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INTRODUCTION

Innovation in natural resource-based industries: a pathway to development? Introduction to special issue

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ABSTRACT

Despite growing academic attention to the relationship between economic development and natural resources in social sciences, the issue has received rather limited attention in the field of Innovation Studies. This is problematic given the centrality of innovation and technological change for growth and development. Against this background, this introductory article aims to make four contributions. First, to assess the extent to which Innovation Studies has analysed the link between natural resources and development. Second, based on recent studies of innovation in natural resource-based industries (NRBIs), we elaborate on and articulate an innovation and industry perspective on the relationship between natural resources and development. In this, we foreground the particularities of innovation in NRBIs. Third, we explore policy implications of the specificities of innovation in NRBIs. It matters greatly for design and choice of policy instruments in support of innovation and development whether and how innovation in NRBIs differ from innovation in other industries. Lastly, we introduce the papers constituting this special issue and propose avenues for further research.

KEYWORDS

Natural resources; innovation; innovation studies; development; innovation policy; sustainability

1. Introduction

Natural resources are indispensable for the functioning of human societies and economies. They are the primary inputs to most production processes and supply much energy for transport, light and heat around the world. Natural resources are unevenly distributed across countries and are therefore extensively traded and can strongly influence a country's industrial specialization (WTO 2010). Management of natural resources has moreover a huge bearing on industrial development in areas of resource production as well as the global scope for moving towards sustainability.

The relationship between economic development and abundance of natural resources has received extensive and growing academic and policy interest (cf. Figure A1). Academic research, however, dominated by the disciplines of Economics and the related fields of Management and Business (cf. Table A2) has tended to pivot around the notion of the 'resource curse' (cf. Table A3); a notion that emphasizes governance problems related to corruption and different aspects of monetary policy (Frankel 2012; Ross 2015;

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Torres, Afonso, and Soares 2013). Surprisingly little attention has been paid to perspectives related to innovation and industry dynamics associated to natural resources (cf. Section 2). This is problematic given the centrality of innovation and technological change for growth and development (Abramovitz 1986; Lundvall et al. 2009; Nelson 2008; Solow 1957). It is the aim of this introduction and the papers included in this special issue to articulate and contribute to an innovation and industry perspective on the relationship between natural resources and development as well as taking stock of the academic field.

There have been different reactions to the dominance of the resource curse thinking. David and Wright (1997), for instance, were pioneers in proposing that natural resource-based development is realized through the generation and use of new and relevant knowledge, and that it is possible for natural resource-based industries (NRBIs, cf. Text Box 1) to lead economic development for extended periods of time. Moreover, several recent studies have demonstrated that NRBIs can be sources of important innovations and technological opportunities for productivity improvements in resource production but also for stimulating innovation in other parts of the economy. These studies include high-income economies such as the US, Norway and Australia (David and Wright 1997; Smith 2007; Ville and Wicken 2012), middle-income developing countries such as Chile, Argentina and Brazil (Dantas et al. 2013; Iizuka and Katz 2010; Marin, Stubrin, and da Silva 2015; Pérez 2010) and low-income countries in Sub-Saharan Africa (Morris, Kaplinsky, and Kaplan 2012a; Teka 2011; UNIDO 2012). Combined, these studies constitute the beginning of a new wave of thinking about NRBIs in relation to innovation and industry dynamics – and about the possibilities for natural resource-based development. This branch of research does not reject all insights from the resource curse debate. Sound management of macroeconomic fundamentals, careful exchange rate policy, institutional quality and 'good governance' are important although in our view insufficient factors in a development strategy. In addition, it is acknowledged that NRBIs historically have often been enclave industries in developing countries. Nonetheless, this budding area of research suggests that such vices need not be inherent properties of NRBIs, but rather symptoms of other shortcomings. In this light, we understand that the main question is not whether, but how innovation and industry dynamics can be managed to deliver development on the basis of natural resources. We draw on the evolutionary approach to innovation and industry studies that underpins this recent research to define natural resource-based development as a process of structural change where the expansion of NRBIs is associated with processes of innovation and competence building within (in producers), around (in suppliers and users) and beyond (knowledge spillovers via diversification) natural resource production to deliver long-term benefits for the national economy (Andersen et al. 2015).

Text Box 1. Natural resource-based industries

Natural resources are defined 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. We refer to the industries in the primary sector as 'natural resource-based industries' (NRBIs) and we refer to economies whose industrial structure is dominated by NRBIs as 'natural resource-based economies'.

As a consequence of unfolding megatrends in the global economy, innovation in NRBIs has intensified in recent years. Such augmented innovation activity, which is

reflected in many of the studies mentioned above, naturally generates a heightened relevance of and attention to an innovation and industry perspective on natural resources; particularly in developing countries. Here, we mention four important trends (Marín, Navas-Aleman, and Perez 2015). First, recent decades have experienced an acceleration of growth in the demand for energy, food and raw materials to the point of straining the limits of resources (Alexandratos and Bruinsma 2012). This increase in the volume of demand has provided opportunities to increase productivity and production via innovation. Second, challenging the commodity notion of natural resources, worldwide demand for less standardized and higher quality goods is expanding (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 that are offered today for culinary, cosmetics (e.g. Amazonia essences), health and ecological purposes enhance the possibilities of differentiation related to natural resources and thus innovation. Third, a 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 NRBIs. Natural resource producers are incorporating these new technologies in the production of natural resources and this is questioning the 'low-tech' notion of NRBIs, as well as forming and deepening of linkages towards other industries creating new opportunities for diversification. Fourth, Multi-National Corporations (MNCs) are increasingly outsourcing non-core functions locally and, due to new forms of competition and resource nationalism, applying Corporate Social Responsibility measures to enhance transparency and engagement with local communities. Combined, these factors can create new opportunities for domestic small- and medium-sized firms if they can respond with innovation and upgrading (Morris, Kaplinsky, and Kaplan 2012a; Narula 2018). These trends point to an increasing role for innovation activity in NRBIs and enhanced scope for further opportunities.

Against this background, this introductory article aims to address three interrelated issues. First, to systematically assess the extent to which the field of Innovation Studies has analysed the link between natural resources and development. Second, based on recent studies of innovation in NRBIs to further elaborate on and articulate an innovation and industry perspective on the relationship between natural resources and development. This pivots around the question of whether, and if so how, innovation in NRBIs differs in some qualitative sense from innovation in other parts of the economy. Indeed, it is the working hypothesis of this special issue that innovation in NRBIs does differ. Third, to explore policy implications of the specificities of innovation in NRBIs. It matters greatly for design and choice of policy instruments in support of innovation and development whether and how innovation in NRBIs differ; particularly for developing countries with large natural resource endowments. In the following, we attend to each of these points.

We proceed by reviewing the Innovation Studies field for analyses of NRBIs via a bibliometric exercise and an interpretation of the literature. In Section 3, we take stock of what we actually do know about innovation in NRBIs. Then, we introduce the issues and papers of the special issue and connect them to different aspects of the introductory review before ending by outlining some issues worthy of further research.

2. Innovation studies and natural resources

Innovation researchers have tended to concentrate on analysing innovation in manufacturing and more recently also service industries thereby creating a bias in the empirical coverage of the field (Martin 2016). That assertion is confirmed by our bibliometric analysis which shows that in the period 1994 until today, studies of manufacturing industries approximately accounted for 3289 of 16,085 Innovation Studies articles (about 20%), while the service sector counts 832 articles (around 5%). In comparison, NRBIs have been analysed in 137 studies (0.85%) of which only 12 articles take a conceptual interest in natural resources and innovation, cf. Figure 1.[1]

It is therefore not surprising that Innovation Studies tends to operate with a manufacturing-based perception of the mechanisms underlying industrial development. This is aligned with early structuralists' views which saw little opportunities for learning and innovation, and linkages in association with NRBIs, and that attributed all potential for development to manufacturing (Hirschman 1958; Prebisch 1950; Singer 1975). It is also aligned with historical studies on catching-up that suggest that low-income countries had to emulate the industrial paths taken by high-income countries to develop (Gerschenkron 1962; List 1841). These studies inspired a branch of research on technology gaps, catching-up, innovation and latecomer advantages contemplating productivity developments in post-World War II Europe and USA and subsequently in the 'East Asian Tiger' economies, and emphasize that for catching-up to happen countries should foster development of the more rapidly growing and technologically progressive industries of the day (Fagerberg and Godinho 2005), by that time manufacturing.

The most recent of these experiences of catching-up is that of the East Asian countries. The rise of the 'East Asian Tiger' economies has been portrayed through the metaphor of a flock of flying geese with Japan as the lead goose followed by first tier (Korea, Taiwan, Singapore, Hong Kong) and second tier (Malaysia, Thailand, Indonesia, and even China) birds. Similarly to the catching-up story, the flying geese model

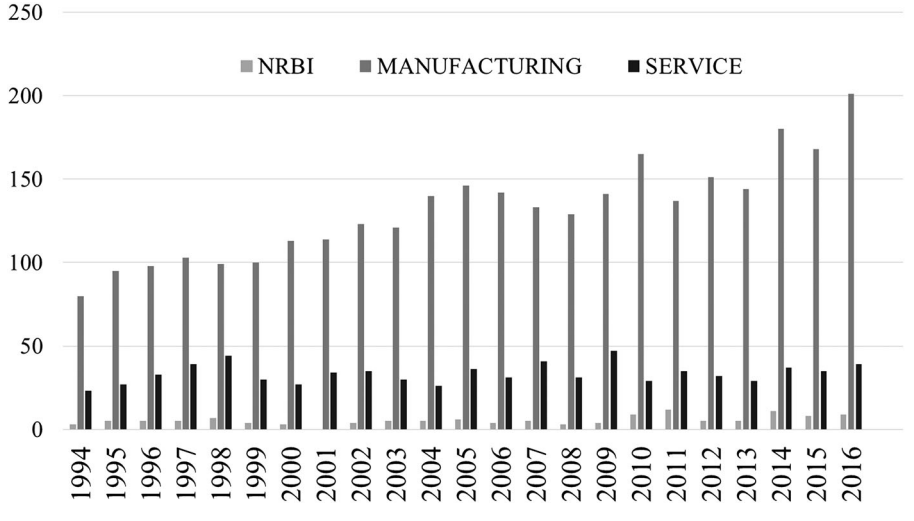

Figure 1. Number of yearly articles within Innovation Studies research on NRBIs, manufacturing and service industries. For methods, see Appendix.

conveys a linear stages-model of dynamic comparative advantage which depends on innovation in the lead country and absorptive capacity in follower countries (Kasahara 2004). Even though the model has been widely criticized for overlooking central aspects of East Asian catch-up (Hobday 1995), it has become very influential and is widely understood as a generic model for catch-up and innovation (Lin 2012; Mathews 2006). It posits that catching-up is roughly a three-stage process. It begins with the copy, replication and reverse engineering of existing technologies developed by lead firms in high-income countries. Subsequently, firms in low-income countries move on to creative imitation (i.e. making minor improvements to the original technology) and lastly they become innovators of novel items and reach the global knowledge frontier (Amsden and Tschang 2003; Hobday, Rush, and Bessant 2004; Kim 1991; Lall 1987; Mathews 2002).

Transfer of technology from the leader to follower countries is a central mechanism of this model. Catching-up firms and countries access this knowledge through a range of different mechanisms such as trade, inward and outward FDI, user–producer relations, joint ventures, mergers and R&D collaborations (Archibugi and Iammarino 2002). In consequence, MNCs are – and increasingly so – seen as central conveyors of industrial knowledge from one national economy to another (Carlsson 2006; Narula and Zanfei 2005). A basic assumption behind this thinking is that (Narula 2003, 5):

> … there is a convergence between countries in the kinds of knowledge being used

Therefore, the relevant technologies for industrial advance are the same globally. Partly as a consequence, studies of catching-up and innovation have predominantly focussed on analysing the institutional arrangements that enable access to, absorption and efficient use of key dynamic technologies (Nelson 2004).

The view that a set of universal key technologies and industries drive development across countries can be accounted for by the fact that catching-up in East Asia was mainly based on manufacturing industries such as shipbuilding, textiles, cars and consumer electronics (Mathews 2006). Such industries can produce homogeneous output given the same input factors and production process regardless of geographical location. This feature of manufacturing industries implies that the technology involved predominantly is generic. Indeed, it is often emphasized as a latecomer advantage that technology and 'roadmaps' for catching-up already exist (Mathews 2006). The latter perspective fits rather well with the notion that shifting techno-economic paradigms – that each has a set of key technologies at its core – drive long-run growth, and whose potential can only be exploited with new and appropriate institutions (Freeman and Louçã 2001; Perez 1985). As a consequence, the main tasks for policy in fostering industrial advance in manufacturing industries include to access, absorb and apply – often foreign – generic technology through different phases of replication, creative imitation, and lastly new-to-the-world innovation.

If one's conceptual starting point is that a limited set of key industries are central for industrial development in each era, it is understandable that researchers focus on the institutional and social arrangements required for reaping the benefits of these industries. However, it is also apparent that the dominance of such thinking – although tremendously valuable – can generate a blind spot towards innovation in NRBIs and theorizing about innovation and development in relation to natural resources. As a reflection of the conceptual bias in Innovation Studies, there has been proportionally little interest in empirically

analysing NRBIs wherefore we currently know comparatively little about innovation and industry dynamics in this type of industries.

3. What do we know about innovation in NRBIs?

In this section, we discuss four main issues characterizing innovation in NRBIs. They are derived from the few studies that have explored natural resources and innovation.

3.1. A dynamic perspective on natural resources

Following an evolutionary perspective on industrial development, the importance of taking a dynamic view on natural resources cannot be overestimated. Such a view implies that natural resources are not static or absolutely finite but rather expand and contract in response to changes in our common stock of knowledge and our valuations (or scarcity) of various resources (Rosenberg 1976). In this regard, it is useful to distinguish between nature and natural resources. Nature is the topic of natural science and concerned with the physical universe which we, for our purposes, can think of a finite and static. Social science, however, is concerned with natural resources which we can understand as that ever-changing portion of nature that is known to man and affects his existence (Zimmermann 1972). Many of the theoretical arguments critical of natural resources implicitly presume that natural resources are not an outcome of production processes but are extracted, with only minimal effort. Humphreys, Sachs, and Stiglitz (2007, 4), for example, argue 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.

It follows that innovation is irrelevant. This line of thinking is, however, flawed. It rests on the assumption that nature, which is freely available, equals natural resources (Andersen 2012). In the interface between nature and natural resources, there are however ongoing processes of resource creation, obsolescing and extension, which are enabled by innovation. This explains how resource deposits continue to grow and how new resources are discovered as we learn. The main implication, however, is that the production of natural resources requires innovative inputs from services and manufacturing activities of varying knowledge sophistication as well as support from science and technology development. The complementarity of these distributed factors in understanding the dynamics of natural resources to some extent calls for a systemic approach to grasp these processes (Andersen and Johnson 2014). The presented perspective opens for the possibility that NRBIs indeed can be drivers of skill creation, job growth, innovation and industrial development with beneficial impacts on the wider economy.

3.2. Innovation and the importance of suppliers and users

First and foremost, it is well known that innovation does take place in NRBIs, and we know that the properties of the supplier industry and professional users, and how these interact with producers of natural resources and knowledge organizations, are crucial for innovation

in NRBIs (see e.g. Adejuwon 2017; Adewuyi and Oyejide 2012; Andersen 2015; Bloch and Owusu 2012; Figueiredo and Piana 2016; Kaplan 2012; Lydall 2009; Morris, Kaplinsky, and Kaplan 2012b; Teka 2011; Torres-Fuchslocher 2010; UNIDO 2012; Ville and Wicken 2012). Inter-industry linkages are thus seemingly relatively more important for innovation in NRBIs. Pavitt (1984), for instance, classified NRBIs as dominated by a supplier-driven mode of innovations. This does not mean, however, that all innovation happens in the supplier industries, independent of natural resource producers. The demands, the quality of the demands and the way in which these are communicated play a crucial role to incentivize and shape innovation in supplier industries. This is even more so if we consider that in many cases natural resource producers are large companies and suppliers small and medium firms. The notion of user–producer interactive learning captures the essence of such linkages (Lundvall 1985). Although a conceptual link to NRBIs has not been systematically established yet, others have discussed a similar phenomenon at the industry level as the mutual dependency between recipient and enabling industries (Robertson, Pol, and Carroll 2003); something which is also discussed in the literature on innovation in low-tech industries (Tunzelmann and Acha 2005). What seems crucial, therefore, is to understand the linkages between natural resource producers demanding knowledge, and the industries supplying equipment's and solutions, how these work, and which are the factors that support or limit innovation within these linkages.

A related challenge is that in situations where MNCs dominate an NRBI in a developing country, there will often be a significant knowledge gap between MNCs and local suppliers. Such conditions can lead to 'enclave type' industries where both upstream and downstream activities are located outside the country. The developing country thus not only loses the chance to capture value added but also, and more importantly, its prospects of developing an own supplier industry. In such cases, local content policies combined with investments in specialized education, training, and research may provide a solution (Guimarães 2012; Mendonça and Guilherme 2013; Ovadia 2014; Ranestad this issue).

The presence of a dynamic supplier industry to the natural resource producers is important because the performance of each of them is mutually interdependent. Indeed, such a mutual dependency between producers and suppliers is often a central aspect of industrial development (Porter 1990). In terms of generating societal value from natural resources, having a strong local supplier industry can be an equally important source of employment and export income as the actual production of natural resources (see e.g. Ryggvik 2013). Nurturing a local supplier industry is, however, even more important because of the learning, innovation and competence building that take place in the process. The technology and competence base used to serve and improve natural resource production can over time become an important platform for diversification of the broader economy. For example, it often happens that technology suppliers to NRBIs build rather generic competences such as automation, ICT or chemical science which can be applied elsewhere (Kuramoto and Sagasti 2006; Lorentzen 2006). In Australia, for example, technology suppliers to the mining industry are heavily engaged in developing software systems (Smith 2007). In Norway, the supplier industry to oil and gas has developed a range of technologies that have found application in, for example, the offshore wind industry (Mäkitie et al. 2018; Steen and Hansen 2014). The servicing company SMAR in the Brazilian sugarcane industry moved from simple equipment repair over automation of cane crushing to developing

digital control systems to the US Navy (Andersen 2011). In South Africa, mining technology suppliers developed a low-radiation, full body imaging device – to scan mine workers for stealing – for the diamond mining industry which was later applied in the medical industry and in airports (Mayer and Altman 2005).

The prospects of long-term natural resource-based development thus often hinge on both developing a local supplier industry as well as the continued upgrading and diversification of that competence base to facilitate industrial diversification.

3.3. Embeddedness in the natural environment

In contrast to the industries of the secondary and tertiary sectors, NRBIs are to a much larger extent immersed in a unique geological and ecological context (Rosenberg 1976). Mokyr (1992, 296), for example, argues that:

> … in mining and agriculture, what worked in one place might not work elsewhere if the topographical, climatic, or soil conditions were different. The American reaper, for example, could not be applied to the British landscape. Fertilizing, drainage, irrigation, seed selection, animal breeding, the erection of fences and hedges – all were functions of local conditions and could not be made to work universally.

Following Andersen et al. (2015), we refer to this feature as 'natural resource knowledge idiosyncrasy' (NKI). It has three important implications for our understanding of natural resource-based development.

First, as a consequence of NKI, knowledge produced in a specific location might not always be useful to every other location. This feature of natural resources questions the conventional model of innovation and development in developing countries that conceptualizes it as a sequence that starts with the copy and replication and, finishes with innovation, cf. above. Recent research has suggested that to face 'NKI' 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 that 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. Marín, Stubrin, and Van Zwanenberg (2014) and Marín and Stubrin (2015) have showed also how Argentinian firms, that began developing soy seeds adapted to local agro-ecological demands, first outcompeted MNCs in the domestic market and then were able to penetrate regional and global markets. This involved complex private and public partnerships and the development of local capabilities in diverse breading technologies among others. These examples show that NKI is important, and might have positive and negative implications for innovation in NRBIs. One the one hand, they are a barrier for the application of standardized solutions and existing equipment developed elsewhere (as is typically the case for manufacturing

industries). On the other hand, they provide an opportunity for entry for newcomers from developing countries and for tracing different technological paths. Paradoxically, carving out an innovation and development path – including developing a local supplier industry – based on local geological and ecological specificities within NRBIs may therefore constitute a more promising development path than aiming to penetrate established and global manufacturing industries (Andersen and Wicken 2016).

Second, the direct relationship between NRBIs and the natural environment implies that industry expansion has a different spatial dimension than manufacturing industries. One implication of this is that NRBIs must often operate on premises of social acceptance from the communities that their production activities affect. For example, institutions governing land and property rights may be particularly important for NRBIs. More generally, as nature is most often seen as a public good, the expansion of NRBIs may, therefore, easily be subject of various forms of controversies affecting their innovation dynamics. All this means, on the one hand, that NRBIs are subject to multiple regulations, and institutions that are used to control exploitations and their effects. Institutions and regulations related to NRBIs are, therefore, crucial for innovation. Countries interested in encouraging innovation, production and also preservation of natural resources and human development have to have in place the right regulations. Companies working with natural resources need to master and be able to face these regulations. On the other hand, it means that innovations should go beyond technological and scientific aspects. Companies and countries need to find ways to involve local communities in a sustainable way to organize their activities. The conflicts related to natural resources are actually often a major barrier for the activity. These aspects suggest that natural resource-based development should, to some extent, be socially inclusive (Arocena and Sutz 2012; Johnson and Andersen 2012; Johnson and Villumsen this issue).

Third, NRBIs are directly immersed in the local natural environment wherefore unsustainable use of nature can directly, and sometimes quite quickly, undermine the production of natural resources. That link is only indirect and very long term for manufacturing industries. Some NRBIs must, therefore, respect and understand the natural environment to a greater extent than manufacturing industries (Iizuka and Katz 2010). This often involves deep understanding of local geology, and ecological systems as well as their carrying capacity that, in turn, can inform environmental regulation and monitoring that can ensure a somewhat sustainable relationship with nature. If such considerations are taken lightly, both economic and ecological crises are likely to occur (Petrasic 2015).

3.4. Innovation systems and policy for natural resource-based development

In light of the points made above we, indeed, see the possibility of building on natural resources to create a pathway to development. But, to identify and formulate the adequate policies to deal with the developmental challenges related to natural resource-based development, concepts and ideas from Innovation Studies need to be adapted to consider the specificities of NRBI.

Following our understanding of natural resource-based development, policy should broadly stimulate innovation and competence building in five different areas: in natural resource producers, in related suppliers, users and supporting knowledge

organizations, in support of diversification and knowledge spillover activity towards non-NRBIs, environmental management capacity, and management of social inclusion and distribution. Knowledge of local specificities is central for each of these activities.

In this section, we point to three important and more concrete issues that should be taken into account for policies related to natural resource-based development.

First, ideas emerging from the innovation system literature are very relevant for natural resource-based development. Following a dynamic view on natural resources, the generation, diffusion and use of knowledge via different forms of innovation is the pivotal issue in natural resource-based development. Basic research, new scientific knowledge and new technological developments in several disciplines related to natural resources are crucial for innovation in NRBIs. Multiple examples come from applications of knowledge related to new materials, biotechnology, ICT and so on. The way in which natural resource producers and their suppliers connect with these knowledge bases support new technological advances, access and shape new knowledge is important. Together with a set of distributed knowledge bases and institutions, producers, suppliers, and knowledge organizations as universities and research institutes make up an important innovation system, which is necessary to support innovation and productivity growth in NRBIs. The innovation system perspective seems thus very relevant to address this issue. Against this background, it is, therefore, meaningful to conceptualize the challenge of natural resource-based development as that of creating and supporting the institutions and organizations 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 innovation system.

Second, such innovation system, however, must be locally anchored to address local specificity of knowledge needed to succeed. This implies addressing issues pertaining to the importance of *in situ* knowledge for appropriate design of technologies and products, the local challenges of environmental management and the particular local issues regarding social inclusion. These are important challenges for developing countries that on many occasions due to the lack of development of their indigenous innovation systems are used to rely on foreign developed technologies and practices (Viotti 2002).

Third, how to support innovation and competence building in the different areas mentioned above is sensible to context such as the changing nature of technologies and markets. Some of the policies that were important for development in countries that grew based on NRBI in the past might be relevant still, but not all of them will incorporate the urgent challenges of the present. An important aspect of the latter is the creation of institutions and regulations that deal well with the new trends and challenges associated with natural resources, cf. introduction. For example, the management of natural resources and the new industries emerging in association with natural resources, such as biotechnology, require new regulations and institutions. Governments need to develop public sector capabilities to introduce regulations and institutions that allow them to reap the benefits of these industries and that protect the sustainability of the activities. Developing countries usually face challenges for the development of such institutions. For instance, regulations related to Intellectual Property Rights (IPR) or to biosafety. Firms need also to develop capabilities to adapt to the changing and demanding regulations and institutions that characterize these industries. Accomplishing IPR and biosafety regulations, for example, can be important obstacles for these types of firms to

compete and survive in this market. Governments seeking to support local natural resource-based companies also need to set up the right institutions and regulations (such as those related to IPR or market concentration) and need to support the creation of knowledge and skilled workers and supportive infrastructure that is more adequate to the domestic capabilities. But to do so they need to have a broad understanding of the industry and an informed view about its future prospects. A key question is, thus, can developing countries develop the capacities and institutions to address these challenges in a creative manner, in the context of a global economy every time more 'regulated' by international agreements? A related aspect is how firms and governments in developing countries engage with MNCs to incentivize and ensure local linkages and innovation, and in particular the development of *in situ* knowledge rather than import of global innovations that might be inappropriate for local conditions.

4. Issues and papers in this special issue

The papers included in this special issue contribute to our understanding of the nature of innovation in natural resources and related industries, how this takes place and should be managed.

One important issue addressed by some of the papers here is the *innovative and technological dynamism of NRBI*. The evidence of some of the papers here confirms that NRBI can be technologically dynamic, generating significant innovations and linkages with other sectors. For instance, the important role of innovation in linkages between natural resource producers and their suppliers is illustrated by how knowledge-intensive service firms (KIB) enable diversification. Particularly, this is increasingly happening in association with advances in the knowledge bases related to NRBI, such as the biological sciences. Countries like the Latin American ones, analysed in several papers in this special issue, are in particular the context for this dynamism which stands in stark contrast to the historical exploitation of natural resources. This is a crucially important issue since to the extent that NRBI are conceptualized as less dynamic, they receive little attention from the point of view of innovation policy, and this might delay possibilities of development related to natural resources, which, as suggested in this article, are dependent on innovation, new knowledge creation and supporting institutions.

Another important issue that emerges from some of the papers analysed here relates to the opportunities and challenges associated with the *local specificity of innovations* required to efficiently produce natural resources. The evidence in this special issue suggests, as previous studies have done, that localized requirements generate an opportunity for local innovations and new entrants from emerging countries. Interestingly, it also suggests that these localized innovations are not always local adaptations of global innovations developed elsewhere. In some cases, as in the case of seeds in Latin America, these local innovations have been developed with a paradigm and proposing a technological trajectory, which significantly differ from that developed by global firms; with a different technological approach, knowledge, by different kind of actors, different institutions and results. This might create the opportunity for different pathways of innovation, more adapted to the capabilities and institutions of developing countries. Existing pathways are many time very difficult for new entrants from developing countries, since entry barriers are very high. Incumbent

firms, block new entrants to these pathways in many ways. The possibility of alternatives is promising as discussed by some of the papers here.

A third important issue that emerges from the evidence in this special issue relates to the possibilities of *diversification related to NRBI* which is necessary to reduce dependence on a few commodities. Two ways in which diversification can happen, as discussed here is through creating differentiated products within NRBI and/or the development of services, knowledge intensive or other kinds, in association with NRBI. In both cases, knowledge creation activities and presence of a supporting innovation system are crucial to foster diversification. Also, the flexibility of firms and supporting innovation system to change over the time to adapt to changing challenges seems crucial.

A fourth significant issue linked to natural resource-based development that emerges from the evidence of these papers is the *importance of buyers*, besides the acknowledged importance of suppliers for innovation in NRBI. Suppliers are important, because they are very often the place where technological innovations related to NRBI take place. Buyers are also crucial, however, since they create the demands, and the incentives for innovations. They should commit financial resources, provide support to developers and create the spaces for experimentation. This is crucially important in the cases where demand is concentrated in a few large firms, like in mining where, given the nature of the business, these are typically MNCs. These companies might create little incentives for innovation, if they travel with their own global suppliers. Policies and incentives should be put in place to ensure a more balanced situation between users and producers of innovations so as to establish a fertile environment for interactive learning along the supply chain e.g. by encouraging MNCs to create incentives for local innovations.

Lastly, understanding the role of NRBIs in relation to climate change and the world's current violations of planetary boundaries is a key issue also addressed in the special issue. Given that NRBIs are immersed in and feed off the natural environment in mostly unsustainable ways, innovation and industry transformation in this set of industries seem crucial for moving towards more *sustainable forms of natural resource production and use* (Lema et al. 2014). Indeed, separation between production and use of natural resources seems impossible when considering sustainability issues in a systems perspective (Elzen, Geels, and Green 2004). It is, for instance, difficult to imagine moving towards sustainable animal farming while maintaining current (and growing) consumption of meat. Although niches of alternative practices and technologies within agriculture and food consumption do exist, they still struggle to influence, e.g. global value chains in food commodities. Changes in institutions such as consumer preferences are needed to create new markets. Regarding more sustainable production of natural resources, it seems that designing, for example, agricultural technology and practices primarily on the basis of the specificities of local ecological systems, is a fruitful direction for innovation to avoid breaching planetary boundaries (Andersen and Wicken 2016; Maes and Jacobs 2017; Tittonell et al. 2016).

In the following paragraphs, we discuss in more detail the contribution of each one of the papers in this special issue.

The first paper by Marin and Petralia (this issue) at a more general level provides evidence supporting the view put forward in this special issue that industries related to natural resources can provide significant opportunities for innovation. It uses evidence

from Argentina and Brazil, and shows that in these countries, which a long tradition of exploitation and accumulation of capabilities around NRBIs, manufacturing industries related to NRBIs, traditionally classified as low tech, have more technological opportunities than industries classified as high tech in the standard industry taxonomies, such as TV and communications and electrical machineries. In this way, the paper questions the relevance of existing taxonomies of industries that based on partial data from a few advanced countries typically classify traditional industries and industries linked to natural resources as having low technological opportunities or poor technological dynamism (Hirschman 1958; Prebisch 1950; Singer 1975). This suggests that opportunities for innovation are not a fixed attribute of industries but depend instead on context-specific developments and are linked to the history of development of each country. Confirming existing ideas about the importance of linkages for innovation in this kind of industries, the article shows that the role of clients is crucial, as an important source of technological opportunities. All the other sources, such as linkages to the knowledge base, feedbacks within the same industry and spillovers from suppliers do not show a significant impact.

The paper by Iizuka and Gebreeyesus (this issue) deals with the emergence of non-traditional NRBIs with a focus on exports. It analyses the emergence and expansion of the export of flowers in Colombia and Ecuador and the same with blueberries in Chile and Argentina. This is an important phenomenon for developing countries with export baskets very concentrated around a few commodities. The article emphasizes the importance of building a system for the introduction and expansion of new exports in developing countries, it proposes thus to use the system of innovation framework to explore these activities. In the four cases, a key role is played by pioneers, which take the lead and all the risks of starting a completely new activity. Interestingly, this role is played by different kind of actors in the four cases. In Colombia, it is a foreign company, in Ecuador and Argentina, domestic businesses, and in Chile, two public institutions. Another very important factor in this case is the access to external markets. Here, both actions taken by the individual entrepreneurs, governments and collective actions were very important. Public support appears very relevant also in all cases, so much that in the presence of almost no public support in Argentina, after a very good entry by a few domestic firms in the business of exporting blueberries the activity slowed down. In Chile, by contrast, the government played a crucial role in starting the business, and then handed it to private firms. Here the activity developed more than in Argentina expanding even towards more complex activities in the value chain, such as research and development in plant varieties.

The special issue contains three papers (Crespi, Katz, and Olivari this issue; Joseph, Thapa, and Wicken this issue; Nuur, Gustavsson, and Laestadius this issue) that foreground the important role of domestic technology supplier industry in achieving natural resource-based development. The papers describe different ways in which interactive learning and linkages between natural resource producers and suppliers, users and knowledge organizations unfold. The findings cement the insight that nurturing an advanced supplier industry is a crucial part of innovation and development in NRBIs.

The paper by Crespi, Katz, and Olivari (this issue) focuses on the emergence of knowledge-intensive services (KIBs) associated with the production of natural resources in two Latin American countries. The emergence of KIBs has been emphasized as one of the main ways in which innovation can be fostered associated to NRBIs because they both are a

conduit for diversification and for intensifying innovation in the NRBI itself. Crespi et al. analyse evidence from three key industries in Latin America, soybean seed developments in Argentina and salmon and copper production in Chile and point to very important issues associated to the role of natural resources in fostering innovation and diversification. First of all, their paper provides important evidence confirming the idea that NRBIs can be an important source for innovation and diversification into knowledge-intensive activities in three very different industries. Developing countries trying to encourage and exploit these opportunities, however, they suggest, have to face important challenges. Five important issues that have to be considered are local specificities; the growing importance of science for innovation in NRBIs and the role of buyers, the accumulation of capabilities, and public policies. In the three cases, it is clear that the emergence and expansion of successful KIBs is a process that requires advances in both private and public sector capabilities. Local specificities and advances in science were crucial in explaining the emergence of domestic KIBs for soybean seeds in Argentina. This case shows also that domestic firms entering the industry and take advantage of local specificities, can follow different pathways to the one proposed and occupied by large MNCs engaged in these industries. However, the success of these firms depends on regulations and it is still not clear how they will progress with current regulations that respond to the demands and pressure of large MNCs. The case of salmon points clearly to the importance of the public sector and local regulations. The public sector was crucial in supporting the emergence of the sector, and then advancing regulations and institutions that support expansion, while looking after public interests. The importance of environmental regulations in this case not only serve public interests but also private by looking after the resources and therefore the productivity in the longer term. Finally, the case of copper, which is less successful, points to the importance of buyers for innovation activities that are concentrated. Mining is an activity performed by a few very large firms, and therefore demand for knowledge and innovation are very concentrated. Large MNCs tend to use their traditional suppliers when they operate in a new location, particularly if this is in a developing country. A key challenge, therefore, for encouraging the development of KIBs is to introduce incentives for MNCs to use and nurture local suppliers.

The paper by Nuur, Gustavsson, and Laestadius (this issue) explores processes of innovation and upgrading in NRBIs via an in-depth study of the mining industry in Sweden. Challenging the view that mining is a low-tech industry applying 'outdated' technology, they show that mining has experienced significant productivity growth in recent years via deployment of ICT and automation technologies. The mining processes from crushing to mineral powder are automated. This is made possible by the integration of several operations into one intelligent steering system. The authors suggest three key features of innovation in mining. First, that innovation is largely incremental due to high-capital intensity of the equipment. Second, innovation in mining is characterized by creative adaptation of general purpose technologies. Hence, at the level of process technologies, innovation can, indeed, be more disruptive. Third, these innovation processes unfold in linkages between mining firms and their suppliers and buyers. The study thus confirms the view that innovation in NRBIs is often characterized by interactive learning relationships between users and producers. The authors further consider the implications of these innovation and industry dynamics for regional policy. Just as the mining industry is considered 'backward'

by some, so are regions dominated by mining activities considered laggards in industrial development and as being without entrepreneurial spirits, skills and knowledge formation. However, documenting the high-tech nature of the mining industry changes the picture. The authors argue that key challenges for regional policy are to support continuous innovation in mining, for example, by helping to attract and train highly skilled workers that can work in these advanced mines.

Corresponding with the view that the success of NRBIs in great part rests on the quality of the surrounding supplier industry and supporting innovation system, Joseph, Thapa, and Wicken (this issue) argue for a 'broad' innovation policy strategy as an essential element of natural resource-based development. Inspired by the notions of 'broad' and 'narrow' understandings of national innovation systems (Lundvall 2007; Lundvall et al. 2002), they describe a narrow innovation strategy as mainly focusing on science-based activities between natural resource producers and their interaction with knowledge producing organizations as research institutes and universities. Such a focus is typically on development and diffusion of high yielding varieties. A broad strategy, however, would incorporate a wider and more diverse set of actors and linkages between them including equipment suppliers and downstream users. The authors argue that natural resource-based development is only possible if coordinated innovation and upgrading take place across producers, suppliers and buyers in a natural resource-based network. Such networks further require the support of a dedicated innovation system to grow. Against this background, the authors present a case study of the natural rubber industry in Kerala, India, which has recently gone through a prolonged period of crisis. In a counterfactual way, the authors suggest that the downfall of natural rubber production in Kerala in part can be explained by the absence of a 'broad' innovation policy strategy. They identify a lack of interactive learning and interaction between rubber producers and users of rubber (manufacturers), and a lack of interactive learning between rubber producers and equipment suppliers. They propose that such a strategy leaves the NRBI rigid and vulnerable to changes in the market. It also inhibits the innovation and industry dynamics that underpin natural resource-based development. In conclusion, the authors suggest that policy-makers in the region should broaden their perspective on innovation policy for NRBIs by involving a wider and more diverse set of actors to develop more inclusive innovation systems.

The paper by Ranestad (this issue) explores the determinants of natural resource-based development by asking: what can explain the divergent experiences of the mining industry in Chile and Norway? Despite rather similar starting points, the Norwegian industry achieved continuous innovation and upgrading to stay globally competitive while the Chilean industry struggled. Ranestad focuses on organizations that contribute to generating, diffusing and using knowledge in the areas of education and training of technicians and specialized engineers, technical mining manuals instructing the work, international knowledge transfers, and geological surveys in the period 1870s–1940s. Ranestad finds that the knowledge organizations serving the NRBIs in the two countries appeared identical but that the functions they played in the respective industries differed significantly. In Chile, the organizations had very limited resources available and their inactivity ended up blocking development, diffusion and use of knowledge. In Norway, rather similar organizations had significant resources and contributed to maintaining an innovative industry, which could adapt to new trends. Ranestad highlights the role public policy in explaining

these differences. In Chile, the industry called for more resources to geological mapping, knowledge transfers and education of engineers but these calls were largely ignored. On the other hand, the Norwegian government was very active in supporting knowledge development in mining but also more generally in society (basic schooling). Hence, some underlying institutions concerning values and preferences of elites and the broader society may be fundamental for understanding natural resource-based development. Regarding the role of the supplier industry, Ranestad notes that MNCs dominated the industry in both countries. However, while in Chile MNCs had an 'enclave nature' with few and shallow linkages to local economy, in Norway they were more effectively integrated with more and stronger linkages to the local economy. One reason for this is that in Chile, there was a large technology gap between local supplier firms (relying on rudimentary/primitive methods) and MNCs that applied state-of-the-art. In Norway, local supplier firms were often more technologically advanced than MNCs in mining. Again, this point to the importance of high-quality supply industry to succeed with natural resource-based development.

The paper by Johnson and Villumsen (this issue) considers sustainability aspects of NRBIs. Here, the authors confront the broader question of whether sustainable development and natural resource-based development are compatible. In terms of environmental impact, the authors distinguish between source (e.g. resource depletion) and sink problems (e.g. pollution). An interesting difference between manufacturing industries and NRBIs is that the former mainly influence nature via sink issues. NRBIs are more directly embedded in the local natural environment and thus unsustainable use of nature can directly undermine the production of natural resources. That link is only indirect and very long term for manufacturing industries. Some NRBIs, especially biotic ones, face an imperative to respect and understand the natural environment to a greater extent than manufacturing industries (Iizuka and Katz 2010). In this context, the authors analyse the state of the world agricultural industry. By reviewing a range of existing studies, they conclude that agriculture currently contributes heavily to moving global ecosystems beyond the threshold of safe operating space. Different possible pathways towards sustainable development in agriculture do exist. Any such path must however consider population growth, the amount, content and distribution of consumption, and technical development. The authors emphasize that changes in these factors presuppose pervasive institutional change such as changing consumer routines, new land rights to avoid deforestation and the need for a new ethics. Such new ethics include new ways of valuing nature that can take us beyond short-term price competition and global commodity markets, and ultimately make world agriculture capable of operating within the given planetary boundaries. The authors see the emergence of a new ethics as the catalyst for other institutional changes that, in turn, support technological and structural change enabling sustainable agriculture within planetary boundaries. The authors further argue that despite having sufficient information about unsustainable forms of agriculture as well as the possible solutions for them, there has still been very little progress. This is seen as a symptom of the power wielded by incumbent actors to avoid 'creative destruction' in agriculture. In conclusion, the authors conclude that there is a need for 'inclusive institutions' (Acemoglu and Robinson 2012; Andersen and Johnson 2015) to undo the systemic and structural lock-in described in the paper.

5. Further research

In this last section, we highlight four issues we consider particularly promising for further research although we acknowledge that the features of innovation in NRBI discussed above all require further scrutiny and research. First, a key theme in this special issue that merits more attention is how the interplay between NKI and innovation can give rise to new path creation in natural resources. From some of the case evidence, it was suggested that due to local specificities new directions of innovation can emerge associated to natural resources. This can create important opportunities for innovation in firms; particularly in developing countries, which face huge barriers to entry into existing industries, dominated by large international players that control not only technology but also institutions (e.g. IPR, biosafety). The evidence presented here, however, is partial, emergent and scarce. More research needs to be pursued to understand better whether this opportunity exists in different contexts, what needs to be done to expand it and the challenges to expand. Recent reflections on innovation systems research acknowledge that there is only limited understanding of how different properties of the natural environment influence innovation emergence of new technologies (Bergek et al. 2015).

Second, the management of natural resources is of great importance to the world's endeavour to move towards more sustainable forms of production and consumption. In our view, much of the Innovation Studies research on sustainability focus on transformations and innovations in the end-use industries such as electricity, transport, water and heating without much consideration for the, often global, supply chain feeding these changes with iron, steel, lumber and rare earth metals. Hence, there is a need for connecting the sustainability transition in the technology-using sectors in the Global North with the production of natural resources in the Global South partly because the latter could seriously impede the former (see e.g. Jacobson and Delucchi 2009; Kleijn et al. 2011; Kramer and Haigh 2009) but also because it is an opportunity for natural resource producers. This would be in line with recent advances in innovation system studies that call for more detailed analysis of the types and extent of innovation in different technology supply chain segments as well as how they are configured and interact across place (e.g. electrical vehicles in Denmark and lithium mining in Bolivia) (Stephan et al. 2017; Binz and Truffer 2017). Such studies could, however, also explore whether and how global sustainability transitions are affected by the particularities of innovation in NRBIs that we have identified above. Innovation in NRBIs is also crucial for climate change adaptation. As ecological systems themselves are starting change in reaction to climate change, NRBIs will be particularly vulnerable implying that current knowledge of local specificities could become obsolete; both in the North and in the South. The latter suggests that new and significant investments in knowledge about local specificities will become increasingly important in the future if production of e.g. food, wood and fish is to be maintained at current levels. However, to our knowledge, there is little or no work on this type of challenge.

Third, we know that NRBIs – although some more than others – are exposed to market volatility through boom and bust cycles. We know rather little, however, about how such swings influence innovation. Crespi, Katz, and Olivari (this issue) show that the demand of natural resource producers for services and products from the supplier industry is procyclical. Corresponding to the latter, recent research suggests that in downturns firms in the supplier industry attempt both market and technology diversification to stabilize their

income stream (Andersen and Gulbrandsen 2018). A related study further shows that some supply firms over time incorporate the market volatility into their business models and innovation strategy, i.e. in the terminology of March (1991), in booms they 'exploit' and in busts they 'explore' while they wait for the market to boom again (Gonzalez 2018). This particular feature of innovation management in NRBIs has, to our knowledge, however not been sufficiently explored. How can competence destruction and soaring unemployment in periods of downturn, be understood and explained in a way that can inform future public policy?

Lastly, most studies reviewed in this introduction focus on innovation in natural resource production via different types of interactive learning. There are notably fewer studies considering industrial and technological diversification on the basis of natural resource production. The distributed knowledge bases underpinning the supplier industry and its innovation activities are key to achieving long-term natural resource-based development. A central question is to what extent and how these knowledge bases can 'spillover' and be redeployed in other industries to strengthen innovation activities and benefit the wider economy. Besides the anecdotal evidence presented above, we know of little research that pursues such questions in relation to natural resources.

Note

1. For more information and methods, see Appendix.

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Appendix. Methods

Social science research on natural resources and development

Using ISI Web of Knowledge we applied search queries that combined typical indicators for, on the one hand, research on natural resources, and, on the other hand, research on development, see Table A1. This resulted in 6405 articles and with a substantial increase in recent years, see Figure A1.

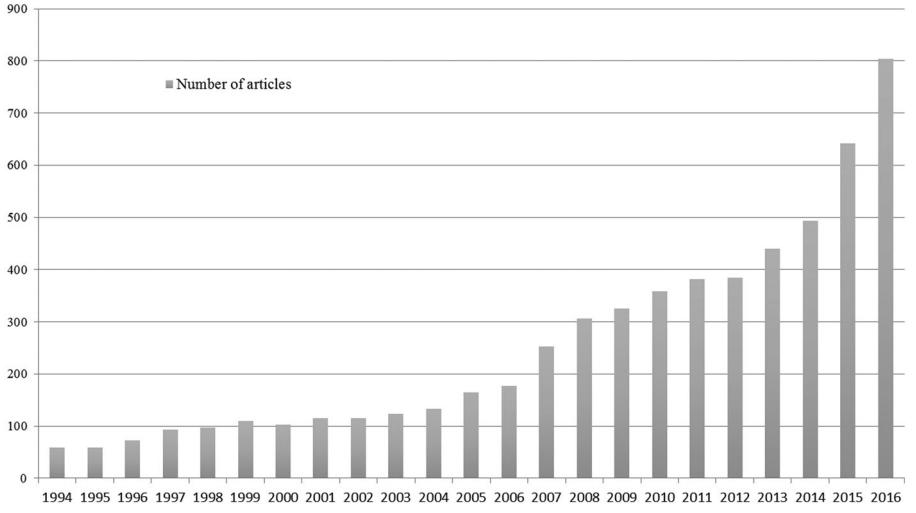

Figure A1. Number of articles about natural resources and development in social sciences 1994-2016.

Table A1. Key terms in NRBI and development.

Natural resources	Development
Natural resource(s)	Economic growth
Resource-intensive	Economic development
Commodity	Development
Primary sector	
Extractive industry(ies)	

This growing body of research is in in terms of scientific disciplines (as defined by ISI) dominated by Economics, and by Management and Business studies, see Table A2.

Also, we used the bibliometric software visualizer programme VOSviewer (Van Eck and Waltman 2010) to further analyse the abstracts of the 6405 articles. We generated a 'relevance score' for key terms in the paper abstracts. The measure reflects how central or important a term is based on how it occurs in relation to other words. For example, a term such as 'method' could occur in many different types of articles, without saying much about the content. If a term occurs randomly across the text, it receives a low relevance score. If the term is clustered in specific contexts and specific constellations of words, it receives a high relevance score. We include here the twelve terms with highest relevance score (we removed terms that did not immediately have any research-relevant meaning such as 'student' or 'share'), see results in Table A3.

Table A2. Dominant disciplines.

Social science discipline	%
Economics	32
Management and Business	19
Environmental Studies	16
Planning Development	15
Geography	13
International Relations and Political Science	8

Table A3. Occurrences and relevance score for key terms.

Term	Occurrences	Relevance
Resource curse	159	5.97
GDP	161	5.74
Foreign direct investment	109	5.52
Commodity price	173	5.03
Export	350	4.87
Natural resource management	257	4.03
Price	462	3.79
Biodiversity	116	3.59
Conservation	409	3.29
Local community	157	3.28
Trade	521	2.94
Economic growth	721	2.87

The relevance scores of key terms confirm the dominance of Economics with a focus on growth and trade and above all the resource curse. Biodiversity, conservation, and local community could be linked to the activities in Environmental Studies and Planning Development, cf. Table A2.

Innovation Studies and natural resources

It is not possible to identify Innovation Studies by use of the science categories classified by ISI Web of Knowledge. Among the 6405 articles identified above, cf. Figure A1, the term 'innovation' appears in 475 articles (title, keyword, abstract) accounting for around 7 per cent of the population. However, use of the term innovation is not the sole right of innovation scholars. Therefore is would be misleading to take that selection as representative of Innovation Studies work on natural resources. Therefore, we chose to delimit our search space via key journals for innovation research.

Our definition of Innovation Studies follows Martin (2012) in using Research Policy's definition of 'Innovation Studies'. Hence, we seek to delimit the field to include studies analysing, understanding and effectively responding to economic, policy, management, organizational, environmental and other challenges posed by innovation, technology, R&D and science. This includes a number of related activities concerned with the creation of knowledge (through research), the diffusion and acquisition of knowledge (e.g. through organizational learning), and its exploitation in the form of new or improved products, processes or services.' Two previous articles (Fagerberg and Verspagen 2009; Fagerberg, Landström, and Martin 2012) have combined identified 27 journals where Innovation Studies research is mostly published (although the journals are outlets for other, related, disciplines as well), see Table A4. These journals constitute the first delimitation of the field of Innovation Studies in this literature review.

Table A4. Selected key journals.

American Economic Review	*Journal of Industrial Economics*	*Research Policy*
Academy of Management Journal	*Journal of International Business Studies*	*Small Business Economics*
Administrative Science Quarterly	*Journal of Management Studies*	*Strategic Management Journal*
Cambridge Journal of Economics	*Journal of Product Innovation Management*	*Structural Change and Economic Dynamics*
Economics of Innovation and New Technology	*Management Science*	*Technological Forecasting and Social Change*
Human Relations	*Organization Science*	*Technology Analysis & Strategic Management*
Industrial Change and Corporate Dynamics	*R&D Management*	*Technovation*
International Journal of Technology Management	*Rand Journal of Economics*	*Academy of Management Review*
Journal of Evolutionary Economics	*Regional Studies*	*Management Science*

Using the web of science database including the full range of data (period 01.01.1994–25.01.2018) we found 41,711 published papers in these journals. These, however, still constitute a rather diverse set of social science disciplines. As a second delimitation of the field of Innovation Studies, we therefore reduce our search space within these journals to only contain papers that have 'innovation', 'learning' or 'technology' in keywords, abstract, or title. This gives us a population of 16,085 articles.

In order to compare the occurrence of innovation research on NRBI with other topics, we distinguish between the primary sector (NRBIs), the secondary sector (manufacturing industries) and the tertiary sector (services and high-tech areas). We selected five thematic and 10 empirical keywords for each category to use as search string, see Table A5. This will give us both information about the extent of innovation research on NRBIs as well as an idea of the relative attention paid to NRBI compared to other sectors in the economy.

Table A5. Keywords for topic search.

NRBI		Manufacturing		Service	
Thematic	Empirical	Thematic	Empirical	Thematic	Empirical
Natural resources	Agriculture	High tech	Furniture	Service	Creative industry
Low-tech	Mining	Manufacturing	Car/automotive	Health	Media
Resource curse	Oil	Industrialized	Aviation	Education	Tourism
Primary sector	Petroleum	Fabrication	Medical/scientific instruments	Transportation	Research
Commodity	Coal	Secondary sector	Television	Energy distribution	Design
	Fishing		ICT		Engineering
	Pulp and paper		Machinery		Retail
	Food		Chemical industry		Finance
	Forestry		Pharmaceutical		Insurance
	Animal husbandry		Textile		Consultancy
	Raw materials		Robotics		

As illustrated by Figure 1 (only shows until 2017), manufacturing accounted for 3289 of the 16,085 articles (about 20%), and the service sector has been studied in 832 articles (around 5%). The primary sector has been analysed in 137 studies and with no significant increase in the latter years. This is as little as 0.85% of all innovation-related articles in the period. Our first round search resulted in 211 articles on NRBIs but by manually reading the 211 abstracts to check for false positives, we excluded 74 articles that were unrelated to innovation in NRBIs. Two of the authors did the latter assessment in collaboration. One author led the coding and another author coded about 50% of the papers to validate and check the first coding supplemented by frequent calibrating discussions to ensure consistency. The subsequent coding followed the same procedure.

Inspired by our reading of the abstracts, we further categorized the 137 papers into three main a groups according to their content. A first group of 47 papers are empirically motivated, they analyse change or innovation in an NRBI setting by use of Innovation Studies vocabulary, and they keep conclusions and insights empirical. A second and largest group of 78 papers are theoretically motivated and seek answers by analysing NRBIs. These papers typically don't mention the natural resource aspects of the empirical material. Instead, the NRBI becomes an incidental context for generic theoretical questions (e.g. what is the effect of management team educational background on innovation?). A third and smallest group counting 12 papers are either theoretically or empirically motivated with a focus on conceptually understanding innovation in NRBIs and their conclusions typically try to depict particular features of innovation in NRBIs, see Table A6. The small size of the last group provides a further indication of the little attention NRBIs have received in Innovation Studies.

Table A6. Content of NRBI papers.

Paper's connection to NRBI	No.
1: Interest in NRBI is empirically motivated or it is an empirical paper including NRBI	47
2: Theoretical part not about NRBI, but paper includes NRBI as a case	78
3: Paper is conceptually interested in NRBI	12

We also computed a relevance score for key terms using the abstracts of the 137 articles, see Table A7. These scores suggest that the research concentrate attention around food and biotech industries, and often apply a company and R&D perspective. However, the relevance scores are quite low which suggests a significant heterogeneity among the papers as also indicated by results in Table A6. The 137 papers are concentrated in the following journals: Technological Forecasting and Social Change (30%), Research Policy (29%), Technology Analysis and Strategic Management (13%), Technovation (8%), and R&D Management (7%). Lastly, among the 137 articles, only 9 explicitly address a developing country context (Search string in title, abstract and keyword: 'Developing countries' or 'Developing country' or 'low-income' or 'underdeveloped country' or 'poor country').

Table A7. Relevance score for NRBI articles (see Table A3 for calculation).

Term	Occurences	Relevance score
Food industry	18	1.77
Natural resource	11	1.62
Biotechnology	12	1.36
Company	18	1.3
India	12	1.2
R&D	14	1.08