essentially a matter of building and sustaining LICS. The Oil and Gas industry is often brought forward as an example of these enormous knowledge gaps that make domestic linkage dynamics appear impossible. But, even here, there are domestic production linkages, including to products with significant technological content in, for example, well construction and completion and control systems and ICT in Nigeria (Adewuyi & Oyejide, 2012).

3.3.5 Infrastructure

Often, large-scale transport and energy infrastructure is needed to move large volumes of natural resources. The provision of infrastructure is therefore an influential factor for domestic linkage formation. In addition, infrastructure developments for mining and other natural resources have significant potential spillovers for the domestic economy and can facilitate economic growth. Some NRII infrastructures, however, entail much less spillover – oil pipelines, for example.

3.3.6 Passing of time

Accumulating knowledge and capabilities takes time. It often takes decades of dedicated effort to create a well-functioning innovation system (Bell, 2006). Years of experience with certain NRII is thus often associated with depth of relevant knowledge bases. However, in some instances, the quantity and quality of linkages deteriorate with time (Morris et al., 2012b). It indicates that time in itself does not lead to unfolding of linkage dynamics, but that e.g. supportive policies are required. This furthermore refers to the importance of a sequencing of initiatives taken to close knowledge gaps, which is a key issue in linkage building. As we saw above, different NRIIs and the various activities within each NRII differ extensively in technological complexity. It is therefore important to start where the technology and skill gaps are limited and can be overcome within a relatively short period – the so-called 'low-hanging fruit'. The more difficult activities require a longer-term approach, e.g. an investment in training etc. to produce the skills that such activities may need in 5-10 years.

3.3.7 International division of labour

Many firms operating in NRIIs in developing countries, whether domestic or foreign, are part of global value chains. Their position within such chains reflects the domestic industry's position in an international division of labour, which in turn strongly influences the size of the barriers that domestic firms face in advancing towards more complex and value-adding products and processes. UNCTAD (2013) reports that an increasing part of production and trade of natural resources takes place within (often buyer-driven) global value chains and that these are increasingly dominated by a few MNCs. In such chains, compliance with quality standards is crucial. This tends to disadvantage domestic small-scale producers and suppliers. Policies aimed at supporting linkage building should thus not only target technical learning and competence building in firms, but also different forms of institutional innovation that can help domestic firms get access to and advance in value chains or, alternatively, create new chains. Linkage policy thus involves trade issues such as export promotion and maintaining competitive exchange rates (UNECA, 2013).

3.3.8 Institutions

It is widely believed to be important that 'good' institutions prevail in the broader economy, inspiring inter alia meritocracy, transparency, and absence of corruption and clientelism, as elaborated on in chapter 1 (Corrigan, 2014).

Moreover, firm ownership is found to affect firms' strategies. It is often held that domestic owners are more embedded in the local society and economy and that therefore more likely to acquire inputs locally. The *institutions* affecting nationality of firm ownership and access to natural resources can thus be central determinants of linkage formation, as shown in Text Box 3 on Norway's concession laws.

3.3.8 Policy: Local content requirements and backward linkages

Although numerous policy instruments are relevant to discuss in relation to innovation based natural resource intensive development (see chapter 6), much recent research has focused on the local content requirements as central for linkage building. As described in chapter 1, local content requirement policy has been on the rise in natural resource intensive developing countries in the last

Text Box 7: Local Content Requirement and Innovation Policy – Brazilian oil and gas

Brazil has been developing its Oil and Gas (O&G) industry since the 1950s with the, at the time, public company Petrobras as an agent of industrialisation and development. Petrobras was for several reasons forced to develop strong innovation capabilities in offshore oil and gas and is today at the technological world frontier (Dantas & Bell, 2011). Petrobras can be seen as a hegemonic agent in the Oil and Gas LICS and has historically been forced by needs for energy and economic growth to speed up its engagement in extraction, production and processing of oil and gas (Furtado, 2003). Petrobras could thus not wait for domestic suppliers to reach a sufficient technology-level. It resulted in the current situation where Petrobras is at the frontier while the domestic supplier industry remains underdeveloped (Mendonça & Guilherme, 2013).

Due to the competition in a globalised economy in areas that are often technologically mature, domestic companies in developing countries often require temporally supportive institutions to move from being technology importers towards being developers (Arocena & Sutz, 2010a). Local content requirement policy can be seen as a tool for creating a home market for different manufacturing and service products. Such a home market can translate into a domestic demand for new knowledge, competences, and innovations from domestic technology suppliers. This is important because the demand for new knowledge is often absent in developing countries (Arocena & Sutz, 2010b). Hence, local content policies should be complemented with policies supporting learning and competence building, involving activities such as training the needed engineers at domestic universities, facilitating knowledge transfer mechanisms as part of local content, and establishing research centres related to the NRII in question. If local content requirement policy is not combined with strategic innovation policy, the emerging domestic supplier firms will not reach similar capability levels as foreign competitors. This was one of the major lessons of the import-substitution-industrialisation period in Latin America (Fajnzylber, 1983). Hence, local content requirements without domestic capability building will not work, and vice versa.

decade. The rationale underlying local content requirement policy is most often the 'infant industry' argument. In studies of technology it is, furthermore, well established that new (to context) technologies and products require temporary protective spaces to experiment and mature until they can face open competition (Arocena & Sutz, 2000a; Kemp et al., 1998). Such measures have been widely applied in high-income countries (Chang, 2002). The main idea is thus to establish more domestic linkages than would be brought about by market forces alone, and thus enhance domestic benefits of

NRII expansion. Even though some studies do exist (see Jegede & Ilori, 2013; Ovadia, 2014), there is in general only little knowledge about how local content requirement policies have recently affected domestic linkage formation in NRIIs. However, historical case studies remind us that local content requirement policy in isolation may have little effect if it is not complemented with activities to support learning, innovation and competence building systems (see Text Box 7). Local content requirement policy, thus, can be an instrument for enhancing the quantity of linkages, but it must be complemented with LICS to support the knowledge deepening of linkages. An important caveat is that the 'rents' created by protection can also work as a way to legitimate clientelism. It is therefore important that protection is temporary and related to performance and learning (Klueh et al., 2009; Ovadia, 2014).

3.4 Forward Linkages

Forward linkages constitute a further potential route for establishing new industrial activities related to natural resources, thereby further diversifying the economy. Forward linkages have been important both historically (see Text Box 8) and in the contemporary period (see Text Box 10). Developing production downstream of NRIIs, forward linkages or beneficiation, appears to be a natural progression – 'we have the iron, why not the pots and pans?' The products downstream of NRIIs are very attractive; they often offer significantly higher value of output and employment than is offered by NRIIs. However, there are important differences between backward and forward linkages. These differences make forward linkages more difficult to establish.

First, backward linkages have the advantage of having a *demand*-pull effect (whose strength is subject to circumstances and policy) (Hirschman, 1958). In other words, backward linkage is often a necessity while forward linkage is merely an opportunity. If you build ships, you need steel. If you produce steel, you don't need to build ships. Forward linkages are facing a different situation regarding both competition and exports. Backward linkages have easier access to a home market.

Second, knowledge gaps are more significant when moving downstream than when moving upstream, making the challenge of building *capabilities in actors* even larger (Hausmann et al., 2008). While this can hardly be generalised, it does seem reasonable to think that, independently of the level of technological complexity, some learning activity and familiarity with local resource intensive activities have accumulated over time; particularly due to the former point about the strength of backward linkages. The latter would, ceteris paribus, be less likely in the case of forward linkages, thus making knowledge gaps relatively larger.

Third, NRIIs have 'natural protective barriers' to varying extent. Many of these have been cancelled by the low cost of international transport associated with globalisation. Still, in some cases processing on site is necessary. For example, some crops degrade very rapidly after being harvested (sugarcane)

Text Box 8: Finland forestry, linkages and diversification

	Phase I	Phase II	Phase III	Phase IV
Exports	Unprocessed natural resource	First-level processing	More specialised first-level processing	Investment abroad
Inputs	Imported	Import substitution,	Export of inputs	Export of inputs
Machinery	Imported (repair carried out locally)	Production under license for domestic market	Export of basic machinery to less sophisticated markets.	Export of all sorts of machinery to sophisticated markets.
Engineering :				
Production →	Semi-imported	Domestic	Domestic	Export
Design →	Imported	Partly domestic	Domestic	Export
Consultancy →	Imported	Partly domestic	Domestic except specialties	Export

The evolution of the Finnish forestry is a story of linkage building. At the end of the 19th century, Finnish export mainly consisted of unprocessed wood (round wood). The production gradually diversified towards more processed products as saw wood, plywood and later furniture and wood products in general. Export of these products topped in the 1950s (Ramos, 1998).

During the 1920s, production and export of wood pulp, cardboard and increasingly sophisticated types of paper took place. Since World War II, Finland has been exporting all kinds of machinery for forestry, like, for example, planting, extraction and processing. During the 1970s, Finland began exporting chemical inputs for the forestry sector (like enzymes).

Ramos (1998) describes this development as one of moving through different stages. During the first stage, natural resources are extracted and exported with a very low degree of domestic processing. The majority of inputs for production, like capital equipment and knowledge services (engineering), is imported. Domestic repair shops do exist, though. In the second phase, processing and export activities are initiated and a start is made on import substitution with domestic production of some inputs and equipment (typically under license for the domestic market), while almost all production engineering services are provided locally except those connected with design. In the third phase, export of the capital products takes place, whose production was set up during import substitution. The products are inputs and basic machinery for relatively undemanding markets (in the case of Finland, the Soviet Union after the Second World War); the engineering services used are almost entirely of do-

Text Box 8: Finland forestry, linkages and diversification - *continued*

mestic origin, and further progress is made in the export of increasingly sophisticated processed goods (such as fine and special papers). In the fourth and last stage (which in the case of the Finnish forestry cluster began in the mid-1970s), all types of goods and services are exported - processed goods of great variety and complexity, inputs and machinery for demanding markets, design engineering services, and specialised consultancy services. In addition, domestic enterprises begin to invest abroad in the same area of activity.

We see how the forestry 'development block' diversifies both up- and downstream into more processed forms of wood and chemical products. The determinant factors behind this knowledge intensification and diversification that have been identified are access to export markets (demand), institutions supporting knowledge upgrading, interaction between suppliers, producers, regulators, and universities, complementary infrastructure, domestic learning, innovation and competence building combined with access to foreign knowledge bases (inter alia via mobility), and mobilisation of and access to financial resources (via institutional reforms) (Blomstrom & Kokko, 2002; Ramos, 1998). The synergetic interaction between these factors over time – co-evolution of institutions, knowledge and industry – can be conceptualised as the emergence and consolidation of a forestry LICS in Finland.

and bricks have very high 'transport to value ratio'. These factors can enhance forward linkages. However, in the current era, most natural resources are available anywhere with little difference in price. For example, the difference in the price of gold (delivered) in Johannesburg is only very marginally lower than the price of gold in Florence. The raw material advantages enjoyed by domestic jewellers with local access to gold are therefore very limited. On the other hand, the Florentine jewellers have developed the skills, innovative competencies, links with retailers, brands and customer loyalties, along with supportive institutions – a jewellery LICS, so to speak – that are key to their success and cannot easily be replicated in South Africa. Forward linkages are possible, but are, in practice, infrequent in developing countries (Hausmann et al., 2008).

However, if the raw material is a significant component of the cost in the manufactured article and being in close proximity to natural resource production is important, domestic processing firms can have a cost advantage. This cost advantage can provide the 'space' for local production and the development of the skills and competencies of local producers. To the extent that a country has a monopoly or a near monopoly over a valuable resource

Text Box 9: Diamonds in Botswana

"Botswana's opportunity to ratchet up the pressure for forward linkages came in 2005 when De Beers 25 year mining license was due for renewal. The Botswana government had a great deal of bargaining power due to De Beers' reliance on production from its 50-50 joint venture with Debswana which supplied around 60 per cent of De Beers' global supply of rough diamonds. Moreover, Botswana produces high quality larger diamonds, which have higher profit margins. The government insisted that this concession would only be renewed (for another 25 years) if De Beers agreed to facilitate and promote forward linkages, beginning with cutting and polishing." (Morris et al., 2012b: p. 67).

In this case, the mining company, De Beers, also manages and undertakes further processes downstream of diamond mining – particularly sorting and purchasing. De Beers was thus in a position to transfer the skill and capacities entailed in downstream activities to local producers. This is unusual – generally, mines engage, if at all, in only the most immediate downstream activity such as refining. Sources of platinum are limited and Zimbabwe was successful in threatening to halt exports of platinum to force platinum miners to build a local refinery. However, the pressure it can exert on consumers of platinum further downstream is very limited.

that cannot be obtained elsewhere, it will have considerable bargaining power as to the further usage of that resource. Diamonds in Botswana is a case in point, see Text Box 9.

Even where governments are in a position to exert pressure for downstream manufacture of minerals, the 'success' of such policies and the economic desirability is by no means certain. The ultimate test will be, as with all economic activities, whether this pressure will allow for the development of competitive local skills. There is far more potential for a positive outcome where, as in the case of diamonds, this pressure can be exerted on foreign firms, who can transfer the requisite skills and capabilities required for downstream activities.

3.5 Linkages for lateral knowledge migration

The notion of 'lateral migration' of knowledge and competences has been used to describe processes where knowledge developed in relation to NRIIs 'migrates' to other areas of application that are not linked directly to resource production

Text Box 10: Sugarcane and bio-energy in Brazil

Sugar production came to Brazil with the European colonisation but remained enclaved for centuries. Industrial growth and problems of importing machinery in the 1930s-40s led to the emergence of a domestic capital-goods industry that eventually supplied to the whole sector (Negri, 1977) it also in turn developed linkages to steel, pulp and paper, petroleum and automation industries. Already in the 1900s, sugar producers experimented with sugar-based biofuels. A market for ethanol was created by government decree in 1931 (Moreira & Goldemberg, 1999).

Both new and existing linkages increased in quantity and quality during the 1970s and 1980s when, as a response to energy crises, there was a large public investment programme on ethanol (Proalcool). Proalcool stimulated development of ethanol cars, ethanol-chemistry, a vast infrastructure for transport and sale of ethanol, and innovation in production and processing of sugarcane (new cane varieties; new grinding systems, fermentation with larger capacity; use of vinasse as fertiliser; biological control of sugarcane beetle; optimisation of agricultural operations; automation of processes). These developments involved intensified interaction between sugar mills, universities, equipment producers and agricultural research institutes which effectively led to the building of a sugarcane and biofuel LICS which, in turn, facilitated (both forward and backward) linkage dynamics (Andersen, 2015).

In the 2000s, further linkages were established: sugar mills became bio-electricity exporters (Goldemberg et al., 2008); production of bio-degradable sugar-based plastics was initiated (Velho & Velho, 2006); ethanol-fuelled airplanes were marketed and experiments with ethanol as rocket fuel initiated (Silva & Fischetti, 2008; UNICA, 2009); application of modern biotechnology to develop better crop varieties and experiments with 2nd generation ethanol technology forged links deep into R&D on enzymes, chemistry and plant genetics (Ragauskas et al., 2006). The sugarcane and biofuel LICS expanded in scope and quality to enable the formation of all these new linkages (Andersen, 2011).

(Lorentzen, 2006). The notion of 'lateral' mainly makes sense when one views the real economy as divided into vertical chains between which knowledge can flow. In broader terms, lateral migration thus refers to the well-known phenomenon of inter-industry knowledge spillovers. Lateral knowledge migration linkages are thus key vehicles of technological diversification induced by activities related to NRIIs.

It is only rather recently that this has received attention in relation to NRIIs – especially in developing countries. Studies on spillover effects have mainly – as Innovation Studies in general – focused on spillovers between different manufacturing industries rather than between manufacturing, services and NRIIs (Castellacci, 2008; Martin, 2013). Consequently, such spillovers are not well understood nor have they been empirically well explored.

Studies of manufacturing industries in high-income countries show that knowledge spill-overs predominantly take place through four mechanisms: (1) incumbent firm diversification, (2) spin-offs and entrepreneurs (individuals with experience from incumbent industry) that start new initiatives, (3) labour mobility, and (4) networking/collaboration (Boschma & Frenken, 2009). The anecdotal material below indicates that each of these mechanisms may also be at work in NRIIs in developing countries.

There are no systematic measures of the extent of knowledge migration. However, we can see a number of transmission channels through which lateral knowledge migration takes place and for each channel we have identified numerous case studies. The partly overlapping transmission channels considered here are: migration of firms, of products, of process technologies, and of training and research organisations.

3.5.1 Lateral migration of NRII supplier firms

It often happens that NRII technology suppliers build competences within rather generic knowledge bases such as automation, ICT or chemical science (Kuramoto & Sagasti, 2006). In Australia, for example, technology suppliers to the mining industry are heavily engaged in developing software systems (Smith, 2007). The development of competences with wide applicability enables firms to enter many other industrial activities, thereby promoting diversification, see Text Box 11.

3.5.2 Lateral migration of products

Individual products developed to accommodate problem-solving in NRIIs sometimes journey into new markets and industries otherwise unrelated to natural resources. In South Africa, mining technology suppliers developed a low-radiation, full body imaging device – called Statscan – for the diamond mining industry. Later, however, Statscan found application in the medical industry. Statscan was developed by De Beers, via a company called Lodox Systems. Statscan was developed to control workers' theft from the diamond mines by rapidly doing a full body scan, whilst also complying with safety regulations in respect of acceptable radiation levels (Mayer & Altman, 2005).

3.5.3 Lateral migration of process technologies

Firms in NRIIs can develop and/or improve process technologies that subsequently are applied outside the resource intensive activities.

Mines are major polluters. There is significant and growing pressure on mining firms to 'clean up their act'. As a result, mining firms have been investing heavily in new activities directed at limiting pollution or at managing waste. Significantly, this

Text Box 11: Automation and Lateral knowledge migration in Brazilian sugarcane

The firm SMAR started in 1974, servicing the sugar mills through maintenance and repairing of equipment. It started doing relatively simple work tasks, but gradually integrated service on steam turbines, which were already then integrated in the mills to generate electricity. In 1975, they developed their first control system for the turbines. It was a system that could control the parallel and thus more effective movements of 2 turbines, placed symmetrically in front of each other. In 1978, they developed an automation system for the process system of crushing cane and extracting juice. In about 1980, the sugar mills started to introduce electrical regulation of the turbines. The firm had until then only been doing 'simple mechanics' and not electronic mechanics – an area beyond their capabilities. The founders invited five engineers from Zanini, who worked with electronic mechanics, to hold talks about the possibility of a partnership. From then onwards, SMAR started to develop a range of products in electronic mechanics based on the imported capabilities.

By 1986, SMAR had developed electronic automation systems to control pressure, temperature and transmission. SMAR now formally invested and hired more engineers. In 1985-86, SMAR started using digital technology instead of analog systems, which has been the main source of improvements since. From the mid-1980s until today, the core products have not changed, but the use of new technology (digital) has improved precision, quality of components, speed of processes, efficiency and unit cost. SMAR's products were actually applicable for any sector in need of control over production involving regulation of flow, level, temperature, density, filters, evaporation (liquid to gas), tanks and distillation. Therefore, the firm pursued market diversification. Between 1980 and 1990, SMAR entered new markets in for example glass, textiles, paper and pulp, ship, food, water and waste-water. Around 1990, SMAR started export, which made it necessary to think in terms of patents in the US system. SMAR got its first patent in 1998, and between 1998 and 2008, they got 24 patents. It now has products in NASA and the US Navy.

An interesting aspect of SMAR's history is that the owners have had a good and trustful relation with owners of sugar mills. This implied that SMAR was allowed to go to the mills to test their new equipment and new products and thereby interact with people in production. The latter is a schoolbook example of supplier-producer learning and of a lateral knowledge migration linkage. Moreover, the story illustrates how complex demand from a recipient natural resource intensive industry stimulated capability building in a related enabling supplier firm (Andersen, 2011).

pressure and the consequent responses of mining firms are not confined to high-income countries. The gold mining industry in Peru, for example, has invested in and acquitted significant capacities in bioremediation technologies. This technology has widespread application outside of the mining industry to any site where pollution is generated. The technology is newly developed. Moreover, the National System of Innovation is very fragmented and characterised by the lack of linkage between firms and tertiary institutions. Nevertheless, there is evidence of a lateral migration of the technology. One study concluded:

> "This case study presents a lateral migration that is not completed yet because of the early stage of development of the technology, however there are promising prospects that a generic technology may grow from the efforts described in this case study" (Kuramoto & Sagasti, 2006: p. 33).

Also, firms supplying mines in Australia have developed technologies to clean up air, water and soil, recycle waste and eliminate pollution. Due to rising environmental concerns, this is an emerging industry with applications in many areas of economic activity (Smith, 2007; Wright & Czelusta, 2007).

In Norway, the supplier industry to offshore oil and gas has developed a range of technologies that have found application well beyond the production of oil and gas. Technologies applied to various offshore and subsea operations in oil and gas have found application in the European offshore wind industry (Steen & Hansen, 2013). Other examples of technologies that were originally developed by firms supplying the oil and gas industry can be found in areas such as health technologies, space and satellite technologies, scanning and simulation tools for many different uses on- and offshore, maritime and marine technologies and fish farming, as well as in different energy technologies (wind, waves, thermal) (Norwegian Oil and Gas Association, 2014).

3.4.5 Lateral migration of Training and research organisations

Training and research organisations can emerge and/or expand due to the need for more complex knowledge in the NRIIs. They engage in different forms of interaction with NRIIs via high quality linkages to enhance productivity and innovation. Over time, these efforts can result in such a transformation and deepening of the knowledge underpinning resource intensive production that very advanced and generic knowledge bases accumulate to the benefit of many other research and economic activities. Moreover, such research and training organisations often go on to diversify their activities into other branches of science and thereby diversifying the economy on the basis of an early impetus from natural resources.

Migration of knowledge is supported in environments characterised by knowledge diversity and intense communication and interaction between different fields of knowledge and competence. There are many types of such environments spanning from stable ones like cities and universities to temporary ones like conferences and exhibitions. Without doubt, governments in many countries have played an important role for lateral knowledge migration related to natural resource intensive activities, perhaps mainly by supporting education and research organisations and technological service centres. In the latter half of the nineteenth century, Sweden's industrialisation and its export was dominated by mining and forestry. Later, new processes led to export of more advanced products from these industries, for example machinery, pulp and paper. The Royal Institute of Technology played an important role in this transformation, both for the education of engineers and for the technical development. In Denmark, industrialisation was more connected to agriculture where rapid diffusion of technical innovations occurred in connection with the introduction of cooperatively organised dairies and slaughter-houses. This stimulated a technical development and diffusion through education, training, and a broad consultancy system covering both farmers and the agro-industry. These processes were also supported by the Royal Agricultural University, founded in the middle of the nineteenth century.

Lateral knowledge migration is becoming more and more important for the development of NRIIs, which are increasingly drawing on many different knowledge bases. This is the case even for very old activities, which throughout history have relied on rather primitive traditional methods. For many thousands of years, honey was the only sweetener known to man and honey harvesting from wild bees was taking place already in the late Paleolithic as documented by cave paintings in, for example, the Arana Cave in Spain. In spite of the long history, beekeeping has been remarkably resistant to technical improvement. The early forms of harvesting entailed destruction of the whole bee family – no doubt because of ignorance of the complex bee biology. Not until the 18^{th} and 19^{th} centuries were methods developed that allowed the bee family to survive.

Today, the situation is quite different. Science is combined with traditional knowledge of beekeeping to fight diseases and protect biodiversity. Traditional crossbreeding techniques have aimed at less aggressive and more productive bees. This has resulted in a substantial loss of subspecies adapted to local conditions, which in turn has made European bees vulnerable to parasites, especially an Asian mite, Varroa Destructor. The European Commission now supports a research project that aims at developing methods that improve the health and diversity of bees. The research draws on several bodies of knowledge, which have not previously been much applied to beekeeping, like genetics, molecular biology, virology, immunology and communication theory and is thus an effort to stimulate technology migration.

These four lateral knowledge migration channels and their interaction constitute a big part of the explanation for how new industries including high-tech manufacturing and services can be promoted by NRIIs. They are, so to speak, part of the micro foundations of the unfolding of development blocks. It is difficult to foresee where lateral knowledge migration linkages will emerge, but it seems possible to support the underlying mechanisms such as firm diversification, entrepreneurship, labour mobility, and cross-industry networking.

Although the evidence is merely indicative at this stage, it seems that the quantity and quality of lateral knowledge migration linkages is vital for NRIIs' ability to promote structural change and long term development via technological diversification of the economy.

3.6 Technological diversification and natural resources

The extent to which the expansion of resource intensive industries can promote long term development depends on whether it contributes to technological diversification of the wider economy.

We have in this chapter outlined how diversification and structural change can be enhanced by expansion of NRIIs via three key processes.

The first refers to learning, innovation and competence building in natural resource producers that via high quality linkages take advantage of new opportunities emerging for these industries, including cost reduction, product enhancement and mitigating environmental spillovers.

The second refers to the development of domestic and knowledge intensive industries, which are suppliers and users to the NRIIs. This is equivalent to promoting the quantity and quality of backward and forward linkages around natural resource production including both manufacturing and service firms.

The third key process refers to lateral knowledge migration linkages where firms, products, technologies and knowledge producers directly related to natural resources journey into industries and markets unrelated to natural resources.

In addition, NRIIs may stimulate wider diversification by financing investments in other industries, by setting up infrastructures such as transport, ICT, and energy with positive externalities for many other activities, and by promoting technical and organisational competence in firms and governments (from participation in global value chains), which may benefit other industries.

The extent to which these three key processes unfold is largely determined by the strength of the natural resource LICS that can support or block the processes. We may thus expect that enhancing diversity of capabilities over time in a natural resource intensive economy will be associated with emergence of various other industrial activities and with economic growth. This process reduces the economy's dependence on natural resources – the relative share of natural resources in the economy – but not necessarily the absolute size of natural resource production. In chapters 2 and 3, we have outlined some of the central processes underlying such a development path.

4. Innovation in natural resources: new opportunities and new challenges

Conventional views construe Natural Resource Intensive Industries (NRIIs) as low-tech, with low technological dynamism, little innovation, and little capacity to create linkages towards other sectors, and even with the capacity to destroy other more dynamic sectors. NRIIs are seen in all these dimensions as inferior to manufacturing activities. This is reflected for instance in taxonomies of industries, all of which classify NRIIs as having low technological dynamism (examples of these taxonomies include the ones developed by Katz & Stumpo, 2001; Lall, 2000; OECD, 1997). As we saw in the previous chapters, these views are, however, being questioned in various ways.

Moreover, international institutions, markets and technologies have changed substantially during the last two decades or so, and these changes have created new and a more diverse sets of opportunities for a larger number of developing countries to take advantage of their natural resources. This chapter tries to understand the nature of these new opportunities that NRIEs are currently facing. We will suggest that as new opportunities are being created, new challenges also emerge, and countries which do not comprehend fully both of these might lose the opportunity opened by this historical moment of change to become advanced innovators in natural resource intensive and related industries.

In this chapter, using the example of seeds, we will explore the existence of both new opportunities and new challenges for innovation in NRIIs in developing countries. Seeds are of course not representative for NRIIs in general. Other natural resource intensive activities may be less innovative. The matter of seeds is, however, an apt illustration of important new opportunities and challenges that may in the future change the role of other NRIIs in economic development. Furthermore, innovations related to new seeds may have very substantial economic effects in agriculture, which continues to be of utmost importance in many developing countries.

The chapter illustrates how linkage dynamics around natural resources contribute to diversification and structural change in the economy. It is a rather extensive empirical account that connects well with the perspectives presented in previous chapters. The chapter has four main sections. In the first section, we discuss the main forces opening new opportunities for innovation in general in natural resources. In section two, we use the case of seeds to analyse how these forces are operating in practice and are opening opportunities for some developing countries. In section three we discuss, using the case of Argentina – a world agricultural leader with a strong and advanced domestic seed industry – how the new opportunities created for innovation in seeds have been taken by some companies in the developing world and how some new challenges are questioning the capacity to pursue further some of these new opportunities. Section four concludes.

4.1. New opportunities for innovation in NRIIs

Recent changes in the world economy induced by Information and Communication Technology (ICT) have radically transformed some of the conditions under which most industries operate. Some manufacturing industries (for example the automotive industry and some electronic goods), which were dynamic and high-tech in the past, are not any longer on the technological front. At the same time, many activities within NRIIs that were low-tech and with low dynamism in the past are now becoming more dynamic (Pérez, 2010). Key examples can be found across soft, hard, and energy natural resources.

The literature has identified four sets of changes which are creating new opportunities for innovation, dynamism and linkages in NRIIs in general: changes in the volume of demand, changes in demand requirements, changes in science and technology and changes in the global market context, including institutions, regulations, and strategies of global actors (Marín et al., 2015; Pérez, 2010). We briefly outline the main characteristics of these changes below.

a) *Changes in the volume of demand:* The rise of Asia and the incorporation of the so-called second world to the market system have accelerated the rhythm of growth in the demand for energy, food and raw materials to the point of straining the limits of resources (Alexandratos & Bruinsma, 2012)2006. This increase in the volume of demand has provided opportunities to increase production via innovation, since the expansion in the production of natural resources can come only from (1) a more efficient and productive use of existing resources (land, mines, fishing areas), (2) the incorporation of new land or the exploration of new mines that generally demand higher costs due to distance and are less productive, (3) the discovery of new uses of natural resources (Andersen, 2012). All these possibilities require different types of innovation. Expectations of rising prices and profitability have throughout the 2000s encouraged such innovations.

b) *Changes in demand requirements:* Worldwide demand for less standardised products, more variety and higher quality goods is expanding. This phenomenon not only applies to manufacturing but also to some NRIIs (i.e. organic wines, more aromatic lavender, tomatoes of different colours, high-quality and sustainable produced lumber, etc.). The large varieties of natural resource products (outputs from NRIIs) that are offered today for culinary based on unique ingredients, cosmetics based on natural assets (e.g. Amazonia essences), health and decoration purposes was not foreseen two or three decades ago when standardisation predominated and the possibilities of differentiation related to natural resources were not even there. This seriously challenges the 'commodity' notion of natural resource products. The threat of global warming and other environmental and social concerns have also opened opportunities for new demands of a wide array of products and services based on more sustainable patterns of natural resource exploitation that were virtually non- existent before. These changes in demand have created new possibilities for innovation, creating new niche and premium price markets. Within these niches, in addition, innovation is not strictly related to production but also to conservation methods, certification (e.g. organic certification), packaging, distribution, branding, etc. These new opportunities are not restricted to natural resource producers but also impact on user industries, which have to innovate in order to deal with a larger diversity of flavours, textures, sizes, shapes, compositions etc.

c) *Changes in Science and Technology*: A fundamental change of recent decades has been the progress in information and communication technologies (ICT). Advances in communication between producers, suppliers and users located in different parts of the world are key to the possibility of innovation to materialise. Local innovations can reach global markets, the needs and demands of users concerned by very specific issues can be attended from all over the planet, remote places can be inserted into global value chains, advances in knowledge occurred in a particular area can quickly reach global spread, etc. Another major change in recent decades has been the emergence of new technologies such as biotechnology and nanotechnology, which are multiplying the possibilities of differentiation and innovation in activities related to NRIIs. Some important innovations based on biotechnological advances have been the use of marker-assisted selection in plant breeding, using bacteria in mining and the development of new vaccines for livestock and fish. Natural resource producers are incorporating these new technologies in the production of natural resources and this is questioning the 'low-tech' notion of NRIIs, as well as forming and deepening of linkages towards other industries creating new opportunities for diversification.

d) *Changes in the global market context.* Multi-National Corporations (MNC) behaviour provides one key example of these changes. In the last decades, MNCs have changed their usual behaviour of acting as an enclave (typically in extractive industries) (Singer, 1950, 1975) towards adopting a more decentralised way of operating and taking advantage of local specialised capabilities in host economies (Cantwell & Sanna-Randaccio, 1993; Cantwell, 1995, 2001; Dunning, 1994; Kogut, 2002; Marin & Arza, 2009; Marin, 2007). Natural resource intensive economies can profit from the MNCs´ new behaviour and even encourage it. But they can also be threatened by them.

Another example is the increasing demand for environmentally friendly products from informed and environmentally concerned consumers and the worldwide strengthening and harmonisation of regulations related to environment preservation, which is generating demand for new products and re-design of existing ones, changes in process towards less contaminant methods, reduction of industrial waste, and cut in energy consumption, among others.

Several studies have analysed how these changes are affecting the potential for innovation and dynamism in NRIIs (Kaplinsky, 2009; Marín et al., 2015; Pérez, 2010). In the next sections, we use the example of the seeds industry to examine how they have affected a particular NRII.

Seeds are, for several reasons, an excellent example to analyse the changes mentioned above. First, seeds are changing status from a quasi-natural and quasi-public good to a private good with high knowledge and technology content. Second, we cannot continue to consider seeds, at least the ones that are commercialised in the market, as pure natural resources. They have – the commercial varieties at least – an increasing component of knowledge intensive services. Third, their market is clearly in times of change, meaning that a single best technology to develop and innovate with seeds has not been selected, not even in advanced country contexts. This is mainly because of the combination of two factors. First, because of the numerous scientific developments in the several knowledge bases connected with seeds, such as genomics and molecular biology, which are permanently opening up different possibilities for new directions of innovation. Second, because of the changing and diverse consumer attitudes and regulations towards the new technologies for seeds development (e.g. genetically engineered crops), which are making it difficult to predict which technologies will be accepted by the market and allowed by regulators.

4.2 The case of seeds: new opportunities for innovation

The emergency and development of the seed industry can be explained by substantial changes in demand, knowledge bases, and institutions, which have taken place for decades (and still are).

Seeds were, historically, public goods. This was because, for a long time, investments in improving them were difficult to recover, as farmers were able to re-use them without paying for them. Public research organisations, accordingly, were central in the development and broad diffusion of seeds while a developed market for seeds did not exist. This situation changed dramatically during the 20th century. First, during the Green Revolution, with the invention of hybrids for some crops (e.g. maize) that started losing their attributes after the first use, private companies gained interest in the activity, and a market for seeds emerged.[14] Second, with the irruption of genetics (which started in the 70´s but diffused more broadly in the early 1990´s) and the possibilities of private appropriation of plants via intellectual property right (IPR), the interest of companies increased (typically, pharmaceutical and chemical firms gained interest in the seed business). In the following we report on the four main forces that have opened new opportunities for innovation in the Argentine seed industry

4.2.1. Changes in demand volume for seeds

According to estimates, demand for agricultural products is expected to grow steadily in the next decades. This upward trend is both explained by a growing population and an increasing demand for energy (FAO, 2009). In particular, demand for cereals (considering both food and animal feed uses) is projected to rise by 1 billion tonnes (being today nearly 2 billion tonnes) – however, changes in the biofuels market can raise these estimates even more.

There are, thus, significant transformation pressures for agricultural production to expand. Seeds are a key and strategic input for agricultural production. Improving the quality of seeds is one of the most economical and efficient inputs to improve crop production and productivity (FAO, 2009). Improved seeds are crucial for yield increases. According to studies, a substantial proportion (that varies from 50 to 90 per cent) of crops´ yield increases is explained by improved seed varieties (others are the diffusion of better agronomic practices, or a combination of both) (Brunis, 2009; Santos et al., 2004; Schnepf et al., 2001; Specht & Williams, 1984). Moreover, as agricultural production expands, it is also necessary to adapt seeds to new agro-ecological conditions. According to estimates, almost all of the land expansion in developing countries would take place in sub-Saharan Africa and Latin America. Much of this land, not yet in use for agriculture, is less productive, suffers adverse agro-ecological conditions and is vulnerable to local diseases and weeds. Thus, innovation in new improved and locally adapted seeds is going to be key to make crop production economically viable in new territories.

Apart from the need to develop seeds to new territories, the continuous modification of the environment (e.g. evolution of disease resistance, development of varieties that perform well in different agro-climatic environments, climate change effects etc.), even in territories that are currently used for agricultural production, creates a permanent demand for new and improved seeds to maintain or attain higher levels of agricultural production. For example, reduced rainfalls in Africa demanded the creation of improved seeds that are drought resistant. Other areas, on the contrary, are expected to experience an increase in the level of rainfall (Brunis, 2009). The effect of pathogens and insects also demands continuous breeding efforts as, according to FAO data, the current annual loss worldwide due to pathogens is around 85 billion US dollars and to insects at 46 billion US dollars.

4.2.2 Qualitative changes in demand

An important change that is characterising the seed market is that farmers are becoming more demanding regarding specialised inputs (Kanungwe, 2009). For some important crops (such as soybean or maize), they do not only demand higher-yield seeds but also seeds that pay specific services (i.e. herbicide or insect resistance) that facilitate the management of agricultural production and allow them to reduce costs. Three examples of seeds innovation that simplify production are (1) RR soybeans[15], which made soy resistant to one particular herbicide and reduced the number of herbicides to be applied to kill weeds – at least in principle – and, (2) Brussels sprout hybrids with uniform ripening and size, which make them more suitable for machine harvesting, and (3) monogerm sugar beet varieties, which reduce the need for laborious thinning and enable fully mechanised cultivation (Brunis, 2009).

Another change is the increasing demand for more environmentally friendly and healthy products. These changes in demand have created a premium price market: Organic and non-GM (e.g. cotton with improved fibre quality and yields, Organic Cotton Association, 2014). For example, some recent seeds innovations addressing health issues are GMO tomatoes with high levels of antioxidants, which could prevent certain diseases such as cancer, heart attacks and degenerative diseases (developed at the Oregon State University and another variety at the University of Sao Paulo); a new variety of broccoli known as Beneforté, developed at the Institute of Food Research and the John Innes Centre using conventional breeding techniques, which contains two to three times the level of the phytonutrient glucoraphanin as compared to commercial varieties; and rice varieties with higher levels of beta-carotene (named 'golden rice'), which can benefit those affected by vitamin A deficiency.

4.2.3 Changes in knowledge bases

Until the 20th century, seed improvements relied almost exclusively on a process of trial and error through which plants with desirable traits were selected, based on their observation (phenotype selection). This method, commonly known as *cross-breeding*, largely relied on tacit knowledge (i.e. the external appearance and performance of the plant). During the last decades, however, a series of advances occurred in areas of knowledge related to breeding activity (e.g. molecular biology) which opened new opportunities to make new kinds of innovations, which were also of more feasible appropriation via IPR instruments (analysed in the next section).

Recent advances in molecular biology, and biotechnology in general, allowed breeders to: (a) complement traditional phenotype selection with genetic information (genotype selection), making it more precise and efficient, and to (b) explore new ways of modifying seeds, using genetic manipulation within the same species or from different species. We briefly summarise each of these possibilities below.

The application of modern biotechnology to seed improvement allows breeders to obtain and analyse genotype information of plants. Thus, the cross-breeding process can benefit highly from the combination of phenotype selection (based on plants´ observable characteristics) and genotype selection (based on plants´ genetic information). Some of the most important advantages of using genotype information are that breeders can anticipate plants' characteristics (such as length of the plant, its resistance to certain pests or diseases, etc.) without the need to wait until the plant is fully developed. This, in turn, allows breeders to significantly reduce the length of the breeding process, making it more precise and efficient. Combining phenotype and genotype selection (by using some biotechnology tools such as molecular markers), breeders can shorten the plant development period with several years.

Genetic engineering technology can also be used to identify, isolate and transfer gene sequences to a plant with the purpose of providing seed varieties with a code for characteristics that they did not originally have, such as resistance to a particular herbicide. Where genetic engineering involves the transfer of gene sequences from one species to another (e.g. using genes from bacteria to modify soy varieties), the plant varieties obtained are known as *transgenic plants*. Crops modified by genetic engineering technologies are soy, maize and cotton. Transgenic events[16] applied to these crops, which have been commercialised, confer them insect-tolerance, herbicide-tolerance and disease-resistance. It is key to remark that the use of genetic engineering to produce new transgenic plants has generated great expectations about what the technology may be able to achieve in the future, creating incentives for massive investments in innovation.

The use of bioinformatics has had a similar effect. Seed companies can use computer-assisted prediction of test results on genetic modification to replace growing every modified plant in the laboratory or green house. The implementation of bioinformatics shortens the breeding process substantially and helps to improve the innovation process.

The examples above focus on how science and technology can increase productivity. However, it should be observed that such developments should also be accompanied by research on the possible ecological effects of the use of new science based methods in seed development. Unintended ecological effects may, in a broader perspective, significantly reduce the social benefits of some of the new seed varieties.

4.2.4 Changes in institutions and the global market

Several important changes in the world market have altered the opportunities for seeds innovation. However, they are affecting the opportunities for innovation and entry to this market in a different manner to different actors and countries. The first and more important is the change in IPR regulations that affect the possibilities of private appropriation of seeds and plants. The second is the associated changes in global market structure of some types of seed innovations (typically traits generated by transgenesis). The third and last one we are going to analyse is related to changes in consumer attitudes towards the different technologies available to improve seeds.

Institutions: IPR regulations

In recent years, the protection of plant varieties via intellectual property rights has increased broadly. Plant certificates first introduced in the US in 1930 for improved plant varieties granted to plant breeders a relatively 'weak' level of protection compared to the rights granted by patents to inventions in other areas. These provided breeders the right to commercially exploit the new varieties, but not the right to prevent farmers to replant their seeds (based on a right known as the "farmer's privilege") or to prevent breeders to use the new varieties as material for future crosses and seeds (based on the "exception of the breeder"). However, this changed in 1980, when the US Supreme Court, after more than 100 years against the patenting of living organisms, gave to seed companies the right to patent certain parts of living organisms. The argument was that living organisms - like any other manufacturing process - are patentable - at least in part, by those that discover new and useful applications of these parts. Initially, this was only for genetic constructs, but then for the whole plant. Companies could then: (i) prevent farmers to replant and breeders to use patented seeds as material for research and (ii) protect a new trait or characteristic (e.g. glyphosate resistance) in many varieties of seeds.

In the rest of the developed world, with some exceptions (Australia, Japan and Korea), the patenting of plants is not allowed, but the patenting of genes and gene sequence and its insertion into existing plant varieties became a de facto patenting of all variety.

In the developing world, until the 90s, to have an IPR legislation for plant varieties was not common. However, this situation changed dramatically in 1994 when the signatories to the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) signed the Agreement on Trade Related aspects of Intellectual Property Rights (TRIPS). The TRIPS Agreement granted a new international standard for IP protection - significantly higher than the so far existing , requiring that all countries signing the agreement provide some form of protection for plant varieties either by patents or by an effective sui generis certificates system or by any combination of both. Most countries signed an international agreement called the International Union for the Protection of New Varieties of Plants (UPOV). There are currently two existing systems: UPOV 1978 and UPOV 1991. The latter is more similar to the patent system. UPOV 1978 still predominates in the developing countries, but there is huge pressure from the advanced countries and MNCs to move in the direction of UPOV 1991. The argument is that this system, by promoting stronger degrees of appropriability, will favour innovation. However, we note that similar to the existing evidence for patent protection in the industrial sector, the evidence is inconclusive regarding the effects of plant certificates on innovation activity (Gutiérrez & Penna, 2004).

Industry structure: World market concentration of transgenic events

As a result of the significant changes in the knowledge base, technology and IPR regulations, the seed industry has become very concentrated. Only a few MNCs own the patents, and they have pushed innovations in a particular direction (the transformation of plants by genetic engineering methods to obtain transgenic seeds) having been able to take advantage of the new opportunities (Fernandez-Cornejo, 2004; Fernandez-Cornejo, J. Spielman, 2002; Schenkelaars et al., 2011) The market of transgenic events is fully controlled by six companies, called the 'Gene Giants' (Monsanto, Syngenta, Novartis, Bayer, BASF and Dupont). They control 66% of the world market and 84% of the patents. Most of these MNCs have their origins in the pharmaceutical, chemical or food industry, and have entered the seed business (mostly acquiring smaller seed firms) attracted by (a) the potential complementarities (between crops and agricultural inputs), (b) the new IPR regulations regarding plant varieties and (c) the expectations generated by scientific advances in biotechnology. They have the size and resources to face the large investments in R&D to identify and isolate genes that can then be used to develop transgenic seeds (e.g. a gene that confers plants resistance to draught or to a certain herbicide), and, what is more important, they can afford the cost of regulations and GM approvals.[17]

Public research organisations and domestic firms in developing countries, however, still play an important role in this market. First, because not all demanded innovations are or can be performed with genetic engineering (productivity increases, for instance, are explained by a multiplicity of genes interacting, which cannot be tackled with genetic engineering); second, because not all markets accept transgenics; and third, because transgenic events (genetic engineered traits) perform well only when they are introduced into existing seeds that are well adapted to local ecology, and these backgrounds are typically owned and developed by local breeders (public organisations of agricultural research and private companies) using cross-breeding techniques.

A clear division of labour was established, thus, in the seed market. On the one hand, a few MNCs, using genetic engineering technologies, develop and commercialise generic transgenic events (e.g. herbicide resistance) that they can patent. On the other hand, domestic companies and public research organisations, based on technologies like cross-breeding or mutagenesis, are devoted mostly to improvements in germplasm, which are more difficult to patent (in many cases not for lack of technological capabilities, but for the high costs of patenting and deregulation of transgenic events, which has been calculated to be 10 times higher than the costs of developing the event), but which every year can deliver new features that assure adaptability to changes in the environment and to new areas of productions.

The presence of local small and medium firms and public research organisations, which is crucial to provide local adaptation, diversity, and market

Text Box 12: Data and methodology

The empirical analysis of this section draws on data from scientific and policy documents; evidence that we collected from interviews with both seed companies based in Argentina (Don Mario, Nidera, Bioceres, ACA and Santa Rosa) and researchers from the National Institute of Agricultural Technology (INTA). In addition, data on agricultural production and cultivated areas was obtained from the Argentinean Ministry of Agriculture (http://www.siia.gov.ar/). The main indicator of innovation was plant certificates obtained from plant registration data compiled by the National Registry of Property of Varieties (RNPC) (www.inase.gov.ar). Plant breeders that wish to protect their varieties under the intellectual property rights system for seeds in Argentina must apply for this registration. The RNPC contains information, for each plant variety, on the name of the breeder, the year in which property rights were requested, the country of origin of the variety, the plant variety maturity group to which it belongs, and whether or not the variety is transgenic. Information on market data is based on certifications on seeds that were placed on the market each year. This data was provided by Asociación Argentina de Protección de las Obtenciones Vegetales (ArPOV) (www.arpov.org.ar).

Information on the strategy of local seed firms was based on two case studies: Don Mario and Bioceres. Don Mario is an Argentinean company, which defines itself as a 'genetic provider'. The firm has its own breeding programmes and makes use of advanced biotechnology tools to develop well-adapted seeds. Its main market is the soybean seeds market. Currently, the firm has 32 per cent of the Argentinean soybean seed market and 25 per cent of the Latin American soybean seed market. In the last years, it has opened subsidiaries in Brazil, Bolivia, Uruguay, Paraguay and more recently in the US. In Brazil, the subsidiary named Brasmax is the leading soybean seeds´ company in that country. Bioceres is a small R&D intensive firm, which is closely linked, through R&D agreements, to Public research organisations and universities. The company is mainly advocated to the gene business: discovery and isolation of genes. Its target is to develop traits. It has three patents in the US and export technology to foreign multinationals.

competition, is, however, as we will discuss in the next section, threatened by several factors: (i) the trend of the seed market to get more concentrated, (ii) the disequilibrium in some countries between the levels of IPR protection that receive genetic engineered events and germplasm improvements, and (iii) the tendency of policy makers to support and encourage genetic engineering technology mostly on the basis of the large expectation that this technology generates.

Informal institutions: Consumer attitudes towards GM technologies

Genetic engineering technologies are well accepted in general to produce crops for animal food or biofuels. However, consumers are not keen to consume food produced using GM technologies, at least in large parts of the world. GM technologies are the most rejected technology in the world after nuclear technologies. There are important concerns about health issues, and biosafety regulations are very difficult and expensive to comply. This creates a challenge for small and medium-size companies and for public research organisations as well, to enter the business of transgenic events. It has, however, also created opportunities for some companies to specialise in non-GM seeds.

4.3 Taking advantage from the new opportunities, but facing new challenges

In this section, we will show how the new opportunities created for innovation in seeds have been taken by some companies in the developing world, using the case of Argentina, and how some new challenges are questioning the capacity to pursue further some of the new opportunities.

4.3.1 New opportunities

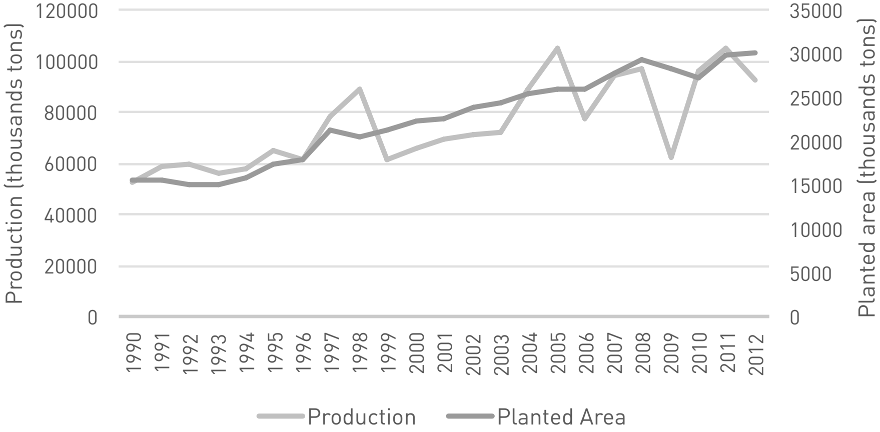
Argentina is a world leader in agricultural production and a pioneer country in the adoption of high-tech inputs in this sector. It has recently expanded agricultural production massively based on the incorporation of new land and the intensification in the use of high technology inputs (see Figure 7).

Together with the massive expansion in agriculture, the rate of seed innovation has expanded significantly in Argentina. Figure 8 shows the increase in the rate of innovation within the four major industrial crops (soy, maize, sunflower and wheat), measured by IPR registered plant varieties, which increased from around 50 new varieties per year in the 1980´s, to around 200 in the 2000´s.

An important phenomenon that has characterised the seed market in Argentina during this expansion has been the diffusion of transgenic events. Between 1998 and 2013, 29 transgenic events were approved in Argentina. These provided soy and corn seeds resistance to 3 herbicides (Glyphosate or Imidazolinone or Glofosinate ammonium) and resistance to 2 types of insects (Lepidotera or Coleoptera) and combinations of some of them (the so called ‘piled events’). These traits have been incorporated into domestic varieties and massively diffused within corn and soy. As a result of this diffusion, Argentina, with a planted area of 24.4 million hectares, is now the 3rd world producer of GM crops.

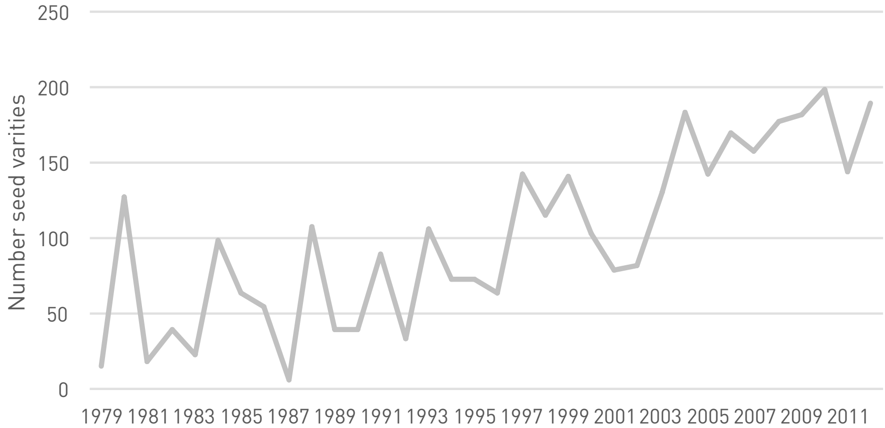
Since these events have been developed by a few MNCs (the six Genetic Giants), many observers have argued that these companies have been the main seed suppliers, have driven the process of seed innovation, and benefited from the expansion of the agricultural sector in Argentina. A careful analysis of the data, however, reveals a different situation. If we explore the number of new plant varieties reg-

Figure 7: Argentina: Development of agricultural production and planted area of industrial crops (soy, maize, sunflower and wheat) (1990-2012)



Source: Own elaboration based on data from the Ministry of Agriculture, Argentina. (http://www.siia.gov.ar/)

Figure 8: Argentina: Seeds innovation – new varieties IPR registered* (soybean, wheat, corn and sunflower) (1979-2012)



Source: Own elaboration based on the data from INASE. http://www.inase.gov.ar.

istered for the major crops, and the market shares of new varieties by company in Argentina, between 1997 and 2013, the two firms that registered most varieties are from Argentina. In the top five, regarding number of new varieties that reach the market, three are Argentinean (see Table 2).

Despite the dominance of some foreign MNCs in the industry, local participation is made possible because of the way in which seeds are developed nowadays. Now, most of the new seeds registered and sold are, similarly to a telephone or a computer, an assembly of different components: (i) a transgenic event (obtained and owned typically by MNCs); (ii) a number of other new traits obtained by cross-breeding and selection of the plant´s germplasm (such as resistances to new diseases, changes in the growth habit, changing the maturity cycle, etc., all of which enhance the productivity of the new seeds), obtained in the case of Argentina typically by domestic firms; (iii) and all the other characteristics embodied in the seeds that derive from years of improvements in germplasm by farmers, companies and public research organisations (each seed has around 28.000 genes).

Domestic firms, which develop germplasm with the best characteristics, typically license transgenic events from MNCs, 'paste' them to their own varieties and then, using cross breeding techniques (assisted by modern biotech tools) and advanced forms of mutagenesis, develop new varieties that reach the market every year, embodying multiple innovations. The most innovative ones, which have managed to bring to the market each year improved

Table 2: New seeds registered in the RNC and sold in the seed market in the period 1997-2013: Share of local firms (soybean, wheat, sunflower, corn)

	Companies	Market Certifications	Share
1	Nidera**	6460596	30,76
2	Don Mario*	3414201	16,26
3	Monsanto****	2139732	10,19
4	Sursem***	1084589	5,16
5	ACA*	997442	4,75
6	Pioneer ****	974964	4,64
7	Klein*	849392,6	4,04
8	Syngenta ****	788132	3,75
9	Bioceres*	607378	2,89
10	Dow Agrosciences ****	581151	2,77
11	Buck*	497981	2,37
12	Seminium ***	359275	1,71
13	Ferias del Norte*	289522	1,38
14	Santa Rosa*	256558	1,22
15	La Tijereta***	250325	1,19
16	Lealsem**	238936	1,14
17	SPS***	231222	1,10
18	Advanta****	148874	0,71
	Others (41)	831552	3,6

Notes: (*) Domestic Companies, (**) Mixed companies (local and foreign capitals), (***) Domestic Companies fully acquired by MNCs, and (****) MNCs.
Source: Own elaboration based on the data from INASE and Arpov.

Text Box 13: The context; local accumulation of capabilities in seed breeding in Argentina

The importance of domestic firms in Argentina in seed breeding is associated with a long tradition of breeding in the country. Public sector and commercial seed breeding activities started very early in Argentina. By the 1930´s, there was already a relatively dynamic seed market of both local private companies and public experimental stations. Three decades later, foreign seed companies joined the local market, the first being Cargill in 1947. Very shortly after, plant breeding became regulated in Argentina by laws that were designed to make the seed market more transparent and to protect farmers´ interests (new plant varieties had to be assessed and authorised prior to their diffusion in the market). By the 1970s, the seed market was sharply divided between foreign firms, which focused on hybrid varieties (mostly corn), and local firms and public research organisations, which developed new plant varieties in non-hybrid plants (mostly wheat) (Gutiérrez & Penna, 2004). However, this division soon became blurred as local companies learned about hybridisation.

Today, Argentina is the 9th largest seed market in the world, valued at 600 million dollars, and is the world's 11th largest seed exporter. Plant breeding is mostly performed by the private sector, which has an annual turnover of 772 million dollars. There are about 40 seed companies, which produce seed for a wide variety of crops. The market is dominated by three different kinds of players: MNCs, domestic companies and the National Institute of Agricultural Technology (INTA), which is the state agricultural research institution. INTA produces knowledge useful for the sector, which is then licensed to other firms, both domestic and foreign, who commercialise the seeds. Despite the importance of INTA for the seed market (e.g. it owns 50% of new seed varieties), this institution does not commercialise seeds itself.

Although MNCs have gained a prominent role in the seed market, especially in the wake of the economic liberalisation of the agricultural sector in the 1990s, domestic firms have developed strong capabilities in breeding technologies and have maintained a key role, together with INTA, at least for some crops. Local firms typically buy biotechnological events from, and sell domestic varieties to, MNCs, and compete with them in the final market, with leading positions for some crops such as soy (where two domestic companies Don Mario and Nidera have 60% of the market).

Argentina was an early adopter of IPR for plant varieties, in the form of a PVP dating from 1973. That regime was revised in the early 1990s to be compatible with the international UPOV 1978 plant variety protection scheme. Patent law in this country allows isolated gene sequences with known function, such as the novel genes introduced into transgenic seeds, to be patented. As with most other countries, with the exception of USA and Japan, Argentina does not allow the patenting of life forms (such as seed varieties) and/or genome (or genes), as found in nature.

varieties highly demanded by the domestic farmers, have managed to gain dominant positions in the market (between 1997 and 2012 yields in soy, that can be exclusively attributed to improvements in germplasm, increased 32%).

The case of *Don Mario* is a good example (Nidera is very similar). *Don Mario* is a local company dedicated to the development of new varieties of soybean. The firm has managed to gain a significant share of the domestic market not only in Argentina but also abroad. The company, with subsidiaries in Brazil, Bolivia, Uruguay, Paraguay (and more recently in the USA) had in 2013 almost 50% of the Argentine soybean market (another 40% was served by another Argentinean/Dutch company *Nider*a), around 25% of the total Brazilian market and 57% of the south of Brazil, where the company is named B*rasmax*, and an estimated 25 % market of all the LAC soybeans market.

Don Mario is deliberately not involved in the development of transgenic events, not for lack of technological capabilities, but because of the significant costs of complying with regulatory biosafety requirements and the costs of patenting – which can reach levels up to 10 times higher than those connected with developing the new event. The company, however, performs crossbreeding relying on advanced bio-technological tools (e.g. molecular markers) and on a complex network of development and experimentation that spreads all over the soy regions in Argentina, the south of Brazil, Paraguay and Uruguay.

Table 3 shows the improvements managed by the company in crucial dimensions of the process of development and innovation in seeds well adapted to different agro-ecological conditions in Latin America. These improvements have resulted in significant genetic gains. It has been estimated that the soy varieties of Don Mario have increased the average yield by 1.63% per year in the period1998-2013. The total yield increased by 22.84%.

Table 3: Evolution of Don Mario innovation efforts (1997-2013)

	1997	2013
Soybean varieties	8,500	400,000
Number of experimental plots	30,000	1,100,000
Number of locations of experimentation	5	70
Breeding time (average)	12/13 years	5/6 years

Source: Own elaboration based on information provided in the interviews.

Don Mario has no patents, since it is not involved in the genetic business. However, it is one of the companies with the largest number of new varieties registered in the Argentine market (in the period 2000-2013, it accounted for 26% of all registered soybean varieties at the RNCP). This is a company, it can be argued, that has been able to take advantage of the new opportunities opened by the expansion of a natural resource intensive industry in Argentina and have done so despite the massive diffusion of transgenic events controlled by a few MNCs.

Another interesting case is *Bioceres*. The company was created in 2001 by a co-operative of 23 agriculture producers belonging to two important trade organisations, the *Asociación Argentina de Productores en Siembra Directa* and the *Asociación Argentina de Consorcios Regionales de Experimentación Agrícola.* The aim of the initiative was to improve linkages between biotechnology research, that was being conducted mostly within public research organisations (INTA and universities), and the needs of industrial farmers in Argentina. The company created its own research lab, INDEAR, in 2008. INDEAR was the result of a public-private alliance with Argentina's National Research Council (CONICET), almost entirely funded with public funds, and is fully dedicated to gene discovery. As one of the interviewees explained:

> "INDEAR has pursued the development of our own technological platform… it is an alternative to outsourcing R&D programmes in public research organizations or universities. The goal was to generate our own transgenic seeds based on our own germplasm and package the product to sell it to the agriculture producers. We consider that this is the way to capture the innovation rent".

A major achievement has been the granting of three patents by the US Patent and Trademark Office. The first, based on collaboration between the firm, CONICET and the National University of Litoral, was for a gene enhancer that confers resistance to hydride stress and salinity. The second was for a gene enhancer that increases the expression level of genes in plant cells, and the third was for a gene, which confers shorter life cycles and tolerance to oxidative stress.

At present, however, Bioceres has not been able to introduce its transgenic events into their own germplasm because the event has not yet been approved for commercialisation. Bioceres had to license them to another large MNC, Advanta. For this reason, they continue to buy transgenic events from MNCs and backcross them into their own seed varieties. One of the main problems concerns patenting and complying with biosafety regulations, which require skills, time and resources that most small and medium companies do not have. To cope with these problems, Bioceres are developing alliances and subcontracting with international companies. Our interviewees stressed, however, that patenting and regulatory hurdles are still serious restrictions.

4.3.2 Challenges

We have discussed two companies, and two completely different models of entering this market. The question is if these companies will be able to survive and expand in the future. In this section, we discuss some of the restrictions that they are facing, in more detail. These are of two types: related to expectations and related to regulations.

Transgenics generate huge expectations. The evident novelty of genetic engineering techniques and very significant investment in the technology by some of the world's largest R&D intensive firms no doubt contributes to these expectations. However, they are to a large extent related to promises about the technology that were not fulfilled so far. The first of these - that genetic engineering techniques will improve the *process* of seed innovation - is based, in large part, on the fact that genetic engineering is able to exploit advanced scientific knowledge in molecular biology. Yet, as many individual scientists and scientific associations are careful to acknowledge, the same bodies of advanced knowledge can be and are being used in crossbreeding and mutagenesis, enhancing the speed and precision of innovation using those techniques, too (Biochemical Society, 2011). The second promise is that genetic engineering can improve the *outcome* of seed innovation. It is striking, however, how little evidence there is in support of that claim. In the early 1990s, advocates of the technology claimed, for example, that increased yields, tolerance of drought, more efficient use of fertilisers, and ability to produce drugs or other useful chemicals were all forthcoming. Such expectations have declined considerably in recent years because 25 years of investment and global effort have basically delivered only two single trait types; herbicide tolerance and pest resistance. Furthermore, while these traits have helped to reduce uncertainty and costs, and have simplified management, they have had no overall effects on intrinsic yield (Qaim, 2009).

However, as a consequence of the high expectations, governments in developing countries, such as China, India, Brazil, Argentina, Egypt and South Africa, are making huge investments in the development of capabilities related to transgenesis, in an attempt to 'catch up' with what is seen as the leading technological frontier in seed innovation (Ministerio de Economía y Producción, 2004; Pray & Naseem, 2007; Uctu & Essop, 2013). The support provided by the Argentinean government to the company Bioceres, which finances its research activity almost entirely with public funds, is a clear example of these kinds of polices. This does not necessarily constitute a problem for companies like *Don Mario,* which are based in germoplasm improvements.[18] Nevertheless, financial resources are limited, and R&D and other forms of support for the development of capabilities in seed genetic engineering means less is available for alternative options (unless the capabilities can be applied generically across innovation approaches).

Beyond that, it is not clear to which extent these investments might capitalise in benefits. For developing country governments, the promise of highly profitable domestic seed firms specialising in transgenic seed innovation might be tantalising, but it is an option that in practice is unlikely to be available for all but the largest MNCs firms since the barriers to market entry are so high. The regulatory costs of commercialising transgenic seeds are formidable. Costs related to food safety and environmental biosafety testing for transgenic seeds (which are not required for seeds created using cross-breeding or intra-genic approaches) can significantly exceed the R&D costs. Estimates from other developing countries of the direct regulatory costs to firms seeking to gain a licence, i.e. the costs of providing the necessary data, range from 100,000 to 4 million dollars, depending on the jurisdiction and crop-event combination, and on whether there already exists, for example, food safety or composition data, as a result of prior applications in other countries. Furthermore, while it is typically the case that R&D costs of a new technique decrease over time, sometimes quite substantially, regulatory costs are unlikely to do so and may well increase.

The outlook for the structure of the transgenic seed industry is reminiscent of that of innovative pharmaceutical firms, where high regulatory costs have helped to create an oligarchic industrial structure. The strategies and experience of our case study firms confirm these points. Thus, Don Mario, despite being a strongly innovative and science intensive firm is not interested in entering into the transgenic seed business because it lacks the scale and the financial resources to afford the regulatory costs involved. Although *Bioceres* is in the transgenic seed business, it faces problems complying with patenting and bio-safety regulations, and needs alliances with much larger international companies to enable it to do so.

In addition to high market-entry costs, there are a number of other reasons why, for developing country seed firms, the transgenic approach may be limited or risky. These include the fact that high regulatory costs mean that large markets are required to justify the development of novel traits. For firms interested in breeding crops grown for relatively smaller markets, transgenic technologies may not be commercially viable. In addition, concerns about potential, but difficult to predict, adverse effects of transgenic crops and food on biodiversity and/or human health have meant that markets for the products of transgenic plants do not currently exist in some jurisdictions, most notably in Europe. Likewise, some crops that are only used in human food-stuffs, such as wheat and rice, currently have no potential market in transgenic forms. Indeed, the entire market for transgenic crop products is vulnerable to the discovery of future adverse negative effects.

Also, IPR systems in Argentina, like in many other countries, clearly disfavour companies like Don Mario, that develop germplasm. Nowadays in Argentina, for instance, IPR that affect plant breeding are regulated by UPOV 1978, which gives a level of protection substantially lower than patents. But gene sequences with known functions, such as novel genes introduced into transgenic seeds, can be patented. This creates an unbalanced situation between the owner of a plant variety (mostly domestic firms such as Don Mario) and the owner of a gene (MNCs), where the former cannot have access to the gene protected by a patent without a license; the latter may legally access the plant variety without the breeders' authorisation and without compensation. Moreover, a similar problem arises when considering farmers' right of saving seeds when it comes to GM seeds, composed by two elements that cannot be separated (the germoplasm and the transgenic gene). As patents protecting a gene do not consider the farmers' exemption, this generates a contradiction in the scope of the rights and their limitations.

Currently, in the soy market in Argentina, IPR asymmetries imply that Monsanto, which is the owner of the traits that are being pasted in the local germoplasm, captures 66% of the value of soybean seeds whereas the other 33% is shared between the developers of the germoplasm (Don Mario, for instance) and the firms that multiply seeds. There is no evidence, however, that the rent is distributed among the different actors in relation to their contribution to the total value of seeds. On the one hand, transgenic traits that confer plants resistance to certain herbicides help the farmers to reduce production costs, but, on the other hand, improvements in germoplasm has impacted more on soybean yield increases (Marín et al., 2014). Local seed firms' claim for the strengthening IPR that apply to improvements in germoplasm (for instance by adherence to UPOV 91), which would reduce the asymmetry between them and the owners of the genes. However, others claim that the full privatisation of seeds, which would impede the "farmer's privilege" of replanting seeds for their own consumption, would go against biological diversity and food security. In addition, we do not know with any certainty whether adopting stronger IPR would encourage further innovation activity by local breeders.

This could be addressed by moving in the direction of making the IPR system that regulates improvements in germplasm more similar to the patent system. This, however, is widely resisted in the country because it is thought to be problematic for small farmers, since their rights to replant will be restricted and because of issues of biodiversity and food sovereignty.

Meanwhile, the large MNCs increase their market power. In the case of crops with approved transgenic events (like corn, cotton or soybean) MNCs occupy a dominant position in the market for transgenic traits. This is mostly due to their capacity to fund the cost of all biosafety and patent regulations that these innovations require to reach the market. However, MNCs do not only sell traits, they also attempt to expand into the germoplasm market by buying small and medium seed firms in developed and developing countries. Countries like Argentina, with a highly developed domestic seed market and domestic seed firms with advanced capabilities in breeding, run the risk of both losing these local capabilities and transferring the ownership of local biological diversity (contained in germoplasm banks owned by domestic firms) to large MNCs.

This is an important policy challenge for agricultural developing countries. Developing the right institutions and policies becomes crucial. But are countries such as Argentina or Brazil able to prevent the advance of monopoly positions in the domestic seed market by MNCs? Will agriculture-intensive developing countries be able to enforce regulations that protect their local productive and technological capabilities as well as their local biological diversity in the context of the world standardisation of IPR regulations and the lobby of MNCs, which threaten to leave the countries if their conditions are not satisfied? Furthermore, which types of regulations are more suitable for the further development and protection of the local seed industry in this type of countries?

4.4 Final Remarks

This chapter analysed new opportunities for innovation in the activity of developing new seeds, which is changing very rapidly. Seeds used to be a natural public good and are now transforming into a knowledge intensive product, which contains a multiplicity of new technology services. New technological possibilities have appeared to develop and embody these services in seeds and an increasing demand is favouring the application of the new technologies to develop different types of innovations in seeds.

Countries like Argentina, which have an important and well-developed agricultural sector, a history of breeding and important public organisations of agricultural technology, are in a good position to take advantage of the new opportunities. We have showed in the case of Argentina that a few domestic firms have gained important positions in the regional market based on a significant investment in innovation.

The case shows that companies from developing countries entering new business related to natural resources can take advantage of the differences in domestic agro-ecological conditions to compete with MNCs. They can serve domestic markets better than MNCs, which mainly offer , and profit from, standardised products, by meeting the specific local demands that emerge in association with the natural resource knowledge idiosyncrasy that characterise NRIIs production. Further expansion of these companies requires them, however, to develop different kinds of capabilities, not only scientific capabilities. They need to adapt not only to the changing agro-ecological conditions, but also to the changing regulations and institutions that characterise these industries.

Governments seeking to support domestic companies in these industries also need to set up the right institutions and regulations, related to IPR and market concentration. They also need to improve infrastructures and support the development of knowledge, competence and skills. In order to do so, they need a thorough understanding of the industry, of its future prospects in the globalising economy, and of the strengths and weaknesses of the supporting LICS.

A key question is, thus, whether developing countries can develop the capacities and institutions to address these challenges in a creative manner, in the context of a global economy increasingly ‘regulated’ by international agreements.

5. Natural resources and sustainable development

Ever since Homo Erectus started to master fire, humans have substantially affected nature (Glikson, 2013). The Neolithic revolution led, with the cultivation of the soil, to an acceleration of humankind's interaction with the surrounding landscape. The accumulated impacts are enormous. Almost all temperate grasslands and most of the temperate forests have been converted to arable farmland. About 60% of the world's soils have been modified by human use. At the same time, urbanisation has radically changed much of the non-farmlands. Over 50% of the world population today lives in cities.

Human interaction with the natural environment is a prerequisite for all civilisations, but it has also the power to destroy not only landscapes but societies as well. Complex societies have existed for many thousands of years and, as a rule, they have collapsed. This has often had to do with the 'niggardliness' of nature. Natural disasters (including climate change), depletion of resources, desertification, etc. in combination with mismanagement of critical issues and inability to respond to threats have been reasons for earlier collapses.

It can be argued that the earlier nature-induced collapses of complex societies were rather local in character. Societies depended on the landscapes nearby and did not have the technologies or resources to seek solutions in, for example, long distance trade or exploitation of other countries through violence and warfare. Today, most societies are strongly connected to the rest of the world, not least through trade, and are less dependent on fragile local environmental conditions. On the other hand, the degree to which the landscapes of the world are drawn into and utilised in economic processes are much higher than before. Economic growth and different kinds of trade has gradually made many environmental problems global rather than local.

Interactions between technical and institutional change generally determine the fate of advanced societies, but it has been documented that in many historical cases, for example in the cases of medieval and early renaissance city-states (Pisa, Siena, Florence), interaction with the landscape also mattered very much (Martini & Chesworth, 2010). Now, increasing demand for natural resources from China and other fast growing economies threatens the sustainability of the ways in which we interact with nature. Societies are not less dependent on natural resources today than earlier and the problem of sustainable development has not become less severe in spite of the increased technical and economic capabilities. A discussion of resource intensive economic development inevitably raises questions of sustainability.

In this chapter, we consider challenges of sustainability in relation to innovation based natural resource intensive development (INRID). The production of natural resources seems to interact in a more direct way with nature than production of for example automobiles or smartphones which may have important implications for the governance of INRID. In this chapter, we start with an extension of our typology of different natural resources that are related to sink and source environmental problems, respectively. We continue the focus on agriculture from chapter 4, which we relate to general sustainability challenges and climate change, and we finish with a discussion of governance and policy.

5.1 Is resource intensive development less sustainable than other modes of development?

According to standard economic dictionaries, natural resources are a necessary ingredient of all economic activity. This follows directly from the traditional, basic conceptualisation of production as a result of the three 'classical' factors of production; land, capital and labour, where land is taken to include all natural resources. Natural resources are defined as factors of production provided by nature (i.e. soils, forests, grasslands, water, minerals, fuels, etc.) and sustainability is about the necessity of allowing nature to continue to provide them. To this, one might add that natural resources are not *freely* provided by nature (there are always extraction costs) and that they may be used in other ways in society than as factors of production. It is also important to note that 'natural resources' is a cultural category rather than naturally given. They are dual – both physical and cultural at the same time. Those components of nature that society values economically are elevated to 'natural resources' and the content and meaning of this category changes as society changes. The increasing awareness of the necessity for human civilization to keep the Earth, seen as a complex bio-geophysical system, stable is an example of how the meaning of natural resources changes as a result of increasing knowledge.

All types of economic activity affect the natural environment, directly or indirectly, in one way or another. The main impacts come from use of energy, land use, water use, emissions, waste generation and transportation. The main environmental problems following from this are related to very different issues like climate change, loss of biodiversity, pollution and loss of amenities. The types of impacts as well as the problems encountered are very different from industry to industry and sustainability cannot be taken for granted in any sector of the economy. Consequently, the environmental impacts of specific economic activities have to be evaluated from case to case.

Except for the unavoidable fact that development that builds on the use of specific non-reproducible resources like minerals, fossil fuels and soil will, sooner or later, deplete the stocks of these resources, there is no obvious reason to assume that natural resource intensive activities are neither more nor less sustainable than other activities. It is, however, important to note that including soil in the picture as a crucial, degradable and to a large extent non-reproducible resource draws attention to present unsustainable practices in agriculture. A starting point for the discussion in this chapter is to make distinctions between both different kinds of natural resources and different kinds of environmental impacts.

5.2 Different types of natural resources and environmental impacts

As discussed in chapter 1, there are several ways to categorise natural resources. In the context of sustainability, it is common to distinguish between the ones originating in the biosphere (where biodiversity and renewability are crucial issues) and the ones originating in non-living and non-organic material (where questions of absolute scarcity and depletion often arise). This results in the dichotomy of *biotic* and *abiotic* resources (in chapter 1, these are, approximately, referred to as soft and hard resources). The abiotic resources are often divided into soil (including minerals), air, and water, each connected to a number of specific sustainability problems.

It is also common to distinguish between resources that are *actually used* and those that are not presently utilised but have the *potential* for this, for example because expected profitability is to low or because there is no appropriate technology available.

The most common distinction, however, is the one between *renewable* and *non-renewable* resources. Both non-renewable and renewable resources are scarce and, hence, we need to economise with them albeit in different ways. Both of them are extracted from nature, which is often done in unsustainable ways. The problems connected to scarcity and to extraction are different for renewable and non-renewable natural resources, which, sometimes, make this distinction useful in the context of sustainable development. Most textbooks on 'Environmental and Resource Economics' use this distinction as an organising principle.

Non-renewable resources are *absolutely scarce* in the sense that there is only a physically limited amount of them on Earth. This is true even if the precise amounts of resources are not known and technologies to recover them do not yet exist. In relation to human needs and wants, non-renewable resources are also scarce in a *relative* sense. This is the traditional way to discuss scarcity in economic theory; while human needs and wants are supposed to be unlimited, the amounts of resources, goods and services are limited, which make it necessary to economise with them.

Soil and minerals that are not presently utilised for production and consumption to satisfy human needs may, thus, be regarded as absolutely but not relatively scarce. As soon as they are entering the economic system, or are expected to enter the economic system, they also become relatively scarce and we need to economise with them. One crucial question in this connection is if and how to invest in development of substitutes when the stocks of natural resources are depleted. Another, related, question is how fast it is acceptable to deplete the stocks.

Renewable resources, on the other hand, pose the question of the sustainable size of both stocks and flows when the resources are harvested. For example, at what rate can one tap a stock of fish in a lake and is it possible to define an optimal stock of fish in that lake?

The distinction between renewables and non-renewables makes economic and political sense since it defines different kinds of appropriate reactions to the depletion of natural resources. It defines specific different policy agendas. However, the neat distinction between these two types of resources tends to be softened up and blurred by technological development, which for example discovers new stocks of non-renewable resources, increases the 'resource productivity', develops synthetic raw materials, and so on.

5.3 Development is a process in the biosphere

In spite of fast technical change, human society remains conditioned by the landscape in the broad sense of this term. 'Landscape' may be understood as a geological entity within the terrestrial biosphere possessing attributes that depend on climate, hydrology, soils, organisms and historical development (Chesworth & Martini, 2010: p. 3).

This broad definition goes beyond more traditional ones, which emphasise the aggregate landforms of a tract of land or region. It also includes natural resources like minerals, which may not be visible as landforms, and invisible forms of life for example germs in the biosphere.

This definition of landscapes is useful in the context of resource intensive or resource dependent development since it makes it clear that human beings and their societies are parts of a system of interdependent entities including minerals, soils, waters, plants and animals. In this perspective, all economic and social development is landscape- and hence natural resource dependent. There is no escape from this condition. Our dependence on and interaction with the landscape is the most basic factor to take into account when considering the possibility of sustainable development.

Man is a species in the biosphere and ultimately depends on biosphere characteristics for survival and development. Since the Neolithic revolution, humankind has become the dominant large bodied species in the biosphere and has increasingly affected - indeed taken over - the landscape. The crucial question is if this process has become so destructive to the biosphere that the civilisation that arose from this revolution and the subsequent practices of farming is no longer sustainable (Chesworth & Martini, 2010: p. 4). All living organisms affect the biome in which they are living, but humans affect it more completely and thoroughly than anything ever seen before in the history of life. Some of the consequences are (1) habitat destruction (especially by deforestation), (2) over-exploitation of abiotic resources, such as soil, leading to land erosion, acidification, salinisation, compaction and soil fertility losses, (3) over-exploitation of biotic resources by fishing, hunting and collateral damage of the biotic resource.

These changes have led to the concept of the 'Antropocene', i.e. the period since the Neolithic revolution during which Homo Sapiens has become a geological force on the planetary surface comparable to volcanism, tectonism, glaciation, and weathering (Chesworth, 2010: p. 20). Different criteria for the onset of the Antropocene has been proposed, but there is considerable evidence that the domestication of several species of plants and animals about 10.000 years ago, which lead to agricultural development driven by social learning and to human modification of ecosystems on a global scale, marks a crucial starting point for the co-evolution of human societies and landscapes (Smith & Zeder, 2013). It is also generally agreed that the scale and intensity of human impact on the landscape has accelerated dramatically since the industrial revolution. As formulated by Herman Daly (Daly, 2005, 2015) we have moved from an 'empty world' in which the economic system was small in relation to the containing ecosystem and the technologies used for extraction and harvesting of natural resources were primitive, to a "full world" in which renewable and non-renewable natural resources rather than human and physical capital have become limiting factors for continued economic growth.

INRID inevitably affects the landscape and the biosphere and an increasing awareness of our dependence of the biosphere and the potentially destructive consequences of economic development is the main reason for the increasing attention to sustainability.

5.4 Source problems and sink problems

The fact that renewable as well as non-renewable natural resources are scarce seems to mark INRID as inherently unsustainable. In the very long run, the laws of thermodynamics make it unsustainable to deplete the stocks of natural resources. If we disregard the unlikely possibility that production and consumption may be totally decoupled from the use of physical materials, exponential economic growth cannot be sustained in the very long run. In the perspective of the more foreseeable future, it requires radical technical and institutional developments to postpone the problems and sufficiently move the limits to INRID forward in time. In fact, it is difficult to visualise any effective strategy for environmental survival that does not make full use of mobilisation of knowledge and innovation.

Economic activities (production and consumption) rely on nature as a *source* for raw material and also utilise it as a *sink* for pollution and waste materials. Before the sustainability of the economic process became an issue, nature was generally regarded by economists as 'generous' in the sense that it tended to provide the economy with sufficient raw materials and had the capacity to absorb the generated waste. One might say that a 'linear' view of an economy within a benevolent natural environment dominated. The linear movement of natural resources from its sources over production and consumption into the sink was not seen as problematic or restricted in any serious sense.

The notion of sustainable development, however, contradicts a linear model. Sources have to be looked after and nurtured, sinks have to be cleaned up and waste re-circulated. Feedback mechanisms have to be included and the model of the economy, thus, becomes more 'circular' (Chesworth, 2010b; CIVM, 2014). The notion of a circular economy is now increasingly referring to the ultimate objective of designing out waste from the outset so that no materials ever leave the industrial cycle.

When sustainable development first entered the scene as a political issue, it was mostly characterised as a 'source problem'. We cannot allow ourselves to use up Earth's limited stocks of natural resources without considering future generations. The focus has shifted over time, from one type of resource to another – rain forests, biodiversity, soils, minerals, oil – but continuing depletion of the stocks of natural resources is now widely regarded as inherently unsustainable.

Gradually, however, the interest has shifted from focusing on source problems towards also including sink problems, often referred to in terms of the limited 'carrying capacity' of the earth. This is a complex notion, which make it clear that nature is not just here to be used but interacts with society: building on what they call Earth system science Rockstrom et al. (2009) have identified nine planetary boundaries that define an operating space for humanity. Transgression of these boundaries is likely to cause irreversible environmental damage. The boundaries reflect nine interlinked processes in which nature and society interact:

1. Climate change
2. Biodiversity loss (terrestrial and marine)
3. Bio-geochemical change (interference with the nitrogen cycle)
4. Change in land use
5. Global freshwater use
6. Ocean acidification
7. Stratospheric ozone depletion
8. Chemical pollution
9. Atmospheric aerosol loading

Even if the distinction between sinks and sources is not always totally clear-cut, these planetary boundaries are predominantly results of the limited carrying capacity of the Earth on the sink side. Actually, people's increased awareness of environmental problems, at least in the West, started on the sink side. It was to a considerable degree a result of the publication of "Silent Spring" by Rachel Carson in 1962. This book documented serious detrimental effects on wildlife, particularly birds, of pesticides.

That problems connected to the limited capacity of the Earth as a sink for economic activity seem to be the most critical ones does not mean that we can forget or postpone environmental protection actions on the source side. Sink and source problems are connected to each other through the very process of economic activity. For example, acid rain (one of the most discussed environmental problems in the 1970's and 1980's) acidifies lakes and oceans and is mainly a result of burning fossil fuels. Also, the accumulation of greenhouse gasses in the atmosphere is strongly connected to the use of coal, oil and gas, i.e. natural resources.

Today, although we, according to Rockstrom et al. (2009), have already overstepped the safe boundaries for the first three processes in the list above and they all pose a threat to human existence, climate change, which is connected to both source and sink problems, is widely regarded as the most immediate danger. There is now almost universal agreement that the global mean temperature is rising due to the human-induced increase in carbon dioxide (CO_2) and other greenhouse gasses in the atmosphere. This is a sink problem of the atmosphere being overburdened which threatens to destroy soils, waters and habitats and thus lead to source problems as well.

5.5 Agriculture and the landscape

The insight referred to above, that human societies are parts of a bigger system including other species and abiotic entities like waters, minerals and soils, is important as a framework for a discussion of sustainability issues connected to INRID. But it is only a first step. We need to move on and identify the most urgent and serious problems of the specific production and consumption activities.

It has already been observed that the environmental problems connected to INRID have to be discussed specifically for every industry. Mines and off-shore oil extraction are for example heavily polluting activities. However, agriculture is the resource intensive activity par excellence, the oldest and still most important in terms of employment and income, and we may use it as an illustration of some important sustainability issues. It is also the most important sector to take into account when it comes to its impact on the landscape. Agriculture contributes heavily to global warming by methane released from cattle and wet rice, nitrous oxide from fertilised fields and carbon dioxide from deforestation. According to recent calculations, almost 25 % of total green-house gas emissions come from agriculture and forestry (New Climate Economy, 2014). It relies more and more on energy intensive technologies 'converting oil into food'. It uses enormous amounts of water for irrigation, pollutes rivers, lakes and costal ecosystems, destroys natural habitats and accelerates the loss of biodiversity. That agriculture in its present form is a major threat to sustainable development is beyond doubt.

The problem is aggravating over time by the combination of continued population and income growth. By mid-century, the world population is likely to be around nine billion people, up two billion from now. Continued economic growth with rising levels of prosperity in, for example, China, India and many African countries will not only increase the amount of demand for food but also change its composition. Meat, eggs and dairy products will most likely increase as share of consumption, which will add to the pressure on land to grow more corn, soy and other crops for forage. In China, for example, production and consumption of pork meat has grown very fast. The average Chinese now eats five times more of this meat than in 1979. This has led to a substantial increase in world demand for soy-beans and grain for feeding the pigs, which in turn has put pressure on land use and led to massive conversion of grasslands and forests into cropland in, for example, Argentina.

The fundamental problem of having enough to eat has during the last 10.000 years been solved by expanding farmland (cropland and pastureland) and by intensifying land use through technical, organisational and institutional change. But there are limits to this process. All the early civilisations built on particularly 'agriculture-friendly' landscapes. The Egyptian civilisation was sustained by the Nile providing fertile soils and water in adequate amounts. The early Chinese civilisation was supported by water and fertile sediments transported by rivers and by wind-borne dust from the Gobi Desert. Other regions, however, have not been equally favoured by nature. As human societies have expanded and populations continued to grow, the ecological footprints of agriculture have become bigger and bigger. Urbanisation and the growth of big cities do not decrease the problem as long as agriculture continues to depend on the landscape.

Expanding agriculture by taking over grasslands and forests is becoming more and more difficult and in the last 50 years agricultural production has grown primarily by increased output per unit of land combined with a relatively slowly growing land base (Alston & Pardey, 2014). Virtually all major grasslands in the temperate areas of the Earth have already been taken over and further deforestation, for example by cutting down rain forests for soy or palm oil production, is met by increasing political resistance.

Soil is a base factor in the ecological system and it is to a large extent a non-renewable resource. But soil degradation is a permanent companion to agriculture and one of its most serious environmental problems. Throughout history, there has been repeated collapses of societies because of soil degradation. Agriculture normally requires soils of a certain depth and quality in terms of nutrients and capacity to hold and deliver water. However, land-cover conversion and land-use intensification has followed the expansion of agriculture and this has led to soil erosion, salinisation, desertification, addition of nitrogen into the natural nutrient cycle and loss of biodiversity. The problems are now aggravated and complicated by climate change, and by the fact that irrigated farmland is particularly threatened by these processes.

About a quarter of the World's agricultural land is severely degraded (New Climate Economy, 2014). The drivers of land degradation are mono-cropping, pollution, nutrient mining, uncontrolled grazing and wood-cutting on common areas, inappropriate tillage, erosion from rainfall runoff, and misapplication of chemicals. The implication is that farming, as it is currently practiced, is unsustainable.

Controlling the population growth and thus the demand for food would be an effective instrument for sustainable development, but for different reasons this is difficult. One reason is that natural selection throughout the evolution of man has resulted in a natural propensity to propagate. Another reason is that the World's major religions consider birth control sinful. Thus, both the genes and the Gods tell us to multiply and, consequently, to increase our ecological footprint.

Since population control is unlikely and conversion of forests and grasslands to arable land is slowing down, sustainable development hinges on agricultural productivity growth through technical, organisational and institutional change. This is also what has happened in most parts of the World. Agriculture has intensified and improved the use of machinery, fertilisers and irrigation combined with new pesticides and improved genetic material derived from scientific research.

Innovation has in fact accompanied the development of agriculture ever since the Neolithic revolution when farmers started to systematically select seeds from successful crop varieties (Alston & Pardey, 2014). Because of the biological character of agriculture, organisational, institutional and technical innovation have always been necessary simply to maintain yields, since climate changes, weeds, pests, insects, diseases and other aspects of the landscape co-evolve and repeatedly change the agricultural conditions. Some scholars, however, think that there are limits to the long-run effectiveness also of this 'innovation solution', in particular because it is almost impossible to avoid soil degradation particularly through erosion. The most efficient way to cope with erosion is reforestation and to switch from cropland to grassland, but as long as farmers want more land and consumers demand more meat and eggs in their calorie intake, these solutions are more or less blocked.

It is clear that there are enormous challenges to sustainable development posed by the present forms of agriculture and nobody really knows if we are heading for an environmental collapse or not. Several ways to decrease or at least postpone agriculture's destruction of the landscape have, however, been pointed out.

Different policies may be devised to avoid further deforestation. Employment policy may decrease the persistent hunger for more agricultural land by creating alternative income sources for landless rural populations. Tax policies and improved information may affect the composition of the average consumption basket. It may not necessarily change towards an ever higher relative weight of meat in the fast growing economies and the weight of the most area-requiring types of food (such as beef) may be reduced in the richest countries as well.

It is true that the growth rate of crop yields (quantity of crop per unit of land) as well as land and labour productivity more generally have been slowing down during the last couple of decades in most countries except China (Alston & Pardey, 2014). But it is also clear that there are still many ways to increase production on current farmland by closing the yield gaps between farms with different levels of efficiency in and, mainly, between different countries. Furthermore, use of water, chemicals and pesticides can become much more efficient by the use of ICT, both for increased productivity and reduced environmental impacts. Organic farming techniques can also be used in conventional farming to decrease the use of water and chemicals. In chapter 4, the expectations for the application of biotechnology in the South as well as the North were discussed and the case of genetics applied to seeds shows that the potential is enormous. Not only can crop yields be generally improved, but plant varieties may be developed for very different local conditions. Resistance may be developed to draught as well as flood, different kinds of bugs and pests, and so on. Better use of existing technologies as well as development of new technologies may be affected by an array of policy instruments in agriculture like in other sectors of the economy.

Lately there has also been an increasing focus on waste reduction. A lot of the food (50% of total weight and 25% of total calories) (Foley, 2014), is never consumed but wasted in transport and storing in the farming sector as well as in households. Reducing waste would be an effective way to improve agriculture's long-run sustainability. Since this would include a substantial change of routines and habits of both farmers, retailers and households, it will not come easy, but a combination of information, taxes, and 'nudging' may prove effective if given time to work. Such policy combinations may also make it possible to retard the increase in the share of meat in total food consumption, which has until now accompanied income growth.

There is, thus, several ways to reduce agriculture's negative environmental impacts; all of them open to policy-making. But there are no quick solutions waiting and the discussion in chapter 4 also showed that many of the optimistic expectations connected to the development of biotechnology have not been fulfilled. Routines and habits in both food production and consumption are often difficult to change and many of the new promising high-tech agricultural methods are costly and difficult to apply; many farmers, especially in the South, cannot afford them and they may be quite difficult to manage correctly; there are many problems related to patents and other property rights; the distribution of income and property tends to become more unequal; fertilisers, pesticides and gene modified crops may have unforeseen environmental consequences, and so on.

5.6 Urbanisation and depletion of natural resources

Agriculture is a basic form of land use and the classical example of natural resource utilisation. But the development of agriculture has been accompanied by urbanisation. People have moved from the countryside into towns and cities and, in connection to this, first industry and then services have increased in relative importance. This has dramatically changed the character of land use and has had a number of important environmental effects of very different kinds.

The urbanisation process in China presently stands out in both speed and scale. In the early 1980s, China had about 190 million city residents. Today there are 700 million and the number increases with 20 million each year. This is an integrated aspect of Chinas rapid economic growth and it poses serious threats to the environment while at the same time opening up new possibilities for environmental safeguards and improvements.

Several problems have recently come into focus (UNDP, 2013). The concentration of industries in urban areas has led to severe local pollution of air and water. Air pollution may now be the main cause of death in China and, in many cities, acid rain (primarily a result industrial emission of sulphur dioxide) is a major problem. Limited water supply is also becoming a severe problem and two-thirds of all cities face water shortages. In addition to this, inadequate waste treatment implies many kinds of health problems.

Even more basically, land for urban expansion is coming closer to its limits (UNDP, 2013). Most of the suitable areas in the south-eastern cities and in the Yangtze River delta and the Pearl River delta have already been developed and land use intensity has become very high in many cities. This has led to severe soil erosion and sudden disasters from floods and landslides.

But the land use for growing cities does not only lead to environmental problems. It also opens up new possibilities for problem solving (Glaeser, 2011). The density and diversity of cities may form creative environments fostering innovative solutions. Modern waste management may transform waste to resources for energy production and material recycling. Good collective transport systems and dense housing can save considerable amounts of energy. Furthermore, in waste treatment, transport and construction, there are very big potentials for reductions of GHG emissions. To a very large extent, the quality and extent of urban planning will determine if the land use connected with urbanisation and city growth will predominantly create or solve environmental problems.

5.7 Amenities – services of nature

Increasingly, and as incomes rise, people seem to value nature more. Not only as a source of raw materials for production of goods and services, but also as a value of its own. Enjoying nature for its beauty, 'magic', healing, recreational powers, etc. or for its ability to stimulate curiosity and thrill is, of course, not a new phenomenon. From the Age of Enlightenment onwards, landscapes have, at least in the Western world, been considered to have an intrinsic quality of their own, regardless of their usefulness to us (Chesworth, 2010: p. 20). The point here is that increasing incomes and satisfaction of material needs increase the relative value of nature in the sense referred to above in section 5.3. The relative scarcity of nature as a direct source of human enjoyment is increasing.

It has become common to talk about the growing importance of natural amenities. These are of course very difficult to measure, but to some extent they may be indirectly indicated, for example by the fact that property situated in the vicinity of forests, lakes, coastlines, attractive landscapes, etc. often have relatively high market prices. Natural amenities are situated close to and connected with land use. This means that they compete for land with urbanisation and agricultural expansion through deforestation. They also compete with extraction of natural resources like coal, oil, minerals and so on. In this sense, there are direct negative environmental effects of natural resource utilisation. As competition for land use increase as a result of economic growth and population growth, these negative environmental effects become relatively more costly. The increasing role of natural amenities in the process of satisfaction of human needs and wants is exploited in different ways by firms in for example the tourism industry or by firms producing an endlessly increasing variety of equipment for utilising natural amenities, like clothes and gear for camping, hiking, mountaineering, sailing, bird watching, hunting, etc.

To some extent, this until recently not very much discussed use of natural resources has been reflected in the discussion of the so-called 'services of nature' or 'ecosystem services', which in the Millennium Ecosystem Assessment Report in the category of 'cultural services' includes for example aesthetic, spiritual, educational and recreational services of nature. The notion of ecosystem services is, however, much broader than this and the report also defines a large number of crucial 'provisioning' and 'regulating' (largely unpriced and often unrecognised) services provided by ecosystems. The main argument, that the health of ecosystems is vital for human civilisation, is found in the title of the synthesis report 'Ecosystems and Human Well-Being'. If utilisation of natural resources for economic purposes threatens the viability of ecosystems, the costs in terms of loss of ecosystems services are potentially very big. Every resource intensive development strategy has to take this seriously into account.

5.8 Natural resource production and climate change

Historically there are many examples of climate change affecting agriculture. Periods of rapid climate change have occurred throughout the Holocene (i.e. the about 12.000 years since the last major glacial epoch). The 6th millennium BP (Before

Present) was characterised by profound climatic change. Since this was also a period in which some of the first complex human societies were formed, the connections between climate and social change have been studied. Usually, it is assumed that climatic stability supports the development of complex societies. For this period, however, it has been argued that rapid climate changes led to changes in the ways in which food was produced, which in turn led to population concentrations that stimulated development of advanced societies. Cooling and aridity led to widespread desertification particularly in Northern Africa and Western Asia. In Sahara, with the collapse of both summer and winter rainfalls, fertile landscapes supporting significant populations were transformed to hyper-arid desert. People reacted by moving to more benign landscapes, by shifting between agriculture and pastoralism and by developing new agricultural technologies.

> "…it seems beyond doubt that in the middle of Holocene Sahara, and during the 6th millennium in particular, severe climatic desiccation was a dominant factor driving migration, livelihood innovation, and changes in social organisation" (Brooks, 2010 : p. 53).

As the only permanent river in the Sahara, the Nile became a natural attractor for population movements triggered by the increasing aridity. This greatly affected the development of the Egyptian civilisation. According to Brooks (2010) this is an exemplary case of how the concentration of population in a restricted area can stimulate social innovation and complexity, leading to social differentiation and stratification, because of climate driven environmental change and resource scarcity.

It seems clear, thus, that climate change may lead to economic, political and social change. It has even been argued (Brooks, 2010) that this has been so common in history that it is possible to identify a number of typical cultural responses to rapid climate change, such as, for example, a shift in the type of landscape exploitation, migration, population agglomeration, increased territoriality, and changes in social organisation, especially more intense social stratification and inequality.

Presently, however, most of the debate is focused on the opposite chain of causation: human civilisation affecting the climate, even on a global scale. As discussed above, agriculture is a major contributor to global warming. It affects climate change through emission of greenhouse gasses – methane by cattle and rice farms, nitrous oxide by fertilised fields, carbon dioxide by deforestation and by the fuelling its machines and vehicles by oil.

Also, other natural resource intensive activities have been noticed for affecting the climate and other aspects of the environment. Particularly, energy-intensive process industries such as steel, aluminium, cement and chemicals have been in focus. The production of cement, for example, releases carbon dioxide both directly through a chemical process when limestone is heated and indirectly through the use of fossil fuels for the heating. Transport of this heavy material also adds to fuel consumption. Cement accounts for about 5% of global carbon dioxide emissions. It is the primary component in concrete and thus crucial for constructing roads, bridges, dams and buildings around the World. It is very difficult to substitute with other materials and it has no viable recycling potential. Efficiency in the production of cement can be increased and alternative fuels can substitute fossil fuels, but cement production will still remain a heavy contributor to greenhouse gas emissions in the foreseeable future. There are other environmental problems with cement, as well. Surface runoff of water in urban areas picks up pollutants such as oil and heavy metals and leads to serious water quality problems, and radioactive and toxic elements in concrete may lead to health problems.

Other natural resource intensive activities, such as mining, forestry and fishing, may also contribute to global warming or be unsustainable in other ways. This must also (like agriculture, cement and so on) be analysed specifically in each case. It does not seem possible to find a stable relationship between, for example, the degree of natural resource intensity of a specific industry and its environmental impact.

One specific natural resource, of course, is conspicuous when it comes to the seriousness of its environmental impact. Fossil fuel (for heating, transport and production) is a pivotal factor in climate change. Not only is carbon dioxide emitted when fossil fuels are used, but due to declining energy return on energy invested (the so called EROI ratio) in the extraction process, oil *producers* are now heavy emitters of greenhouse gas. As for agriculture, fossil fuels have to be analysed as specific cases. This was, however, the main theme for the previous Globelics Thematic Review (Lema et al., 2014) and will not be discussed further here. The conclusion so far has to be limited to the observation that every resource intensive activity leaves its own ecological footprint and raises its own sustainability issues. Two main sectors, however, stand out when it comes to climate change – agriculture and fossil fuels. Furthermore, these two sectors feed upon each other since modern agriculture relies more and more on energy intensive technologies and crops can be used for the production of fuels.

It is not surprising that climate change is increasingly regarded as the major present threat to sustainable development. It illustrates the idea of a tipping point where the Earth system and its complex interacting subsystems (the cryosphere, atmosphere, hydrosphere, biosphere and stratosphere) can shift states in sudden and irreversible ways (Rockström, 2015). This is a scaring scenario since nobody knows how human societies would be affected and how people would react. In spite of shorter periods with significant climate change in different parts of the world (as for example the middle Holocene Sahara mentioned above) the Holocene as a whole has been remarkably stable with average global temperature staying within a range of 1°C. Only during the Holocene the biosphere has taken the form we know (with grasslands, wetlands forests, polar ice sheets, fisheries, hydrological cycles and so on), which has been a precondition for civilization. Moving outside the Holocene stability, which continued climate change implies, will make much of mankind's accumulated experience and knowledge about living in the biosphere useless.

5.9 Common pool resources and threats to complex socio-economic systems

Natural resources are provided by nature but controlled and utilised by man. Obviously, the institutions determining the control of natural resources affect the sustainability issues connected to them. This is underscored by the fact that many natural resources can be classified as common-pool resources. They share properties with both public and private goods.; it is costly to develop new institutions, costly to exclude potential beneficiaries from using the resources, and one unit of the common pool resource that is appropriated by one person is not available to others (Ostrom & Schlager, 1996).

Common-pool resources may be renewable or nonrenewable. Renewable common-pool resources may sustain resource harvesting for longer periods of time if use patterns are kept within limits. For nonrenewable resources, the problem is about the timing of the extraction flow and not about the sustainability of the system itself. Both renewable and nonrenewable common-pool resources, however, have stock as well as flow characteristics, which both need to be governed. Hardin (1968) put forward that open access to common-pool resources leads to overexploitation and this provoked a whole literature about "the governing of the commons". It is now clear that unsustainable exploitation of common-pool resource is still a widespread phenomenon and that it often is difficult, time consuming and costly to develop an adequate institutional framework to cope with these problems. For example, in the cases of salmon farming in Chile (Iizuka & Katz, 2011) and soybean production in Argentina (Katz, 2013), lack of knowledge about biological processes and inadequate or lacking systems of regulation and infrastructure raise serious questions about sustainability.

In many cases, common-pool resources are situated and the systems of governance have evolved over long periods of time giving local people specific knowledge about resource flows and crucial roles in their governance. The knowledge base of the regulation often includes traditional and tacit knowledge and governance systems often rely on informal institutional traits like social norms, trust, rules for inclusion and exclusion, rewards and punishments and so on. It is not surprising that processes of rapid economic growth, changing patterns of international trade and capital movements, expansion of market regulation, and so on may destroy well-functioning local governance systems of natural resources without taking the long-run costs of this into account.

These costs include destruction of livelihood and loss of knowledge resources of local communities and indigenous people, which may have depended on and been the real stewards of common-pool resources for very long times. From a development point of view, this constitutes destruction of *substantial values*, i.e. values in their own right, which local people have enjoyed. Development has been defined as expansion of the freedoms that people have reason to value (Sen, 1999) and destruction of such freedoms (for example, the freedom to control and utilise local natural resources) in itself contributes negatively to development.

The costs of destroying local governance systems may also include loss of *instrumental values* that contribute directly or indirectly to the freedoms that people have to live the way they would like to live, i.e. to development. For example, it has recently been reported from World Resource Institute that securing local peoples' right to the forest that they live in and from reduces the deforestation of rainforests that is responsible for a substantial part of climate change. Converting forests to which local communities and indigenous people have legal or customary rights into, for example, palm oil plantations has been a major contributor to global warming and loss of biological diversity. Deforestation rates inside community forests with strong legal recognition and government protection are very much lower than in forests without such protection or with weaker protection (WRI, 2014).

One successful example of how government protection of the rights of indigenous people can check deforestation is that of Brazil's Indigenous Lands. In Indigenous Lands recognised by the government, the communities have the rights of exclusion and to sustainable management of the forest with formal property rights retained by the state. It is reported that in spite of very high levels of deforestation pressure, Indigenous Lands achieved stronger protection of the forests than any other regime of forest rights. WRI (2014) reports that from 2000 to 2012, forest loss was less than 1% inside Indigenous Lands compared to about 7% outside and that 27 times more CO_2 emissions were produced outside Indigenous Lands than inside.

International comparisons show that formal legal rights of local communities and indigenous people are not in themselves enough to protect the forests. The rights have to be actively backed up by the state. Governments may, for example, protect community rights by helping map forest borders, expelling illegal loggers, and providing technical assistance and training. It is of course crucial that the government does not grant commercial concessions over community forests to outside firms. It is also important that governments recognise the contribution that sustainable forest management makes to environmental and climate protection by providing economic support and by supporting international initiatives in this area, like, for example, the REDD+ initiative.

5.10 Some policy aspects

The discussion in this chapter shows that there are many kinds of natural resource intensive activities that affect the sustainability of economic development in many different ways. The discussion has also touched upon different kinds of policy action, and it is clear that it is not possible to provide a narrow set of 'one size fits all'-policy instruments for controlling the environmental effects of INRID. But this is not a problem in itself. A wide array of established instruments for sustainable development already exists, which may be used pragmatically from case to case.

If we look at agriculture or, more broadly, land use as an example, it is obvious that productivity needs to increase sharply to match an increasing demand for food. At the same time, the pressure on land, in particular forests, has to be reduced to support the vital services of nature provided by ecosystems, and the emission of GHG has to be curbed. This is a complex set of problems with a built-in tension: Increasing agricultural productivity tends to lead to increased demand for inputs, including land. Deforestation and hence increased GHG emissions may, thus, be the indirect and unwanted consequence of improved agricultural technology. Successful policy making in a complex situation like this needs to take a number of different policy instruments into account. However, some policy approaches (which should be regarded as complementing rather than excluding each other) stand out as particularly interesting in this context.

The most important issue and the most optimistic expectations are connected to increasing agricultural productivity through *technological change,* notably biotechnology and GM crops (gene-modified crops). Economic incentives (for example taxes and subsidies) and direct regulations (laws, ordinances, decrees, injunctions, etc.) may be used to improve agricultural technology. It is crucial, however, to take the complexity of the economic and ecological systems as well as their interactions into account. For example, agricultural productivity may be increased by fertilisers, but the subsidising of especially nitrogenous fertilisers has induced farmers to overuse with sharply increased GHG emissions as a result. Another example is that government support of R&D in more productive and resilient crop varieties may be an effective instrument, but the use of it also has to take into account that the new varieties have to address location specific problems caused by the increasing land degradation. In addition, a shift to GM crops have unforeseen and unwanted effects in terms of soil degradation. Such complexities necessitate very high levels of competence of policy makers, which may not be present at every regional or national level. The difficulties connected to high-tech agriculture have stimulated development of organic methods, which in many places have improved the soil quality and proved effective against insects and pathogens. It has also prevented the accumulation of debt, which is a common experience of small farmers applying the costly new high-tech methods. For policy makers, it should not be a question of choosing either a low-tech or a high-tech way forward. Neither is it a choice between organic agriculture or GM agriculture. In terms of choice of technology, the best way is probably a combination of different paths to a more sustainable agriculture.

A second set of important policies is connected to the character of the *rights to land*. The institutions that govern the access to and use of land have implications for deforestation, land degradation, ecosystem services, etc. If, for example, the rights of local people are violated in the exploitation of natural resources this may not only reduce the efficiency and sustainability of resource utilisation but also conflict with the very meaning of development. International initiatives like REDD+ may constitute important support for policies, which have to be strongly anchored at local and national levels.

A third group of instruments has to do with *new institutions* that increase the efficiency of resource utilisation. New regulations and norms may, for example, ease the development of the so-called *sharing economy.* If the utilisation of the stock of private houses, flats, cars, tools and so on can increase through sharing, this will at least temporarily reduce the demand for natural resources. Policy makers may also support implementation of resource management principles in accordance with the notion of *the circular economy* with information, tax incentives and regulation.

A fourth group of instruments could be designed to *affect norms and values* connected to the demand for food. Post-harvested loss of food and food waste needs to be drastically reduced and the composition of the calorie intake needs to be changed away from the most GHG intensive food products, especially beef. Information, education, taxes and subsidies, along with 'nudging' may be useful instruments.

Putting institutions, norms and values on the policy agenda draws attention to an important issue. To keep development within the planetary boundaries most likely imply not only radical technological change but also radical changes in institutions, norms and values. This means drastic changes in the ways people can live their lives, which will most likely only be possible if broadly accepted principles of justice and fairness when it comes to distribution of income, wealth and power are honoured. Distribution policies are important in natural resource based development.

In this chapter, we have discussed a number of environmental problems connected to different types of INRID. We have shown that such problems are indeed both frequent and serious. It is also obvious that industries that exploit non-renewable abiotic resources cannot avoid the problems constituted by the absolute scarcity of these resources. However, since all economic activity unavoidably involves natural resources, the discussion in this chapter does not imply that INRID is intrinsically more unsustainable than other less natural resource intensive modes of development. The sustainability of an economic activity depends on scale, intensity, organisation and technology, and has to be analysed from case to case.

6. Towards innovation based natural resource intensive development: some policy issues

This final chapter presents some aspects of policy making related to development based on the expansion of NRIIs. Throughout this review, we have argued that there are no strong reasons to believe that the secondary and tertiary sectors are universally more developmental than the primary sector. It is more fruitful to focus on how different activities contribute to learning, innovation and competence building regardless of the sector to which they are categorised as belonging. We have also argued that when analysing natural resource intensive industries, the view should be broadened from looking exclusively at the companies producing natural resources to include the networks of users and producers that make up blocks of development across the tripartite classification of sectors into primary, secondary and tertiary products (see chapter 2). Furthermore, the possibility of INRID in both the short and long run should be seen as complementary to, rather than in competition with, development strategies addressing other aspects of the economy less related to natural resources, such as manufacturing and services. The present chapter builds on these assessments.

Moreover, this chapter refers to the three development challenges related to the sector composition of the economy identified in chapter 1: The macroeconomic challenges, the institutional challenges and the industry and innovation challenges. While we acknowledge the importance of all three challenges, and the interactions between them, the focus, however, in this chapter as well as in the review as a whole, is on the industry and innovation challenges.

In the introduction, we set out three questions guiding this Review: (i) to what extent it is currently possible for a country to develop on the basis of natural resources? (ii) What are main underlying mechanisms of resource intensive development paths? (iii) How can such mechanisms be supported politically?

Regarding the first question, this Review has formulated an emerging approach to natural resources and development which considers that the extent to which it is currently possible for a country to develop on the basis of natural resources depends on to what extent that country can succeed in moving towards innovation based natural resource intensive development.

With respect to the second question, we have in this Review argued that innovation based natural resource intensive development consists of at least four, often complementary, key processes:

1. The first process refers to the importance of learning and competence building in natural resource producers to participate in interactive learning and to take advantage of new opportunities emerging for these industries, including cost reduction, product enhancement and mitigating environmental spillovers.
2. The second process concerns the development of locally based and knowledge intensive industries, which are suppliers and users to the NRIIs. This is equivalent to promoting the quantity and quality of backward and forward linkages around natural resource production including both manufacturing and service firms.
3. The third key process relates to different types of interaction between NRIIs and other parts of the economy, which may be both positive and negative. The Dutch Disease is certainly a negative one. Positive forms of interaction are: (a) lateral knowledge migration where firms, products, technologies and knowledge producers directly related to natural resources journey into industries and markets unrelated to natural resources (b) financial resource rents reinvested in other industries, (c) shared infrastructure, such as transport, ICT, and energy, and (d) the promotion of technical and organisational competence in firms and government from participation in global value chains, which may benefit other industries.
4. The fourth key process refers to social inclusion connected to learning and innovation in a long-run development path. Lack of inclusion may be a serious development problem (Johnson & Andersen, 2012). Connecting the expansion of NRIIs with poverty reduction and broad job creation has not been very successful in the recent natural resource boom (AEO, 2013). Also, it is important that the expansion and upgrading of NRIIs do not damage the local or global ecology undermining continued reliance on a strong primary sector.

The last question we set out in chapter 1 deals with policy. It is the purpose of this last chapter to provide, on the basis of previous chapters, an answer to that question. The four key processes have to be addressed in all development strategies centred in natural resource intensive activities. In addition to this, policy has to address the specific characteristics of the particular natural resources in question. In this review, for example, we have pointed out that natural resource intensive activities very often require locally specific knowledge and may have negative environmental effects.

The different policy issues discussed in the present chapter are derived from the idea that support to building natural resource innovation systems defines a number of relevant policy approaches. Without going very deep into any specific aspect, the chapter gives an overview that shows that INRID is potentially open to many kinds of policy intervention. While some development will occur via the market, government has a key role to play in accelerating and deepening INRID.

6.1 A LICS approach to natural resource policies

A LICS approach is very much about linkage building. The Review has introduced different types of linkages including backward, forward, and lateral migration that all have qualitative and quantitative as well as domestic and international aspects. A LICS-building policy approach should be open to all these kinds of linkages, but will realistically only be able to act on a quite limited number of them.

As complementary to building new linkages, it is important to keep existing ones open, i.e. to avoid unnecessary closing down of activities and linkages. It is important to create a 'linkage friendly' climate, i.e. a curious and experimenting economy open to new connections and experiences. It is thus important to have the double ambition to preserve and further develop established competences and at the same time be open to new relations and linkages – i.e. to build an 'ambidextrous' innovation system. Building a linkage friendly economic climate is a matter of institutional change. Inclusive institutions and social capital are key aspects. Policies for this may work through education, communication infrastructure, physical infrastructure, free and diversified press, gender equality and so on.

In a LICS approach, it is not the various factor inputs per se that are decisive but rather how they interact and 'feed upon' each other. Processes of cumulative causation between changes in these factors bring about new situations including contradictions and problems, which feed learning and innovation. This brings the institutional set-up of the economy into focus and institutional improvements to support innovation become a key policy agenda. It is obviously not enough to have access to abundant natural resources. But if a country can build an institutional framework and an infrastructure for the utilisation of specific natural resources, which supports development of new knowledge and competences that can be applied in a range of different activities up- and downstream, INRID is possible.

Innovation entails the entry into the economy of new processes and products. This means that development is always and inevitably connected to changes in the structure of production. It involves evolution of networks and other patterns of interaction betwee n different production activities that feed structural change. It also involves insertion in global value chains leading to new patterns of interaction and affecting the structure of the economy.

The LICS approach embraces a process view on development, which take into account that unregulated markets are not always good when it comes to development of new skills. As a consequence, development of well-functioning innovation systems is not automatic but should be coordinated and supported by policy. The LICS approach provides an analytical framework for understanding the evolution of complex economic systems and, hence, for learning how to formulate and implement a policy for INRID. While much linkage development can unfold as the outcome of uncoordinated decisions of individuals, firms and organisations, governments can also play a key role – potentially both positive and negative – in fostering and enhancing linkages and addressing the challenges that currently face natural resource intensive activities. Policy can, for example, manipulate or supersede market forces to allow for gradual transformation of the comparative advantages of domestic versus foreign companies through skills development and technological learning (Amsden, 1992; Wade, 1990). In cases where firms in developing countries become part of global value chains with lead firms in high-income countries, policies to link the firms in the chain to local and domestic firms become important in order not to lose much of the 'learning by interacting' potential.

When moving on from generic insights to the examination of actual policies, it is useful to keep a basic observation in mind: There is a difference between on the one hand continued or increased utilisation of natural resources in already existing, ongoing processes, and on the other hand starting up utilisation of idle resources i.e. 'orchestration' of new resource utilisation. For example, to venture into mining and utilisation of rare earth minerals in Greenland, which has very limited experience in any kind of mining, is very different from expanding oil production in the Norwegian part of the North Sea. Extending natural resource deposits is often less challenging than the creation of new natural resource production. More generally, there is a distinction between resource development projects in the South and in the North since they start from very different positions in terms of knowledge, competences, institutions and infrastructures. Especially in developing countries, major natural resource development projects may require participation of large transnational firms. Can these be encouraged to participate more effectively with local economic development? This would highlight institutional innovation, for example in relation to issues of property rights, transparency and corruption. It also draws attention to how participation of firms in global value chains may affect development.

To develop policies for formulation and implementation of an innovation based natural resource intensive development strategy, one needs to consider a number of issues – the policy activities that make up the strategy, the policy makers and other stake holders, which from their own specific perspectives try to implement the strategy or specific parts of it, the goals that the different policy makers set for themselves, and, finally, the instruments that policy makers control. These different policy issues serve to structure the following sections where we will discuss each very shortly.

6.2 Policy Activities

Discussions of public policy normally include policy formulation, policy implementation and policy evaluation. These may, at least to some extent, be seen as (partly) consecutive phases with a number of feedbacks between them (Jordan et al., 2015). In relation to policies for innovation based natural resource intensive development (INRID), we may note the following, partly overlapping and interacting, policy activities, including mainly policy formulation and implementation:

- Searching, creating and mapping resource stocks and flows. Knowledge about the specificities of local natural resources is necessary not only for starting new resource using activities, but for improving ongoing activities as well. It is also important for both the scope for domestic linkages and for the ability to sustainably manage the source challenges.
- Mapping the parts of natural resource LICS that already exist, including relevant properties of strategies and capabilities of domestic and foreign actors (including public policy makers, research organisations and universities, and technology transfer agencies), structure and dynamics of markets and value creation, relevant domestic as well as international knowledge bases, institutions and infrastructure. Such mapping presupposes a conceptual and theoretical knowledge about innovation systems (and their connections to the international division of labour). Lack of such knowledge may effectively limit the usefulness of all LICS inspired policies.
- Developing a multi-temporal vision for INRID that connects and coordinates short-term strategies with long-term strategies and goals. Such a vision can be used to seek alignment of the strategies followed by the set of key actors involved. This policy activity will most likely require the creation of new supporting institutions and organisations (such as a natural resource development agency).
- Building infrastructures for utilising natural resources. Mining, harvesting, processing, and transport of natural resources often relies on roads, railways, harbours, electricity, internet and other investment-heavy infrastructures, which often have to be provided by the government. The type of infrastructure needed does, however, tend to differ across types of natural resources. For example, the concentrated infrastructure needed to produce offshore oil is likely to have less spillover potential than the distributed infrastructure needed for knowledge-intensive agriculture.
- Building a range of different institutions and institutional frameworks that particularly support learning, innovation and competence building, but also social inclusion and sustainability, is relevant for development on the basis of NRIIs. Also, other institutions matter. Well-developed legal and regulatory systems including policing and court implementation are, for example, important.

- Developing new skills and competences in domestic companies and organisations that are applicable and needed in relation to materials, products, and processes of NRIIs.
- Providing information about new technological opportunities in natural resource intensive activities and building domestic capacity for accessing and utilising international technology and scientific knowledge bases. This concerns establishing research organisations and universities – specialised within NRII relevant knowledge – and connecting these with the industrial actors via high-quality linkages that may spur interactive learning and positive feedbacks. The Argentine seed industry discussed in chapter 4 is an example of this.
- Developing good practices, manuals and quality control systems for NRIIs on the basis of known skills competences and technologies.
- Supporting linkage dynamics, including backward, forward and lateral migration in the process of innovation system building. Especially backward linkages and local content requirements seem to be important. The quality of linkages (in terms of knowledge and learning inducement) may also be nurtured by policy makers. Policies to enhance linkage development should build on a degree of shared interest between, at least, natural resource producers (often foreign), supplier and potential supplier firms, research and training organisations, and government.
- Sometimes natural resource intensive industries are parts of global value chains dominated by foreign or multinational firms. This may reduce domestic policymakers' influence over the development of 'their' NRIIs, but it does not reduce the importance of linkages and linkage building. To harvest learning and competence building from domestic firms' participation in global value chains regional and national government bodies and other policy makers may negotiate about the role of material suppliers, labour markets, infrastructure, environmental regulation, taxes, etc. To help domestic firms to enter and benefit from global value chains may thus become an important policy activity.

6.3 Key actors in policy making

In relation to a knowledge intensive natural resource intensive development strategy, there are several very different types of policy makers with very different agendas, competences and powers. It is important to notice that policy actors may have different and sometimes contradictory goals. We do not normally have a situation where one central policy maker controls the other ones and the different actors are likely to act on the background of their expectations about what the other actors will do. Development policy will normally not take the form of consensually coordinated sequences of actions pointing towards a well-defined set of goals. Sometimes, the best option is to accept that multiple more or less uncoordinated paths are followed.

Still, enabling LICS building relies on some degree of collective endeavour, making attempts to align key actors under a shared vision important (Andersen & Andersen, 2014). The inclusion of different stakeholders in policy design and implementation may be necessary in order to increase transparency and tackle tensions and conflicts, for example between different industries, between local, regional, national and foreign interests, and so on. The following policy actors are of importance:

- National, regional, and local governments, which may have differing agendas for innovation based natural resource intensive development. These may to some extent be in conflict with each other. Policy goals like employment and environmental protection may for example look quite different when viewed from a central or local point of view.
- Larger cities are increasingly becoming crucial policy makers in connection with natural resources. They are big land users and use a lot of water and energy, etc. City management and development, thus, very much affect the demand for natural resources.
- International organisations like WTO, IMF, WB, OECD, and UNFCCC. Some of these (for example IMF and WTO) have considerable regulation competence and power. Other organisations have more indirect power; OECD is, for example, mainly an organisation for statistics and economic advice and UNFCCC is mainly a negotiation framework.
- Donor organisations affect the natural resource agendas in receiving countries. They have, for example, often been involved in the construction of dams for electricity production and in capital investments and competence building related to agriculture. We believe there are several special tasks for donors in relation to INRID (see Text Box 14).
- NGOs are involved in many different kinds of natural resource related activities, for example connected to environmental issues and agriculture, forestry and fishing.
- Large national and international corporations are major actors in the utilisation and development of natural resources. When domestic national resource intensive industries are parts of global value chains, leading foreign firms further up or down the value chain may become policy actors. They may for example try to influence the property rights and regulation frameworks for utilisation of natural resources and seek negotiations in these areas with regional and national governments.

6.4 Policy goals

There are both instrumental and substantial values connected to natural resources and development. Natural resources cannot exclusively be seen as leverages (instruments) for economic development (for example as factors of production, employment, and export, and sources of learning and competence building) since they are often regarded

Text Box 14: Special tasks for donor organisations

The increasing focus on the role of agriculture in climate change and other environmental problems, along with the new challenges connected to population growth and food production, changes the character of donor involvement. In chapter 5, the topics of technical change, for example to avoid soil degradation, the establishing of new institutions (connected to the rights to land, the sharing economy and the circular economy) and new values connected to the demand for food were briefly discussed. These changing policy areas will also affect the tasks for donor organisations.

The increasing economic and political attention to natural resources in general, generated by the recent natural resource boom, will presumably also affect donor organisations. Donor organisations have often been involved in infrastructure development in connection with production of natural resources. The need for such activities may now increase. Also, environmental issues may define new tasks about technical and institutional change, and competence development. The essential requirement to avoid the resource curse makes competent advice about institutional development crucially important. Another, but connected, area that may increase in importance concerns the rights and living conditions of local communities and indigenous people, who are affected by new or intensified natural resource utilisation.

Foreign firms are still primary players in the exploitation of many natural resource activities in developing countries – oil and gas and minerals, in particular. Resource nationalism is rising – these foreign firms will have to respond by becoming more deeply engaged in helping local economic development. Donor agencies have a role to play in supporting and encouraging foreign firms to engage more effectively with local economic development; to limit corruption by being more transparent – hence, the 'codes of conduct' signed

as having values in their own right. For example, the exploitation of natural resources is intimately connected to different ideas and ambitions of community and sustainability. Many people insist there are natural resource 'imperatives' – things that have to be observed and respected when natural resources are utilised. This may be indicated by notions like 'the intrinsic qualities of landscapes', 'the health of the land', 'the land organism', 'the Gaia hypothesis', and the reduction of 'carbon footprint'. Also, 'biodiversity' and the continued existence of areas of relatively undisturbed nature are often regarded as having a substantive value of its own beside its instrumental values for economic development. The importance of these values seems to increase with the level of income. This is, however, not always reby many of the major companies and supported by donor agencies.

One of the most important tasks for donor organisations may be to mitigate the dominance of macroeconomic and institutional challenges and perspectives in the discussion about resources and development. Bringing forth the industry and innovation perspective may stimulate a more nuanced picture of the development potentials residing in NRIIs. It would also present an array of strategy and support opportunities for donors that are much wider than transparency and management of resource revenue. Moreover, bringing forth an industry and innovation perspective enables more actors to perceive how these three dominant perspectives interact with each other in both positive and negative ways.

For example, as discussed in chapter 1 (see Dutch Disease), many resource intensive developing countries have made financial stability a fundamental part of their development strategy. This resulted in accumulation of reserves and financial assets abroad. Still, as UNCTAD (2013) points out, in a world of scarce financial resources, such accumulation comes with the opportunity cost of bypassing strategic investments in the real economy in terms of linkages, infrastructure and capabilities. UNCTAD (2013) further suggests that this staunch insistence of donors, NGOs, and international financial institutions on financial stability (avoiding Dutch Disease) de facto implies that the predominant international financial architecture gives resource intensive developing countries limited choice in how to invest their resource income. This, in turn, calls for a more nuanced understanding of the role of natural resources in development among this set of actors.

flected in policy making, even if strong arguments can be made about the dangers for modern civilisation in neglecting nature (Vetlesen, 2015).

In addition to such substantive values connected to natural resources, resource intensive activities have instrumental values for development. The natural resource intensive activities are contributing to the usual development goals, i.e. economic growth, employment, equity, health, education, social security and so on. In this respect, they are not different from other industries. However, since natural resources are particularly linked to sustainability and community, the conventional views on economic development, especially the more narrow ones encompassed in economic growth and employment, are not sufficient.

6.5 Policy instruments

From the discussion above – on activities, actors and goals in policymaking – it is obvious that many different types of policy instruments can support development of LICS to promote NRIIs. The basic idea is that the instruments should be used to enhance backward, forward and horizontal linkages. It is not, however, easy to separate the instruments (used for creating these types of linkages) from each other. Many instruments are related to issues of information, institutions, infrastructures and other 'framework conditions', but they also include instruments aiming at specific resources and specific groups of people. The following list of policy instruments is not exhaustive. It is intended to illustrate that natural resource intensive development may be affected through many channels:

- Instruments affecting 'incentives' (for example taxes, subsidies, positions).
- Creation and distribution of 'information' (for example about resource stocks and flows in the home country and abroad, new technological opportunities, environmental risks and costs, etc.).
- Education (for example of engineers, resource managers, environmental experts, etc.).
- Mobilisation of individuals, groups and organisations for resource utilisation and development.
- Setting up information and communication platforms where policy-makers meet with natural resource intensive firms and their suppliers and customers.
- Different kinds of 'task force' building.
- Identifying, defining and strengthening local/endogenous property rights.
- Public capital investments.
- Infrastructure investments.
- Qualitative measures like regulations, laws, etc.
- Setting up new (or redesigned) organisations for utilisation of natural resources.
- Entering into international agreements and international institution building (which may then imply use of the instruments mentioned above).

6.7 From curse to opportunity – the mindset for innovation based natural resource intensive development

Developing countries that are rich in natural resources are not helped by economic experts that characterise the resources of those countries as a curse. A problem-solving policy attitude that looks for the development potentials in the natural resources is far more constructive – especially, since many of the present high-income countries to a considerable degree have built their own development, at least an important part of it, on natural resources.

This does not mean that there may not be serious problems, such as corruption, unsuitable exchange rates and lack of structural diversity, connected to development building on NRIIs. The literature has many examples of natural resources being linked to these constraints on development. There may also be problems related to a diminishing control with firms that become integrated in global value chains. But these problems can be countered by policies and regulations and it is, still, a good strategy to build natural resource LICS that can benefit from the productivity enhancing effects of global value chains and significantly support domestic growth and development, and to seek ways in which these activities might be leveraged so as to develop other areas of economic activity. A critical component of this is to both enhance skills and competences within natural resource intensive activities and, simultaneously, seek policies that can facilitate the migration of such skills and competences into other areas of economic activity.

The discussion in this last chapter indicates that there may be many ways and possibilities to utilise natural resources by building LICS. We have seen that there are many activities, which may contribute to such development; that there are many relevant goals and instruments; and that several stakeholders may be brought into the policy process. This should feed hope rather than despair.

Postscript by Raphael Kaplinsky

Learning, innovation and competence building in the natural resource intensive sector in an era of global value chain driven growth[19]

There is a variety of drivers of sustainable income growth and development. One is the capacity to gainfully exploit favourable endowments of natural resources. A second is the productivity gain that comes from structural change, as economies shift from low to higher productivity sectors and activities. And a third is the gain that arises from enhanced knowledge content in production, which enhances the value arising in production. All of these three drivers are, to a greater or lesser extent, relevant in the development trajectories of resource intensive economies. All of them have implications for learning, innovation and competence building. As this Review evidences, in the more successful NR intensive economies the three drivers often interact. Resource deposits are enhanced by the application of knowledge to their extraction and the development of backward and forward linkages; they can also provide the fiscal base and skills that allow for the development of unrelated sectors.

This Review also provides convincing evidence that the synergistic knowledge-driven interaction between the natural resource and other sectors has been a long-lived phenomenon, stretching back at least until the nineteenth century and almost certainly to earlier centuries. However, it would be a grave analytical and policy mistake to assume that the balance of these three growth drivers and the character of their interaction remain unchanged over time and space. In particular, there has been a marked shift in the character of national and global production systems over the last few decades, which has important implications for the application of knowledge to production and for the manner in which economies take advantage of their resource endowments.

Prior to the industrial revolution, production and consumption were predominantly local in character. As the industrial revolution unfolded and drew in an increasing number of (Northern) economies, so production and consumption became increasingly disconnected – trade provided the capacity for specialisation and productivity growth. Yet, until the 1980s, this trade was largely a process of exchange in 'products' between parties who were, with the exception of production and trade in internalised MNCs, unrelated and who operated in a low-trust and arms-length environment.

The extension of Global Value Chains (GVCs) after the 1980s fundamentally altered this pattern of global specialisation, the character of productivity change, and the resultant challenges for policies designed to support learning, innovation and competence building. This was driven by a strategic agenda in which lead firms focused on their core competences and then (globally) outsourced those activities in which they were unable to generate and appropriate rents. It requires a focus on supply chain development and longer term and more trust intensive relationships across the chain. In turn, this results in an increasingly fine division of labour in production, and an increasingly dispersed production system. Critically, firms and economies specialised less and less in 'products' and more and more in tasks and capabilities.

From a developmental perspective, a number of related challenges have emerged:

- As Adam Smith observed, the division of labour (the source of productivity growth) is a function of the market and, particularly in small and medium-sized economies, sustained productivity growth has been closely associated with participation in global export markets. Production and consumption have become increasingly divorced in spatial terms.
- 'Output' and 'sectors' have become blurred categories as the division of labour has increased. In the case of the iPhone4, for example, the product, which retailed for $495 in the US and was exported from China at a unit fob value of $175, contained only $6.50 of value added in China. As a wider phenomenon, it is no longer the case that the dominant terms of trade shift is that between commodities and manufactures, but rather a trend within manufactures and commodities. Hence, the long-term commitment to a structural shift from the resource

sector to manufacturing has lost its attractiveness as a source of sustainable income growth.

- Related to this, sustainable income growth in all sectors arises from the capacity to escape from intense competition by developing the capacity to generate, protect and appropriate rents, and it is here that the crucial role of learning, innovation and competence building surfaces as a critical component of sustained income growth.
- But in the context of GVC-led growth, the innovation challenge widens from a traditional focus on process and product innovation to a wider perspective in which positioning within the chain ('functional upgrading', for example by moving from manufacturing to design) and chain-shifting (for example, shifting from computer hardware to software services) are important sources of sustainable rents.
- Since GVCs are to an increasing degree finely specialised, with production of intermediates, assembly and post-sales servicing spread across the globe, coordination has become a major driver of chain competitiveness. At the same time, the division of labour within the chain is the determinant of rent distribution. This has led to the emergence of chain-governance as the core of chain competitiveness, and the growing importance of lead firms in global production and trade. Unlike earlier generations of global integration, these lead firms do not only operate as equity-based international investors (FDI), but may exercise their dominant role through the development and implementation of standards and other mechanisms of chain inclusion and exclusion.
- Although there is no clear definition of GVCs, there is widespread agreement that they will play an increasingly significant role in global trade, accounting by some estimates for around two-thirds of total global trade.

There is a growing consensus that the extension of GVCs and their role as primary drivers of growth in outward oriented economies provides a major challenge to traditional policies of structural change and the character of innovation systems. The pursuit of an 'industrial policy' and inter-sectoral structural change no longer adequately meets the policy challenge of ensuring sustainable incomes. A focus on capabilities and the lateral movement of capabilities within and between sectors and subsectors are, in many cases, more important targets for policy development.

How does all of this relate to the challenge of learning, innovation and competence building in the NR sector? Here, there is an important divide between two families of GVCs:

- 'Vertically specialised' GVCs reflect the Apple iPhone4 story sketched out above. These are sectors in which individual elements of production can occur in parallel. They also arise in sectors in which the transport-to-value ratio is low, and where the base resource and individual intermediates do not degrade, or do not involve substantial processing loss. These vertically specialised GVCs account for around 75% of total GVC trade and are predominantly found in manufacturing and services. Notwithstanding this concentration in manufacturing and services, there are pockets of the resource sector which lend themselves to vertically specialised production (most notably in the textile and apparel value chains).

- 'Additive' GVCs, by contrast, involve production processes which are necessarily sequential in nature, where transport-to-value ratios are high and which are characterised by processing loss and/or input degradation. They account for around one-quarter of the total GVC trade and are predominantly found in the resource sector. Here, too, there are exceptions, and some chains in the manufacturing (for example shipbuilding) and services (for example, in health care) are predominantly additive in nature.

In some respects, the policy implications for sectoral development and the associated patterns of innovation systems are common across both families of GVCs. Each requires that an emphasis be given to human resource and institutional development. Each requires closer interactions between users and producers, and cooperation between firms and between firms and supporting institutions. Yet, in other respects, the LICS challenges differ between these two families of GVCs.

Vertically specialised GVCs thrive in an open trading environment. A focus on core competences global outsourcing requires openness to trade, a reduction in trade barriers and many of the associated policy instruments in traditional industrial policy. Firms and economies operating in these chains generally need to specialise and 'thin out' their contribution to product value added. The focus is thus on capabilities rather than traditional 'sectors'. Linkages are often lateral in nature, with the development of generic capabilities that span traditional economic sectors and sub-sectors (for example, iron-ore-to-steel), they are now optimally focused on capabilities which provide 'thin' knowledge-intensive inputs into many sectors, including iron ore and steel (for example, new materials). This does not mean that innovation is unimportant or that there is no role for a set of policies facilitating the extension of relevant LICS to the development of generic capabilities and their incorporation in particular chains.

By contrast, in additive GVCs, the policy agenda is more similar to traditional industrial policy. Trade policy impediments, local purchasing and the deepening of value added ('thickening') are characteristically of greater importance than the thinning out and development of specific generic capabilities. Although there is scope for horizontal linkages and lateral; movement across sectors, the primary linkages are backward and forward in nature.

Thus, whereas vertically specialised chains thrive on the 'thinning out' of value addition, in additive chains, the target is to 'thicken' and deepen the share of value added in the chain. And, whereas vertically specialised chains require the development of LICS that span sectoral capabilities, in additive value chains the focus remains more centrally on the development of sector specific LICS

The case-studies of successful resource led growth that are described in this Review bear out this 'thickening agenda' and the policy instruments designed to achieve these ends. While they may in many cases overlap with the success drivers in vertically specialised GVCs, there are also important points of divergence. Policy to the development of LICS in resource based economies necessarily needs to be informed by both these similarities and differences.

Briefly, in additive chains, the development of LICS will require a combination of some or all of the following components:

- Active and interventionist sectoral trade policies, which is not a problem-free policy agenda given the hegemony of WTO rules, but there are loopholes which countries can use to foster the development of individual sectors and value chains (which may cover systemic links between sectors like, for example, agriculture-textiles-apparel-branding).
- Policies specifically designed to promote backward linkages (for example, local sourcing of capital goods and other inputs), forward linkages (for example, processing of resources before exportation, as in the case of China and Indonesia) and horizontal linkages (for example, cross-sectoral capabilities such as in engineering and metalworking). These policies need to be sensitive to the need to promote both 'extensive' linkage development (more of the same) and, increasingly, 'intensive' linkage development (with enhanced knowledge content and productivity).
- While, at least in the early stages, this puts the primary policy focus on sectors and value chains, there may also be a need and an opportunity to invest in LICS that foster the growth of generic capabilities across sectors and chains, for example energy efficiency and logistics, which generally have important implications for all links in resource intensive GVCs.
- The strategic capability to deal with lead firms in the resource sectors. These lead firms play a crucial role in determining who does what, where and when in the chain, where LICS are built and how they are incorporated in production.
- The development of a supportive policy environment, with effective and appropriate incentives and disincentives (including, but not only, fiscal policy instruments) designed to support the growth of LICS in these resource sectors.

Beyond these specific policy instruments lies the need to invest in the development of relevant skills (both sectoral and general) and supportive institutions (including Research and Technology Organisations, RTOs) as well as ensuring the availability of relevant business services sectors (such as those providing specialised certifications for the environmental, labour and organic standards which are increasingly required in the resource sectors).

Context is, of course, important. For example, resource sectors differ in complexity and scale (compare oil extraction with vegetable production). Countries differ in their size (compare China and Rwanda) and their resource endowments (compare Saudi oil deposits with Brazilian deep-water deposits). Economies have very different economic structures (compare Chile with Zambia in the copper sector) to support the development of linkages and LICS. And, experience is an important determinant of LICS availability (compare the Nigerian and Angolan oil linkage sectors). Such differences are inevitable. But what they do not do is to rule out the application of the principles outlined above for the exploitation, generation and protection of rents in the resource sector and the need to set LICS development in the context of the dominance of global trade by GVCs.

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Notes

1 We use the terms "natural resources" and "resources" interchangeably throughout the review.

2 Non-fuel primary products corresponds to SITC categories 0, 1, 2, 3, 4 and 68: 0 - Food and live animals; 1 - Beverages and tobacco; 2 - Crude materials, inedible, except fuels; 3 - Mineral fuels, lubricants and related materials; 4 - Animal and vegetable oils, fats and waxes; 6 - Manufactured goods classified chiefly by material. Albeit these empirical categories cover vast diversity and are far from exhaustive, they delimit the scope of natural resource intensive industries in this review.

3 We use the terms "natural resource intensive industries" and "resource intensive industries" interchangeably.

4 An economy may thus be both NRDE and NRIE. We also use terms as "resource intensive developing country" synonymously with NRIE.

5 We use the term 'natural resources' rather than 'commodities'. Commodities are part of natural resources but a narrower term. Natural resources also include resources that in terms of market transactions, investment, and standardisation are not actual commodities but rather smaller scale and niche products.

6 'Quality of institutions' is in this literature most often understood as effectiveness of government, incidence of corruption, strength of the rule of law, or state's capacity to promote development.

7 Methodology: Following Fagerberg and Verspagen (2009), we select the core journals of Innovation Studies. These include: Research Policy; Journal of Evolutionary Economics, Industrial and Corporate Change; Economics of Innovation and New Technology; Structural Change and Economic Dynamics; Industry and Innovation; Technological forecasting and social change; Technovation; Technological Analysis and Strategic Management; Science and Public Policy; R&D Management; Economics of Innovation and New Technology; Strategic Management Journal. Our period of interest is: January 1st 1994 - January 1st 2014. The total number of papers published in the selected journals, in the period between 1994 and 2013, was 10.529. We use a set of keywords to distinguish between studies concerning particular

sectoral orientations. We distinguish between the primary sector (natural resource intensive industries), the secondary sector (manufacturing industries), the tertiary sector (services and high-tech areas), and other studies without a sectoral focus. Keywords for primary sector: natural resources; resource intensive; commodity; Dutch Disease; Resource Curse; primary sector; agriculture; mining; oil; energy. Keywords for secondary sector: manufacture; manufacturing; industrial; industrialized; fabrication; factory; secondary sector, engineering. Keywords for tertiary sector: service; knowledge intensive business service; finance; banking; insurance; consultancy; retail ; wholesale; transportation; distribution; entertainment; media; tourism; design; telecommunication; ICT; Health; Life sciences; high-tech; biotechnology; bioengineering; pharmaceutical; nanotechnology; robotics; artificial intelligence. "Others" are the papers remaining.

8 This classification is not identical to the tripartite classification discussed earlier, though it is similar. In any case, similarities between these classifications are not of relevance at this point.

9 Hirschman (1958) applies input-output tables from Italy, Japan and the US as the basis for identifying linkage potential.

10 According to OECD classifications, a sector is high-tech if it (firm average) invests more than 4% of turnover in R&D, a sector is medium-tech if it invests between 1% and 4% of turnover in R&D and a sector is low-tech if it invests less than 1% of turnover in R&D. R&D is, in turn, defined as production of new knowledge and practical applications of knowledge (K. Smith, 2005).

11 Institutions are sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups. Organisations and institutions are distinct although they interact and affect one another. Organisations are actors while institutions are conceived as a structure that influences actors. We here distinguish between formal and informal institutions. Formal institutions are typically visible, codifiable rules and laws. Informal institutions are the non-explicit common practices of a society (norms, traditions and customs). These two types of institutions interact in positive and negative ways (Edquist & Johnson, 1997).

12 Furthermore, the framework of recipient-enabling industries emerged from studies of the Australian economy, which is also natural resource intensive. Also, the development block concept emerged from studying natural resource intensive industrialisation in Sweden. Many of our concepts thus have a history with natural resources.

13 Fast-rising oil exports during the 2000s, driven by prices that rose from USD 35 a barrel on average in 2000 to USD 100 on average in 2009, make it the dominant feature of Africa's trade over that period. Nevertheless, this feature tends to obscure the fact that African manufactured exports – including machinery, transport equipment and processed commodities but excluding processed foodstuffs (SITC 6-9) – approximately doubled in nominal value between 2000 and 2009 (AEO, 2011).

14 The development of hybrid seeds helped companies to recuperate the research and development costs

because, contrary to open-pollinated seeds, farmers need to buy new hybrid seeds every season to maintain the improved traits of the original seed. Hybrids are common for maize and sunflower.

15 The RR soybean (Roundup Ready) or soybean 40-3-2 is a variety resistant to the herbicide glyphosate.

16 It refers to the unique DNA recombination event that takes place in one plant cell, which is then used to generate entire transgenic plants.

17 Regulatory costs to bring a GM crop to the market can vary from 15-30 million US dollars to 100-180 million US dollars. Similarly, the estimated regulatory compliance costs for GMO approvals vary from 10-30 million US dollars to 80-110 million US dollars (Schenkelaars et al., 2011).

18 Indeed, different seed innovation strategies may not be incompatible with one another (except where contamination of non-genetically engineered seeds or crops with trans-genes has implications for seed input and/or crop output markets).

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