22 On manufacturing development under resources constraints

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1. Introduction

Manufacturing development and resources constraints are linked by a complex array of structural relationships which have been unfolding in a variety of ways in different countries since the Industrial Revolution. Resource constraints are *sector specific* and affect production tasks within each sector in more or less deep ways according to the production units involved and relative levels of aggregation at which economic systems are operating. This implies that, at each stage of structural change and according to the countries' different patterns of specialization, resources constraints (or abundance) will affect economic systems differently. Ultimately problems of resource scarcity tend also to acquire an international character and, as such, become a geopolitical and multi-polar issue, to the extent countries become integral parts of the increasingly modularized global manufacturing system.

Within this complex and inherently dynamic architecture, interdependencies across sectoral value chains are the main channels through which resource constraints affect countries' manufacturing development trajectories. The aim of this chapter is to show firstly how multi-sectoral models of production in which resource constraints are structurally integrated offer critical analytical tools to unpack such complexity. In disentangling the relationships between manufacturing development and resource constraints, the chapter then focuses on the way in which the 'manufacturing apparatus' transforms the nature of scarcity by making it a 'relative' phenomenon functionally linked to incremental as well as disruptive technological changes. Building on an analytical-historical reconstruction of countries' structural learning trajectories, the

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chapter points out the inter-sectoral nature of 'technological scarcity' but also how scarcity-induced technological innovations may trigger cumulative technological transformations across sectors.

An understanding of these resource-led structural dynamics provides fresh lenses to investigate the political economy of resource constraints at the national and international level. Going beyond the dominant 'resource curse' debate, the chapter concludes by sketching a number of specific policy implications. In particular, the lack of alignment of manufacturing, technology and resource policies (and, thus, the missed opportunity of creating and capturing value through resource-triggered complementarities over time) is identified as the main constraining factor for countries at both initial and more advanced stages of manufacturing development.

2. Unfolding interdependencies in manufacturing development: opening the black box of resource constraints

Manufacturing development is the most dramatic and pervasive structural transformation that countries experience along their economic growth path. It consists of the creation and sustained expansion of production activities across different industrial subsectors, from resource based manufacturing activities towards increasingly technologically complex ones. Not only does manufacturing development trigger a process of industrial structural change, it also induces an increasing interconnectedness of the manufacturing base with the economic activities in other sectors such as agriculture, mining, construction and services (Ames and Rosenberg, 1965; Baranzini and Scazzieri, 1990; Andreoni, 2013).

Throughout this manufacturing development process, production interdependencies take different forms. They involve input–output multi-sectoral relationships, but also a variety of linkages among the technologies adopted in different sectors and manufacturing subsectors. In their unfolding, these interdependencies and linkages are shaped by a number of *structural tensions* such as rigidities, bottlenecks and indivisibilities in production structures (Kalecki, 1976; Kaldor 1985; Landesmann and Scazzieri, 1996; Andreoni, 2014); complementarities, horizontal and vertical externalities (Scitovsky, 1954; Hirschman, 1981; Dahmen, 1988); and disproportional variations in technological coefficients and natural resource constraints (Quadrio Curzio, 1967; Pasinetti 1981). As a result of these structural tensions, manufacturing development is intrinsically characterized by disproportional dynamics and various forms of dualism, that is, dynamic processes of cumulative differentiation within and across countries (Spaventa, 1959).

The way in which natural resource scarcities constrain national manufacturing development was at the core of the classical economic debate. The dialectic between 'almost unlimited producibility' à la Smith and 'scarcity' à la Malthus and Ricardo (in its absolute and relative forms respectively) defined the two main axes along which economists have disentangled the structural dynamics of manufacturing development.

Building on the Smithian idea of 'absolute dynamic producibility', a number of structural economists developed multi-sectoral models in which the constraining role played by natural resources on increasing production scale remain mostly unexplored (Leontief, 1953; Pasinetti, 1981). Even in those cases in which natural resources were factored in (Leontief *et al.*, 1977; Kuznets 1965), there was a tendency to stress the idea that technologies are able to neutralize scarcity problems by shifting them to an 'indefinite' long term. In other words, these contributions underestimated the fact that resource constraints unfold *throughout* the manufacturing development process. Thus, the fact that technological change will neutralize resource constraints in the future does not guarantee that it will be able to do it over time along specific manufacturing development trajectories.

This overall attitude towards the problem of resource scarcity can be also found in classical development economists (e.g. Singer, 1950; Prebish, 1950; Hirschman, 1981). Although the manufacturing development process was at the core of their investigation, the relationship with the commodity sector was mainly explored in terms of whether resources were beneficial (or detrimental) to the process of industrial structural change. The commodity sector (especially hard commodities) was perceived as an enclave activity, that is, a sector relatively detached from the rest of the economic system and characterized by low technological development and relatively few linkages and spillovers. This is why, in contrast to classical economists, the early development economists formulated the hypothesis according to which the commodities-manufacturing terms of trade would have moved in favour of manufacturing (Harvey *et al.*, 2010).

The idea of 'relative scarcity' originally conceptualized in Ricardo opened a different line of investigation of manufacturing development under resources constraints. In particular the work started by Alberto Quadrio Curzio (1967 and 1986) was developed in a number of different ways (Quadrio Curzio and Pellizzari, 1999). These developments offered an open-structural framework to disentangle the way in which natural resources direct and shape different manufacturing development trajectories. With respect to the specific relationship linking multi-sectoral structural change dynamics, technologies and natural resources constraints, this framework introduced a critical distinction between *techniques* and *technologies*.

Within a multi-sectoral model, each technique relies on a certain natural resource and produces one raw material adopted in the production of all other commodities, both directly and indirectly. Technologies are the n techniques that have been activated, at whatever production scale is feasible given the constraints imposed by natural resource scarcity. Each technology is thus linked to the others through scarce natural resources at each point in time. More importantly, each technique is 'connected dynamically in the process of accumulation to other techniques. The dynamic process, therefore, occurs at variable rates over time and is uneven across commodities. This raises complex problems of structural compatibility between techniques and it generates some residuals, that is, net products that cannot be utilized in the process of accumulation' (Quadrio Curzio and Pellizzari, 1999, p.33).

From a manufacturing development perspective, this *compound technologies scheme* opens the black box of resource scarcity by pointing out the possibility that different compositions of techniques are bounded in scale and structure by resource constraints. In other words resource constraints become an integral part of the *manufacturing apparatus*, that is, the set of manufacturing production processes that rely on natural resources as factor inputs. Not only does resource scarcity become a structural problem, its dynamic character is also revealed. Resources are constraining forces involving all sectors at the same time and over time in both direct and indirect forms. This is why the activation of different orders of techniques along different countries' structural trajectories is no longer a simple matter of production and technological capabilities transformations.

3. The resources-manufacturing matrix: compound production units, resources sector-specificity and shifting constraints

The adoption of a compound technologies scheme as the critical analytical core of a multi-sectoral model of manufacturing development is a powerful focusing device with respect to a specific set of complex dynamics.

The first of these is related to the relationship between production units, resources constraints and the time required for their renewability. Production processes take place within production units that may be identified at different levels of aggregation, such as the productive establishment, the constellation of establishments, the sub-sector, the sector and, finally, the production system as a whole (Andreoni and Scazzieri, 2013). Depending on the active production units and relative levels of aggregation at which the economic system is operating, a given natural resource may or may not be a constraint. For example, a certain endowment of natural resources may not constitute a constraint for a given sector while it can become a binding constraint as soon as more than one sector relies, both directly and indirectly, on the same type of natural resources. In fact, given a number of active production units operating at a certain level of aggregation, a relative scarcity problem may become absolute scarcity. Thus, resource bottlenecks may unfold at a certain point in time and along a certain country structural trajectory. Even when these natural resources are renewable, the time required for restoring them – i.e. *time renewability* – might be too long to satisfy the pressure that fast manufacturing subsectors may impose on a certain natural resource. This means that given fixed time renewability, production units may be affected by resource availability misalignments over time.

These resource-triggered structural tensions may hinder the pattern of structural change an economy is undergoing and, ultimately, it might force a shift towards a different structural trajectory. The new structural trajectory will be characterized by different 'compound technologies', that is, a different set of active techniques. Moreover as these new techniques will reshape the relationship between manufacturing production and scarcity, a new 'compound production units scheme' will also have to emerge. What we call here a *compound production units scheme* identifies the *n* active production units and relative levels of aggregation characterizing a multi-sectoral model of manufacturing development under resource constraints.

The complexity introduced by the consideration of different production units can be also extended to an open economy system. In this specific case it was observed how '[w]hat appears a relative scarcity for a single economic system could become historically an absolute scarcity for the planet as whole' (Quadrio-Curzio and Pellizzari, 1999, p. 6). In fact, even those countries that have been lagging behind in terms of their manufacturing development might indirectly face resource constraints in their early stages of industrialization. To the extent developing countries provide industrial value chains and networks at the regional and global levels with intermediate resource inputs, the relevant level of aggregation at which scarcity problems unfold in these countries becomes difficult to identify and delineate geographically. This implies that the political economy of resource constraints involves the domestic structural change and relative institutional-power dynamics as well as linkages among countries along different manufacturing development trajectories.

The second issue that emerges from opening the black box of resource scarcity is that there are different types of natural resources and that the relationships they have with each sector is not a linear one. In fact, it implies a complex set of direct and indirect relationships. Table 22.1 addresses this challenge by proposing a simple *resources-manufacturing matrix* whose architecture is defined by a taxonomy of natural resources (related to certain commodity sectors) and by a standard list of manufacturing subsectors.

Natural resources have been clustered here in three main groups, namely: *soft commodities* (mainly related to different agriculture products and industrial crops), *hard commodities* (including a number of materials coming from mining and quarrying) and, finally, *energy commodities* (both traditional sources such as coal, gas and crude oil, but also nuclear and renewables). Of

Table 22.1: *The resources-manufacturing matrix*

MANUFACTURING APPARATUS, NATURAL RESOURCES		Inputs to industry																					
			D: Manufacturing																				
			17RB	23LT	15RB	26LT	24MHT	16RB	27LT	20RB	18& 19RB	21– 22RB	21RB	28LT	36RB	31& 32MHT	25LT	34& 35MHT	29& 30MHT	33MHT		
		Final consumption inputs	Textiles	Coke, ref. petroleum products & nuclear fuel	Food & beverages	Non-metallic mineral products	Chemicals & chemical prod (pharmaceutical included)	Tobacco products	Basic metals	Wood products (furniture excluded)	Wearing apparel, fur, leather & footwear	Printing & publishing	Paper & paper products	Fabricated metal products	Furniture; manufacturing n.e.c.	Electrical machinery & apparatus / Radio, TV & communication equipment	Rubber and plastic products	Motor vehicles, trailers & semi-trailers / other transport equipment	Machinery & equipment n.e.c. / Office, accounting & computing machines	Medical, precision & optical instruments	E: Electricity, gas & water supply industries	F: Construction industry
SOFT COMMODITIES A: Agriculture, hunting & forestry B: Fishing	**Industrial crops**																					
	Wood																					
	Cereals																					
	Livestock																					
	Beverages & other fluids																					
	Fisheries																					
HARD COMMODITIES C: Mining & quarrying	**Stone**																					
	Sand																					
	Precious metals																					
	Ferrous metals																					
	Non-ferrous metals																					
	Rare earths & metals																					
ENERGY COMMODITIES C: Mining & quarrying E: Electricity, gas & water supply	**Coal**																					
	Natural gas																					
	Crude oil																					
	Nuclear																					
	Renewables																					
Natural structural change pattern peaks (Real GDP per capita, 2005 US$)			**5,000**		**7,000**				**9,000**			**11,000**	**13,000**				**15,000**		**27,000**			

Source: Author

course, some soft commodities such as palm oil may be used as energy sources and vice versa an energy-related resource such as crude oil is also used as a raw material (substituting industrial crops or livestock) in the wearing apparel and footwear subsector. Thus, there is a certain degree of substitutability among different types of resources.

Manufacturing subsectors have been grouped according to standard industrial codes (ISIC rev. 3) and by adopting a standard technological classification distinguishing Resource Based (RB), Low Tech (LT) and Medium-High Tech (MHT) manufacturing industries. Industries have been then listed along the horizontal axis following a specific sequence, that is, the one that is possible to obtain by tracking the 'normal structural change pattern' experienced by countries in their manufacturing development process. The GDP per capita levels at which the share of the individual manufacturing subsectors peaks in terms of share of total GDP was extracted from a number of empirical studies (Chenery and Syrquin, 1975; Alcorta, Haraguchi and Rezonja, 2013; UNIDO, 2013). The construction and electricity, gas and water supplies industries have been added as part of the secondary sector.

At each intersection of the matrix, a relationship between certain specific natural resources and certain industry subsectors is identified and highlighted in grey in Table 22.1 The manufacturing apparatus is constituted of two kinds of manufacturing subsectors. There are *transformative industries* that process, combine and modify the properties (and, thus, functions) of different kinds of natural resource commodities to obtain a number of raw industrial materials. These materials are then used by *manufacturing industries* to produce an array of intermediate and final products of different kinds (e.g. more or less resource dense). Finally there are a number of natural resources that are consumed with very little (almost no) processing or beneficiation.

This matrix does not pretend to show a full set of input–output flows. Instead it is aimed at considering the different unfolding interdependencies between manufacturing subsectors development and different types of resource constraints. Firstly, resource constraints are sector specific. Moreover, each resource may constraint sectors in more or less direct or indirect ways. For example, materials such as sand are used for producing semiconductors in a certain transformative industry (*direct resource constraint*); semiconductors are then used in the electronics sector to produce basic components such as transistors, cells and integrated circuits (*indirect resource constraint*). Of course, all sectors tend to be more or less directly dependent on energy commodities, although the type of energy source they rely upon may be different according to the technology adopted in the subsectors as well as the stage of economic development of the overall economic system.

The fact that certain sectors that are relatively more important at certain stages of economic development are also relatively more dependent (either directly or indirectly) on specific subsets of natural resources introduces three orders of complexity.

First of all, countries at different stages of structural change will be constrained by different combinations of direct and indirect resource constraints. The resource-manufacturing matrix shows how, at advanced stages of development, countries tend to become directly dependent on a number of natural resources such as rare earths and metals that are critical for the production of subsystems' components or technologies underpinning complex system products. The second problem is that these resources represent a binding constraint since an increasing number of countries enter certain subsectors and increase the production volume of certain complex system products to capture greater manufacturing value and increase their manufacturing resilience. With the exception of two subsectors (Food and Beverages, and Chemicals – including Pharmaceutical) the only manufacturing industries that maintain a contribution to GDP above 1 per cent (from their peak point until highest stages of economic development) are those with the highest scope for technological innovation. Finally, to the extent sectors become vertically disintegrated and modularized production tasks are undertaken by specialized production units in different regions and nations, resource constraints tend to affect countries in more direct or indirect ways according to their specialization patterns. In sum, countries are affected by *shifting resource constraints* along their manufacturing development and specialization patterns.

The last order of complexity is represented by the fact that resources constraints will be shifting also as a result of technical change. In fact, throughout its development, the manufacturing apparatus becomes increasingly able to develop techniques and activate technologies that do not simply shift resource constraints away but also reshape the frontier of production possibilities determined by them. In other words, the manufacturing apparatus changes the nature of resources constraints.

4. The manufacturing apparatus: turning resources constraints into technological opportunities

The compound technologies scheme on which the previous section's analysis is grounded stresses the need for a truly structural understanding of the relationship linking 'resource scarcity' and 'technological scarcity' within a multi-sectoral production framework. This relationship is described as follows:

technical change (a phenomenon which includes both technical progress and the choice of techniques and technologies) due to choice of techniques is dependent not only on the degree of internal efficiency of each of the single techniques available, but also on the compatibility of the structures of the various techniques, which will be put successively into operation on account of the constraints imposed by the non-produced means of production (Quadrio Curzio, 1986, p. 336).

Given that the definition of techniques incorporates 'scarce natural resources' (this is what is meant by 'non-produced means of production'), resources constraints are structurally embedded in the multi-sectoral technical change dynamics described by this model. This means that technical change is triggered by material structural components of production. These are the constraining natural resources used as factor inputs in the manufacturing apparatus. In this sense, this approach is distinctively 'more structural' with respect to technical change than those multi-sectoral models in which technical change is triggered simply by exogenous production or consumer learning dynamics (e.g. Pasinetti, 1993).

Building on the original idea of 'induced invention' (Hicks, 1932) this model incorporates an idea of 'innovation scarcity', namely the possibility that innovations may be triggered by the scarcity of natural resources (Quadrio Curzio and Pellizzari, 1999). Models of induced innovation like the ones adopted to explain agricultural change (Ruttan and Binswanger, 1978; Quadrio Curzio and Antonelli, 1998; Andreoni, 2011) focus on the changes in relative prices of factors inputs. These alter the signals that the market sends to producers regarding their choice of techniques. Similarly, within a multi-sectoral model of production under resources constraints, the focus is on market prices and rents as specific signals of relative scarcity.

The learning dynamics that have historically led to scarcity-induced technological innovations, as well as broader disruptive technological changes, have been only partially analysed within this framework. Specifically, three main *stylized mechanisms* have been identified. Firstly, the extension of the boundaries of the locations where the natural resources are exploited often requires the development of new technologies (e.g. deep water oil drilling). Secondly, technological change allows the substitution of scarce resources with relatively more abundant natural resources. Finally, the reduction in the use of natural resources and primary commodities per unit of production is the result of the introduction of more efficient techniques that increase resource productivity.

However, in order to go beyond these stylized technical change mechanisms, the concept of *structural learning* appears useful as it allows us to understand in which specific ways, and along which learning trajectories, the manufacturing apparatus is able to turn resources constraints into technological opportunities. The concept of structural learning has been introduced to characterize the continuous process of structural adjustment triggered and orientated by existing productive structures at each point in time (Andreoni, 2014). In particular, the transformation of structural constraints such as resource bottlenecks and technical imbalances into technological opportunities is made possible by the existence of complementarities, similarities and indivisibilities acting as focusing devices within and across sectors.

The process of structural learning in any given sector may in fact develop an inter-sectoral character. In other words, complementarities (as well as innovations that can be applied to similar tasks performed in other productive activities) may spread from one sector or subsector to others, triggering a specific form of structural learning called *inter-sectoral learning*. The latter expression identifies a dynamic process of interlocking and mutual reinforcing technological developments that link the innovative patterns of two or more sectors in a relationship of complementarity and/or similarity. Given that many resources are intermediate inputs in many different manufacturing industries, scarcity-induced technological innovations may transform production activities across sectors. This also implies that one scarcity-induced technological innovation in one sector may be responsible of compulsive sequences of technological transformations across sectors. For example, during the last decade, a number of technical developments in multistage hydraulic fracturing and extended-reach horizontal drilling in a number of manufacturing industries have made the production of shale gas viable and revolutionized the energy sector in the United States. These complex technological systems were only partially triggered by market prices signalling the need to identify new energy commodities.

Economic historians have documented a number of cases of such structural learning dynamics, especially of the inter-sectoral type (Innis, 1957; Rosenberg, 1976, 1982, 1994, 1996; Wright, 1990; David and Wright, 1997). The analytical discussion of these cases is beyond the scope of this short chapter. However, a number of analytical points can be highlighted to show the complexities underpinning scarcity-induced structural learning trajectories and, thus, the relationship between resource scarcity and technological scarcity.

Let's take the structural learning trajectory of the United States as an example (Barnett and Morse, 1963; for more country examples see Wright and Czelusta, 2004; Best, 2001; Bianchi, 2013). In that case the development of the manufacturing apparatus did not merely allow for scarce resource substitutability. In fact, what is even more crucial is the fact that the *range of substitutability among materials* kept expanding over time (Rosenberg, 1976, p. 240). This phenomenon is responsible for an expansion of the range of compound technologies that the economic system can activate. The range of possibilities also tends to expand because manufacturing industries are not bound to specific resources *as such*, but rather to their specific properties and functions. If materials available in greater abundance can substitute the functions performed by other scarce resources, manufacturing industries will substitute them (Scott, 1962).

However, substitution processes require increasing rounds of fixed capital investments and equipment replacement. Without them the manufacturing apparatus is not able to use certain new materials or resources as inputs. Also, since '*[t]oday*'s factor substitution possibilities are made possible by *yesterday*'s technological innovations' (Rosenberg, 1976, p. 253), the substitution process made feasible by certain technical advancements might not be viable in historical time or might require a prolonged adjustment period. The possibility that certain feasible techniques are not activated as they do not satisfy conditions of contextual viability is strictly related to the distinction between techniques and technologies (see earlier). Structurally feasible trajectories (development patterns made possible by technological changes or because of resource scarcity) may never unfold in reality if they do not find a viable historical and institutional context (Andreoni and Scazzieri, 2013).

Manufacturing development is a process transforming the structural-technological production system as well as the set of social technologies – i.e. institutions – in which it is embedded. That institutions might be the ultimate constraint in manufacturing development was a point stressed by Simon Kuznets (1965, p. 208) when he said, 'It is the social and political obstacles that are likely to be more serious than our technological capacity', and then restated by Wassily Leontief *et al.* (1977, p. 6): 'The principal limits to sustained growth and accelerated development are political, social and institutional in character rather than physical'. The last concluding section of this chapter addresses the political economy of resources constraints and, thus, deals with the possibility to develop policies beyond resource, technological and institutional scarcity.

5. Beyond resource, technological and institutional scarcity: the political economy of resources constraints

Today's political economy debate around natural resources constraints is built on a quite simplistic, linear and static understanding of the relationship between resource, technology and institutions. For example, in the context of developing countries, the 'resource curse' thesis has pointed out how natural resource abundance has adverse consequences for economic growth. Alongside various explanations (e.g. Dutch Disease), this thesis builds on the idea that natural resources (especially minerals) tend to be concentrated in 'point resources'. As a result, it is relatively easy to loot them (high risk of 'lootability' and rent capture).

This influential thesis has been recently challenged (Lederman and Maloney, 2007; Morris *et al.*, 2012). The reason why resource-abundant developing countries do not exhibit strong and sustained economic growth has to be found in their condition of 'technological and institutional scarcity', more than in their inescapable resource curse (Chang 2007, 2011). The structural trajectories followed by today's industrialized countries provide very clear historical evidence in support of this argument. In many country cases (e.g. the United States between 1870 and 1910) natural resource abundance was a 'socially constructed' condition (achieved through purposefully designed institutions and policies) more than a geologically preordained one (David and Wright, 1997, p. 203). In the opposite scenario, as stressed by Simon Kuznets (1953, p. 230), 'the have-not societies are poor because they have not succeeded in overcoming scarcity of natural resources by appropriate changes in technology, not because the scarcity of resources is an inexorable factor for which there is no remedy . . . this is a matter of social organisation and not of bountifulness or niggardliness of nature'. Despite their different trajectories, these countries stylizations raise the same three fundamental challenges underlying the political economy of resource constraints and developmental policies (Chang *et al*., 2013; O'Sullivan *et al*., 2013). Let us look at them through the analytical lenses developed earlier in this chapter.

Countries who successfully developed their manufacturing apparatus (under resources constraints) adopted integrated policy packages combining manufacturing, technology (including institutional) and resource policies. Given the sector specificity of resources and the existence of technological interdependencies across sectors, policy packages have to match and, at the same time, transform the country's specific structural sets of compound technologies, institutions and natural resource constraints. Within a multi-sectoral system, this *transformative matching* can operate in different ways. By targeting different levels of aggregation of production activities, policies can change the compound production units scheme and, thus, the relative conditions of resource scarcity. The intensity as well as selectivity of these policies may vary substantially and can operate both *along* and *across* sectoral value chains. While some of the policies may simply introduce scarcity signals to induce market-driven technological innovation, others may change the rents appropriation mechanism and channel resources towards targeted sectors and technologies (both related and unrelated). The redistribution of resource rents across sectors changes power relationships across (but also within) the same interest groups (Khan and Jomo, 2001). At the same time, it may offer different economic actors a focal point of coordination that sets the conditions for a certain manufacturing development trajectory.

If the integration of manufacturing, technology and resource policies (given certain resources constraints) allows the full exploitation of complementarities among interdependent economic activities *in time*, the possibility of shifting natural resource constraints will depend upon the coordination of complementary activities *over time*. This is why the *synchronization* of resource, manufacturing and technological policies is even more critical than their integration at each point in time. *Policy synchronization* is not trivial as policymakers have to consider a plurality of policy targets and relative trade-offs among them over time. The composition of these trade-offs also generates structural tensions in the form of conflicts among and within interest groups. Moreover, with the expansion of the manufacturing apparatus and the unfolding of new interdependencies, policy synchronization becomes extremely complex as policies can affect both different resources types and manufacturing sub-sectors (Table 22.1). At the same time, a number of new value creation and value capture opportunities associated with shifting resource constraints may emerge. For example, a new technology today may allow the substitution of a certain scarce material in a product system (and complementary products or activities) tomorrow.

With the increasing interconnectedness of different countries' manufacturing apparatuses, specific sectoral trajectories of one country are increasingly intertwined with other countries' same (or different) sectoral trajectory. The same manufacturing sectors in different countries may be more or less directly competing for the same set of scarce resources and being affected by the same set of resource-related risks (Farooki and Kaplinsky, 2011). Because of the increasing dependence of many product systems on scarce resource-based platform technologies, even apparently unrelated sectors in different countries may be constrained more or less directly by the same natural resources. Recent technical studies identify a number of resource-related global risks, such as the increasing scarcity of minerals and metals and the consequent supply instability in specific sectoral value chains; the emergence of a number of disruption processes; the concentration of critical resources in a limited number of countries; finally, the fact that energy critical elements (ECEs) such as Tellurium, Germanium, Platinum and Lithium are now part of a myriad of high tech and environmental equipment, from smart phones, to solar panels to jet engine parts, wind turbines and hybrid cars (DOE, 2010; APS, 2011; EU 2011; Heck and Rogers, 2014).

Within this new complex and multi-polar resource scenario, the possibility of designing and implementing effective developmental policies increasingly depends on the availability of appropriate structural heuristics (Andreoni and Scazzieri, 2013). Among them, the multi-sectoral models of manufacturing development under resources constraints discussed in this chapter have pointed out the analytical and policy challenges posed by various forms of scarcity and the critical importance of embedding resources within structural dynamics frameworks. Not only do multi-sectoral production models allow unpacking structural dynamics of realized manufacturing development trajectories, they also point to the existence of alternative 'still-to-come' patterns. Without such form of structurally grounded virtuality, developmental ways of managing scarcity would remain unexplored.

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