Why did some countries catch-up, while others got stuck in the middle? Stages of productive sophistication and smart industrial policies

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Why did some countries catch-up, while others got stuck in the middle? Stages of productive sophistication and smart industrial policies

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Abstract. Development studies on the middle-income trap have highlighted the challenges for developing economies to transform their productive systems from simple towards high value-added activities. Here, we use trade data of 116 countries to quantify the stages of productive sophistication and reveal the critical phase that countries encounter at intermediate levels of economic sophistication. Our results reveal that only five countries (i.e. Ireland, Israel, Hungary, Singapore, and South Korea) overcame the gravitation towards simple products and fully transformed their economies towards complex products between 1970 and 2010. They successfully made use of windows of opportunities in the digital and electronics sectors through smart industrial policies that promoted endogenous skills and access to international knowledge sources. In contrast, countries like Brazil or South Africa still struggle with the gravitation towards simple economic activities, social fragmentation, and a lack of coherent industrial policies.

Keywords: catching-up; economic complexity; economic growth; industrial policies; product space, productive sophistication

JEL: B20, D85, E02, F10, O25

1. Introduction

Many studies have highlighted the role of productive transformation in the ability of economies to catch-up and leapfrog ahead (Abramovitz 1986; Cimoli et al., 2009; Lee, 2013). Several related strands of the literature on economic development—such as the development pioneers, the Structuralist school, industrial policy research, and economic complexity— share a general understanding that economic development is associated with a structural transformation towards more value-added and knowledge-intensive economic activities. Moreover, they highlight structural constraints that can impede economic catch-up and sophistication processes. But how can these structural constraints and opportunities of a country's productive structure be measured? And why have some countries, such as South Korea, Israel, or Ireland managed to sophisticate their productive structure and caught-up with economically developed economies, while other countries, such as Brazil or South Africa remain trapped in the production of relatively simple products? Here, we contribute to addressing these questions by combining new empirical methods from economic complexity with qualitative insights from case studies about industrial policies and economic development.

Imbs and Wazciarg (2003) showed that countries diversify over most of their development path; only at intermediate to high levels of economic development countries start to specialize. This empirical finding refutes the theoretical idea that mere specialization in few comparative advantages is sufficient to achieve high levels of economic development. Moreover, this finding added to the evidence that countries may go through different stages of economic development (Rostow, 1971). However, recent studies in economic complexity have shown that the number and type of products and technologies that a country produces matters (Hidalgo & Hausmann, 2009; Hausmann et al., 2014, Hartmann et al., 2017). Countries need to sophisticate their productive structure to achieve higher levels of economic growth and social welfare (Hidalgo & Hausmann, 2009; Hartmann, 2014; Romero et al., 2015; Hartmann et al., 2017). Methods from network science help to quantify the complexity of products and show that the ability to produce less ubiquitous and knowledge-based products, like medical equipment or electronic microcircuits, is associated with higher levels of income and new opportunities for diversification (Hausmann et al., 2014; Pinheiro et al., 2018, Alshamsi et al., 2018).

These empirical studies also have confirmed old ideas of the Latin American Structuralist School and political economy who argued that while mere emphasis on natural resources and agricultural products can help economies achieve a certain minimum GDP, it is not sufficient to ensure long-run economic welfare (Prebisch, 1949). Specializing in high value-

added and knowledge-intensive products is a good strategy for welfare creation; conversely specializing in natural resource-exploiting and low labour cost-based products can impose structural development traps and undermine long-term development prospects (Chang & Lin 2009). Moreover, these studies confirmed ideas of innovation economics showing that while efficient resource allocation is important for economic competitiveness of countries, mid- to long-run economic catch-up is mainly driven by innovation and a country's ability to move into new sectors at the right time (Lee & Lim, 2001; Lee, 2013: Alshamsi et al., 2018; Pinheiro et al., 2018).

However, many questions remain unanswered and new insights can be gained from the intersection between qualitative approaches and new empirical methods. For instance, there is ample evidence from case studies about the widespread use of industrial and innovation policies in developed economies (Chang, 2002; Mazzucato, 2013). However, it remains an open question which precise structural constraints and opportunities each country faces, or which precise industrial policies are necessary to overcome the middle-income trap, and when it is the right time to move into the right industries.

Despite the new empirical possibilities to reveal patterns of structural transformation, there is still scarce research on how the middle-income trap looks like from an economic complexity perspective (Jankowska et al., 2012; Hartmann et al., 2019). The term middle-income trap became synonymous with an economy based on cheap labour and/or natural resource abundance, which faces challenges in entering knowledge-based and high added value activities (Bresser-Pereira et al. 2020). In that context, the middle-income traps refer to structural problems in terms of productive sophistication of an economy. Accordingly, terms 'intermediate development trap' or 'intermediate sophistication trap' are perhaps more appropriate than 'middle income trap' as the problem appears to be more of an issue of the type and stage of economic sophistication of an economy than an issue of aggregate quantitative output (i.e. GDP) (Hausmann et al., 2014; Hartmann et al., 2017).

Following methods introduced by Pinheiro et al. (2018) we contribute to the literature on catching up and the intermediate development trap by analysing how close or distant to complex products countries are at different stages of development. Moreover, we identify which countries have been able to overcome the intermediate development trap. Finally, we analyse the type of industrial policies that differentiate successful economies, such as South Korea or Ireland, from less successful countries, such as Brazil or South Africa. The article proceeds as follows. Section 2 reviews the theoretical literature on economic development and catching-up processes. Section 3 introduces the S curve of productive sophistication that

combines information on the level of economic complexity and closeness to complex products of 116 countries in the period between 1970 and 2010. Section 4 scrutinizes the industrial policies of the success cases that moved up the steep part of the S curve. Section 5 discusses less successful cases such as Argentina, Brazil and South Africa that got stuck at the bottom of the S curve. Section 5 provides concluding remarks.

2. The role of productive structures for economic catching-up

Research on the factors explaining economic catch-up processes have a long tradition in economics. Originally, researchers analysed how continental Europe and then later the US managed to catch-up from the 19th century to the beginning of the 20th century with the industrial frontrunner England (Veblen, 1915; Gerschenkron, 1962). Later, rapid economic growth of some Asian countries in the post-World War II period fostered a new wave of interest in the catching-up processes. Abramovitz (1986) argued that social capabilities are a key factor for a country's ability to catch-up and leap-frog ahead. Other authors analysed particular cases of countries, such as Japan (Johnson, 1982; Freeman, 1987), South Korea (Amsden, 1989; Chang, 1993), and Taiwan (Wade, 1990). Later, several authors summarized the similarities between successful cases and the differences of unsuccessful ones (Chang, 2002; Reinert, 2007; Kohli, 2012; Zagato, 2019). Some of the key lessons were that the successful countries used a smart combination of industrial and social policies, along with inwards and outwards oriented development strategies. Several researchers highlighted the importance of building up technological capabilities, promoting learning societies, and moving into more sophisticated industries (Cimoli et al., 2009; Lundvall et al., 2011; Stiglitz & Greenwald, 2014). Moreover, several scholars pointed to the so-called 'middle-income trap' (Agénor & Canuto, 2012; Eichengreen, Park & Shin, 2013; Gill & Kharas, 2015). In this trap, intermediate economies would face additional challenges to catch-up. On the one hand, they already had relatively expensive labour, which would reduce their competitiveness in the international market of low value-added goods. On the other hand, they already achieved a level of structural sophistication to internationally compete for high value-added goods.

In parallel, development economists since the 1940s (Rosenstein-Rodan, 1943; Nurkse, 1953; Lewis, 1954; Myrdal, 1957; Hirschman, 1958; Chenery, 1979; Prebisch, 1949; Furtado, 1961) have highlighted the relevance of promoting structural change as a means of overcoming bottlenecks of development. They highlighted possible broken links between or absence of crucial sectors in economies that kept developing countries in poverty traps. Moreover, they argued that development necessarily involved a reallocation of labour from low to high

productivity sectors, in other words, from agriculture to manufacturing and then to more sophisticated services (Gala, Rocha & Magacho, 2018). Scholars like Nurkse (1953), Lewis (1954), Hirschman (1958), Myrdal (1957), Prebisch (1949), Furtado (1961), and Chenery (1960, 1979) pointed out that long-term economic growth is a 'sector-specific' process. They argued that development involves an increase of the industry share in GDP, which provides the highest potential of productivity, spillover effects, and forward and backward linkages, as well as technological externalities. They emphasized the identification of bottlenecks and rigidities that block structural change in underdeveloped economies and the role of the state in overcoming these failures.

Nurkse (1953) argued that to overcome the vicious circle of underdevelopment, a balanced growth strategy with simultaneous investment in multiple sectors was necessary. In contrast, Hirschman (1958) argued that this in practice is not feasible and rather an unbalanced growth strategy and investing in prolific industries that can have positive spread effects on other industries should be promoted. Additionally, recent research shows that certain Asian countries that caught-up and leapfrogged ahead, i.e. were able to reach high levels of income and productivity, successfully promoted diversification into industries with relatively short industry life cycles, such as certain types computer parts and electronics. By the mean of smart innovation policies and using windows of technological opportunity, South Korea for instance skipped steps previously adopted by leading countries (Lee, 2013).

Yet while these approaches have provided important insights on development processes and potential policy measures, they have not been very successful in quantifying the specific productive constraints and opportunities of each country. In this regard, recent research on economic complexity and the relatedness between different industries has made significant methodological and empirical advances (Hidalgo et al., 2007; Neffke et al., 2011; Hausmann et al., 2014; Pinheiro et al., 2018; Balland et al., 2019; Hartmann et al., 2019). These methods capture how close or distant companies, regions, or countries are from potential new products in terms of productive capabilities. They help to identify the unique structural constraints and opportunities of countries at different stages of productive diversification and the right moment to jump into complex products (Alshamsi et al., 2018; Petralia, Balland & Morrison, 2017; Pinheiro et al., 2018). For instance, countries at intermediate levels of productive diversification tend have significantly higher likelihood to jump into more distant and complex and unrelated activities (Pinheiro et al., 2018). However, developing and emerging economies may also be constrained by a gravitational pull towards simple and resource exploiting products (Hartmann et al., 2019a, 2019b). Gravitation towards 'low hanging fruits', such as agriculture products,

crude petroleum, and mining, can perpetuate exploitative institutions, high levels of inequality, and lack an emphasis on innovation and economic sophistication. (e.g. Engerman & Sokoloff, 1997; Hartmann et al., 2017, Hartmann et al., 2019). Overcoming the intermediate development trap is arguably not only about diversifying into new industries, but also about understanding which products have been dropped and how institutions and industrial policies have changed during the process of structural transformation.

3. Data and methods

To estimate the stages of productive sophistication of countries, we use data on international trade, economic complexity, and product complexity from the MIT's Observatory of Economic Complexity (atlas.media.mit.edu). The trade dataset combines exports data from 1962 to 2000, compiled by Feenstra et al. (2005) and U.N. Comtrade, for the period between 2001 and 2010. We use the Standard International Trade Classification SITC-4 rev 2 as it provides an extended time series from 1962 to 2014. In line with Pinheiro et al. (2018), we reduce noise coming from underreporting and from variations in the size of the economies of countries and products by discarding very small countries and products with very low trade values. The Economic Complexity Index (ECI) measures the knowledge intensity of a country by considering both the diversity and ubiquity of the products that it exports (Hidalgo & Hausmann, 2009; Hausmann et al., 2014). Thus, the ECI not only considers the aggregate level of production, such as GDP per capita, but also how many and which types of products countries are able to produce and export. For instance, while many countries are able to export only agricultural products, only a relatively limited number of countries are able to export sophisticated machinery. In contrast to GDP rankings, highly industrialized countries, such as Japan or Germany move up positions in the ECI ranking, while crude petroleum or other primary products rich countries, such as Iran or Saudi Arabia in relative ranking positions. Similarly, the Product Complexity Index (PCI) depicts how many unique and complex are products (Hidalgo & Hausmann, 2009). For instance, vegetables or textiles are relatively simple products that are produced by a large number of countries; in contrast robots or advanced medical instruments are complex products that are produced by few complex economies. (Full rankings of ECI and PCI between 1968 to 2017 can be accessed at the Observatory of Economic Complexity https://oec.world).

There is arguably a gravitation of learning by doing activities, public and private awareness, and policy emphasis on economic activities that are present in a country and/or that are close to a countries current productive portfolio (Hartmann et al., 2019). To estimate the

extent to which a country's productive portfolio is close or distant to complex products, we make use of methods from research on the product space (Hidalgo et al., 2007; Hausmann et al., 2014; Pinheiro et al. 2018). The product space estimates the levels of shared productive capabilities between two products, based on the conditional probability that countries export both products with a revealed comparative advantage (Hidalgo et al., 2007).

$$\phi_{pp'} = \frac{\sum_c M_{cp} M_{cp'}}{\max(k_p, k_{p'})} \quad (1)$$

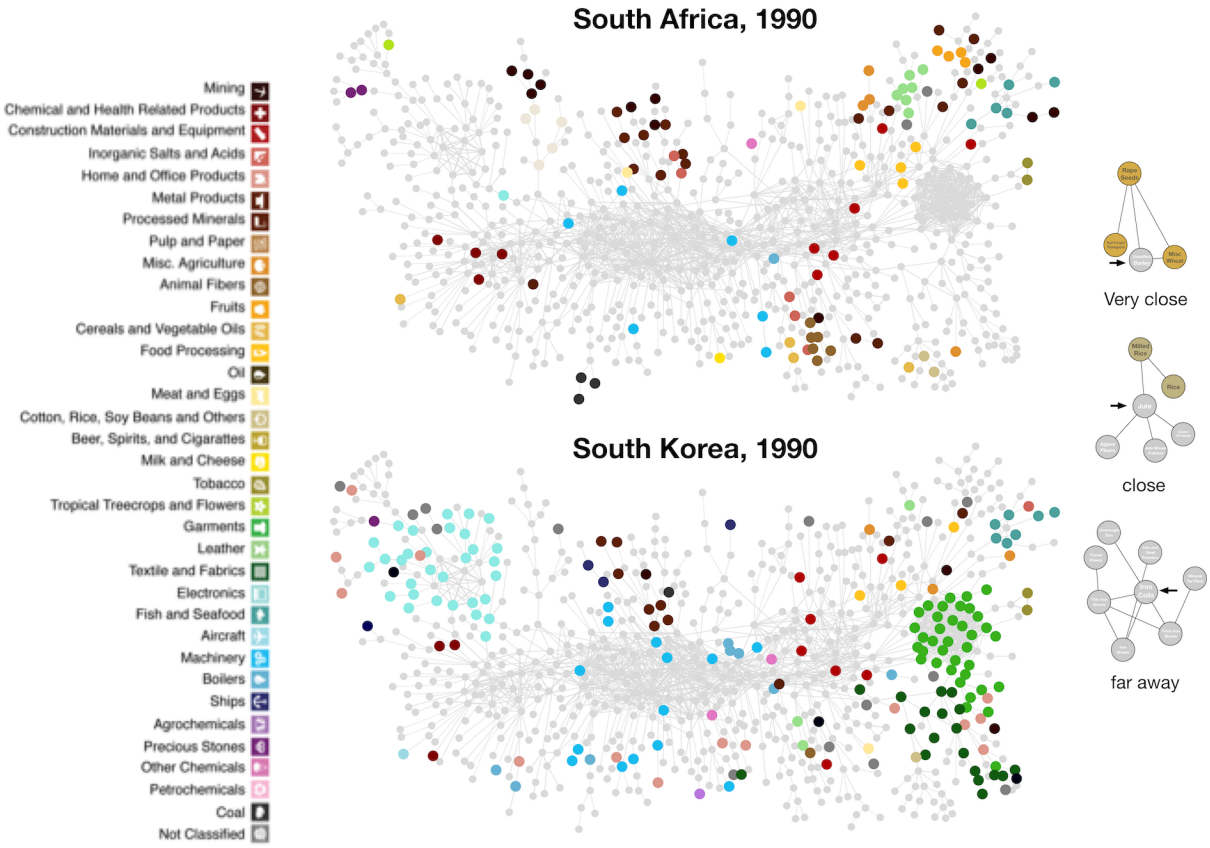

Figure 1. Relatedness and the export portfolios of South Korea and South Africa.

where $\phi_{pp'}$ measures the relatedness between two products p and p' in the product space; the matrix M_{cp} is 1 if a country c has a revealed comparative advantage in product p and is otherwise 0. Moreover, the product space allows us to estimate the likelihood of a country entering into new products, according to the density of comparative advantages of this country in products that are related to potential new products. For this purpose, we measure the density ω of products with revealed comparative advantages around product p in the product basket of country c.

$$\omega_{cp} = \frac{\sum_{p'} M_{cp'} \phi_{pp'}}{\sum_{p'} \phi_{pp'}} \quad (2)$$

Moreover, we analyse the distance of each country's export portfolio to or simple complex products and how this distance changed during their process of economic development between 1970 and 2010. To capture the distance to complex products, we measure the Pearson correlation between the measured density (ω_{cp}) of products without revealed comparative advantage in country c and the Product Complexity Index (PCI) of these products. A positive correlation implies that countries are closer to complex products, while a negative correlation indicates that a country is closer to simple ones. (Pinheiro et al. 2018; Hartmann et al., 2019). For instance, South Korea was both close to simple products in textile and food industries as well as close to more complex products, like electronics and machinery; thus, it was at a critical stage of productive transformation. In contrast, South Africa's productive structure was close to simple agricultural products in the periphery of the product space and was far away from more complex products at the centre of the product space (see **Figure 1**).

Mathematical formulation of the S curve of product sophistication

The information on the achieved level of economic complexity of countries and the average closeness of their product portfolio to complex products can be combined to get a better understanding of the structural transformation process, constraints, and opportunities that countries tend to face at different stages of economic development (Pinheiro et al., 2018). The resulting S-shaped curve of productive sophistication of countries (see Figure 2a) shows both the current level of economic development of countries (measured by the economic complexity index) as well as their future economic diversification and sophistication opportunities (measured by their closeness to complex products that they do not export yet with a comparative advantage). To calculate the closeness of a country's productive structure to new products into which it could diversify, the first step is to identify the complexity of the products that a country does not yet export with a comparative advantage (i.e. products with $M_{cp} = 0$). Then, the density (ω_{cp}) of adjacent products with revealed comparative advantages is calculated for each these potential new products. Finally, the Pearson correlation between the product complexity (PCI) and the density (ω_{cp}) of adjacent products is calculated to estimate the closeness of a country's productive structure to rather complex or simple products. Formally, the correlation can be computed as:

$$\rho_c = \frac{\sum_{j \in O_c}(PCI_j - O_c^{PCI})(\omega_{cj} - O_i^{\omega})}{\sum_{j \in O_c}\left(PCI_j - O_c^{PCI}\right)^2 \sum_{j \in O_c}\left(\omega_{cj} - O_c^{\omega}\right)^2} \quad (3)$$

where O_c is the set of products in country c with $M_{cp} = 0$, while O_c^{PCI} and O_c^{ω} are, respectively, their average complexity and density. A negative correlation indicates that the diversification opportunities of a country are mainly simple products, a positive correlation indicates that the closest diversification opportunities are mainly complex products. A null correlation indicates that the country is equally close to simple and complex products.

It is important to mention that in this measure of "closeness to complex products", we consider only products for which a country has not exhibit a revealed comparative advantage yet. Such choice has two main reasons: first, the focus of this measures is on the future development opportunities at different stages of economic development; secondly, measuring distance/closeness to existing products ($M_{cp} = 1$) is redundant as such products already make up a country's portfolio and thus contribute already to the economic complexity index (ECI) that are tracked on the x-axis of the S curve.

4. Analysing the S curve of productive sophistication

The combination of the economic complexity index (ECI) and the closeness of a country's portfolio to simple or complex products allows us to draw the S curve of productive sophistication (see **Figure 2**). The S curve of productive sophistication illustrates how countries move closer to complex products at different stages of economic development. On the x-axis we can observe 116 countries' level of economic complexity—i.e. the diversity and sophistication of their export portfolio—between 1970 to 2010. On the y-axis, we have the correlation between PCI and density of development opportunities, which represent an estimate of the distance of their export portfolio to complex products.

As we can see, only few highly developed economies, such as Switzerland, Germany and Japan, have a productive portfolio that is predominantly close to very complex products. Most economies, including all African economies and most Latin American and Asian economies, remain close to simple products and distant from complex products. The S-shape of the curve indicates that the development is not linear, but that there are different stages of productive sophistication. It seems that over most of the process of economic development, countries diversify into rather simple products. As they move to intermediate stages of development, they start to diversify into more sophisticated products. At intermediate development levels, countries tend to be close to both simple and complex products, and they have a greater likelihood of jumping into unrelated and more sophisticated activities (Pinheiro et al., 2018). Yet, they may also face significant institutional challenges to transform the economy, by

reducing old, and increasing new economic activities. Most countries have been unable to transform their economies into the production of mainly sophisticated goods.

At the top of the S curve are highly industrialized and sophisticated economies, such as Switzerland, Germany, or Japan. Close behind are other highly developed economies and complexity followers, such as Italy, Slovenia, or Israel, that have a large share of sophisticated exports. At intermediate to high stages of productive sophistication are countries, such as Spain, Norway, or Canada, that have both a large share of sophisticated products, but also a significant presence of primary goods, such as crude petroleum or other agricultural products. Most developing economies are the bottom of the S curve and have a very low closeness to complex

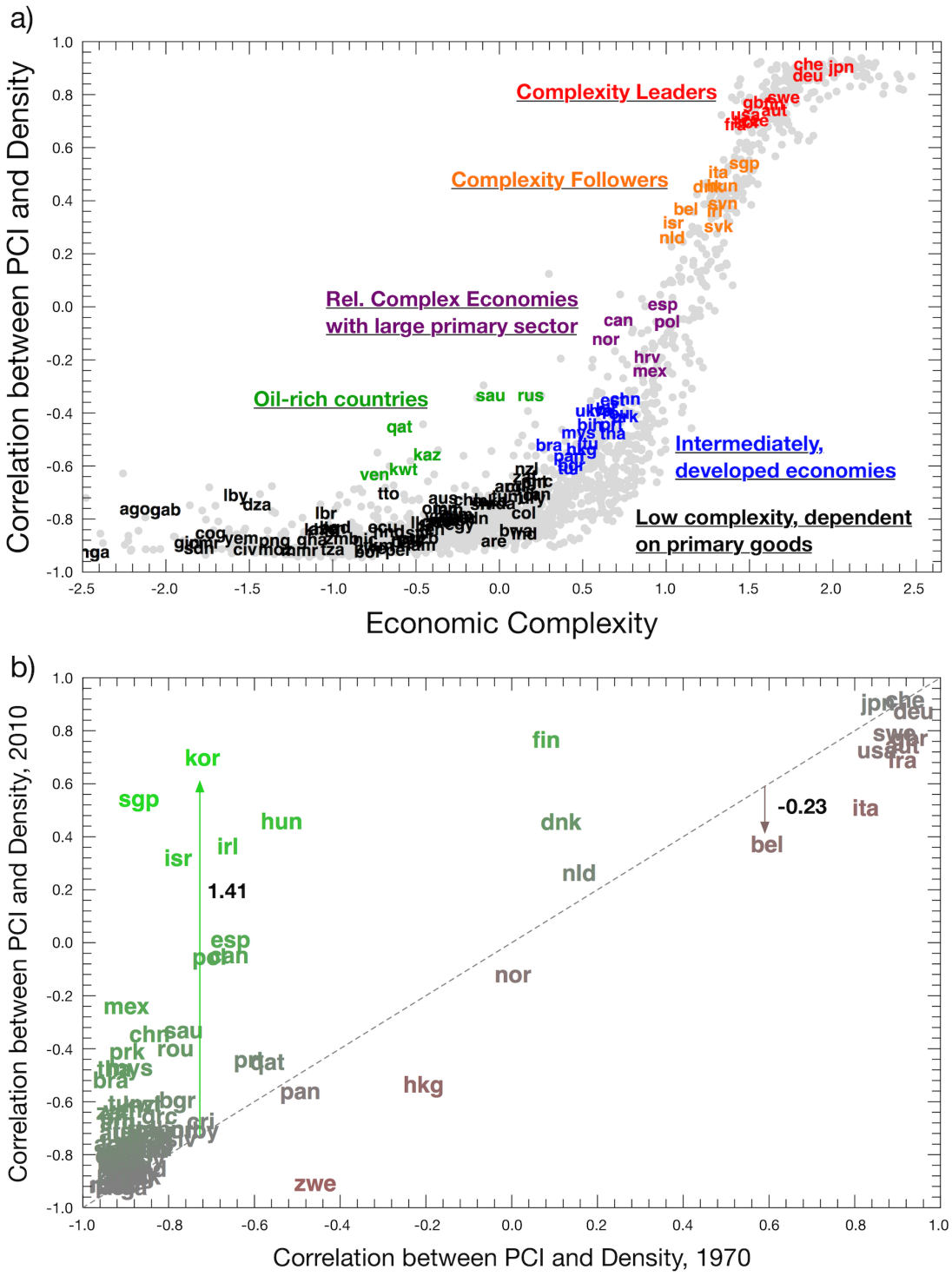

Figure 2. A. The S-curve of productive sophistication, illustrating the level of economic complexity and closeness to complex products of 116 countries. Each node represents a country's value in 1970, 1980, 1990, 2000, and 2010; the values in 2010 are highlighted and coloured according to the continent of the countries. B. Changes in countries' closeness to complex product between 1970 and 2010.

products. Some of these countries have diversified into simple agricultural and mining products, but few developing countries have been able to focus on sophisticated products, such as medical equipment or airplanes. Moreover, there is a set of oil and gas rich economies, such as Saudi

Arabia, Russia or Qatar, who are in a category of their own. They do have some sophisticated activities associated to their advanced petroleum or gas industries, yet export few to no other (sophisticated) products.

The group we are most interested in this article are countries that are (or were) facing the difficult development stage of the bottom of the ladder of productive sophistication. This includes countries, such as Brazil and South Africa today, or South Korea, Israel and Ireland not long ago in the 1960s and 1970s. Indeed, between 1970 and 2010 only Israel, Ireland, Hungary, South Korea, and Singapore managed to move up from the bottom to the top of the sophistication ladder (see **Figure 2**, bottom panel, and **Figure 3** on the movement in the S curve of these economies). Other countries, such as Brazil or South Africa, still have the steep parts of the S curve ahead and struggle to significantly transform their productive structure towards more complex products. A large share of the productive structure of countries at this intermediate development stage consists of low complexity products; thus, these countries face gravitational forces towards the production of low complexity products due to their strong comparative advantages in relatively simple and low labour cost products. At the same time, these countries show that they are able to produce some complex products and have the basic capabilities necessary for more knowledge-based and value-added products. As we will discuss below, arguably smart industrial policies are necessary to overcome the gravitation towards simple and low labour cost products at this stage of development. It is noteworthy in this context that most countries in the world do apply some kind of industrial policies, but relatively few developing economies have been able to successfully design and execute smart industrial policies and move up the ladder of economic sophistication.

The S curve of productive sophistication demonstrates that the development process may be understood as a movement between two different gravitational poles: on the one pole countries mostly produce simple goods, on the other pole countries mostly produce complex goods. Therefore, understanding how countries can jump from one gravitational field to another is key to explaining how countries may leapfrog. Great institutional changes and joint efforts from a wide range of segments of society, i.e. companies, workers, politics, science, and civil society, are necessary at this critical stage of development. Arguably due to the difficulty of this coordination task, only a limited number of countries (noteworthy small or medium-sized countries) were able to fully sophisticate their economies and move up the ladder in recent decades. In this regard it may be noted that while China has made impressive progress and some parts of its economy are at the technological frontier, yet a large amount of its workers still

depends on jobs in simple activities, meaning that China has not fully climbed up the ladder yet.

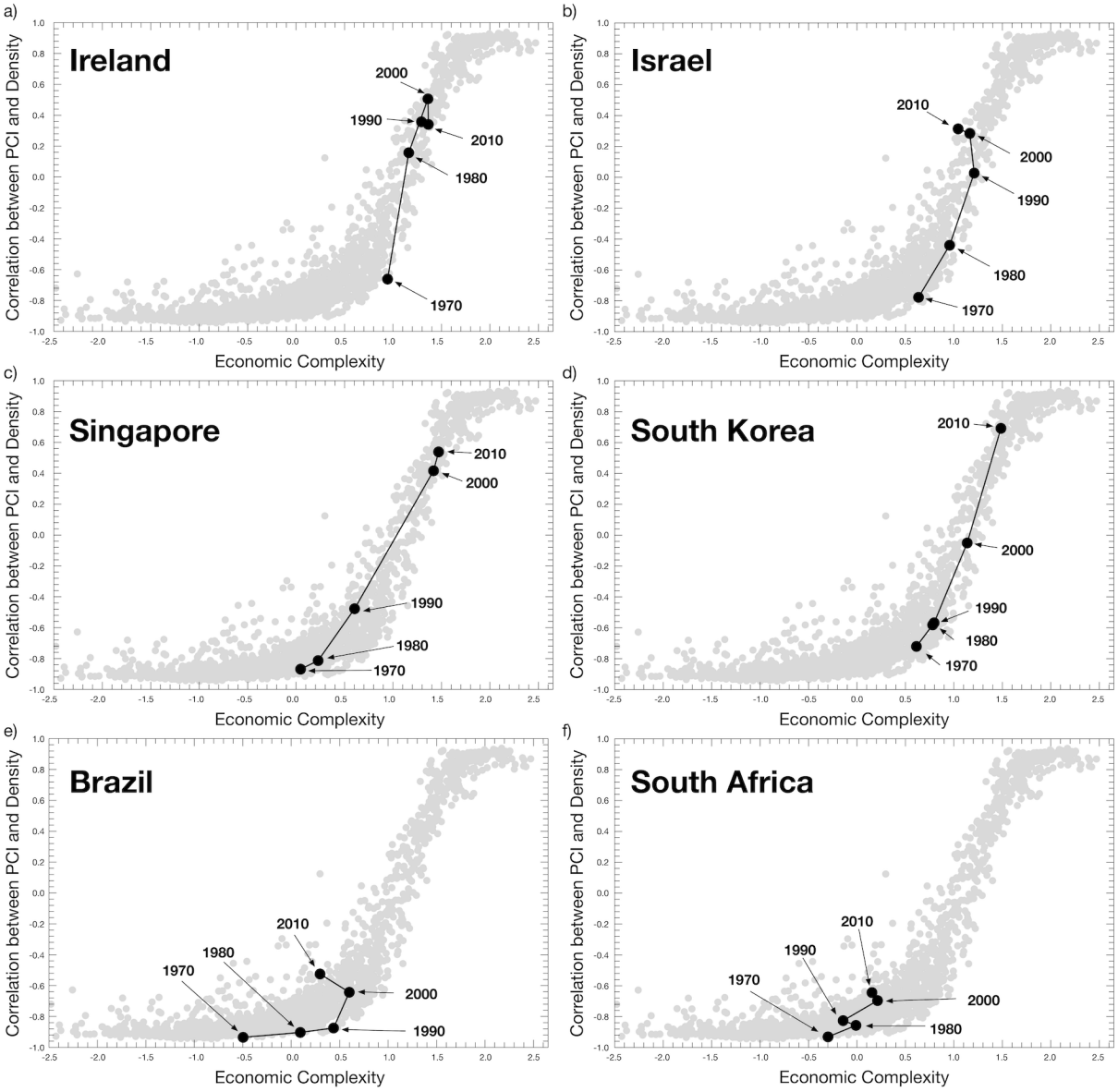

Figure 3. Evolution of countries that did (not) successfully catch-up to developed economies

5. Learning from success cases

Next, we analyse the similarities and differences of the success cases of South Korea, Singapore, Israel, and Ireland[1]. Previous studies indicate that these countries have to a greater or lesser extent i) combined state and market forces ii) implemented industrial and social policies (Chang, 2002; Rodrik, 2008a; Cherif & Hasanov, 2019), iii) maintained sound

[1] We do not analyze the case of Hungary because its comparatively low wages and high complexity, transition from Hungarian Soviet Union to Hungarian European Union relations, and the strong role of outsourcing production activities require careful scrutiny and seem to be beyond the scope of this paper.

macroeconomic policies and prices (Rodrik, 2008b; Bresser-Pereira, 2019; Guzman, Ocampo & Stiglitz, 2018) and iv) promoted both endogenous innovation and access to international knowledge sources (Fu, Pietrobelli & Soete, 2011). Here in this article, we focus in more detail on how these success countries sophisticated their productive structures and which industrial policies they applied. One issue that needs to be highlighted is that these countries sophisticated their productive structures by jumping into the right products in the right moment (Lee, 2013; Pinheiro et al., 2018). Another issue is that these countries have significantly reduced the share of simple products and were able to focus on more complex products. But how did they do this?

We start with the cases of South Korea and Singapore, as they are good examples of countries that combined state and market forces to move into more complex products. The industrial structures of both countries have progressed through different stages of development, from labour-intensive manufacturing to capital and technology-intensive manufacturing and, finally, to high-value added services. Yet, they also show different paths of structural transformation and comparative advantages today. South Korea became one of the leading technology producers (Lee, 2013); and Singapore became a regional headquarter of foreign multinational corporations and hub for finance, trading, transportation and telecommunications (Yue, 2005).

South Korea

Having moved in less than fifty years from a small rural economy to one of the most advanced technological countries in the world, South Korea became one of the classic examples of countries that caught-up through a smart combination of industrial policies with social policies. Several authors highlighted that the Korean state acted in a pragmatic way by adopting both liberal and interventionist measures in order to diversify into more complex products (Chang, 2014; Zagato, 2020). This strategy has been very successful; between 1970 to 2010 South Korea gained revealed comparative advantages (RCA) in 146 new products with an average product complexity index (PCI) of 0.51, while reducing RCAs in 178 products with significantly lower average level of PCIs of -0.33 (see **Figure 4**). This structural transformation process of adopting complex and reducing simple products allowed South Korea to move up the ladder of economic complexity and being now mainly close to complex products.

But how did South Korea achieve this transformation and which policies did it implement to make this structural transformation happen?

Under General Park's rule (1963-79), the country relied on a development strategy of planning and enforcement of guidelines for technological upgrading and sectoral diversification. The

Korean bureaucracy was responsible not only for creating these plans, but also for enforcing them, through the adoption of metrics of success. At each stage of development, the state would

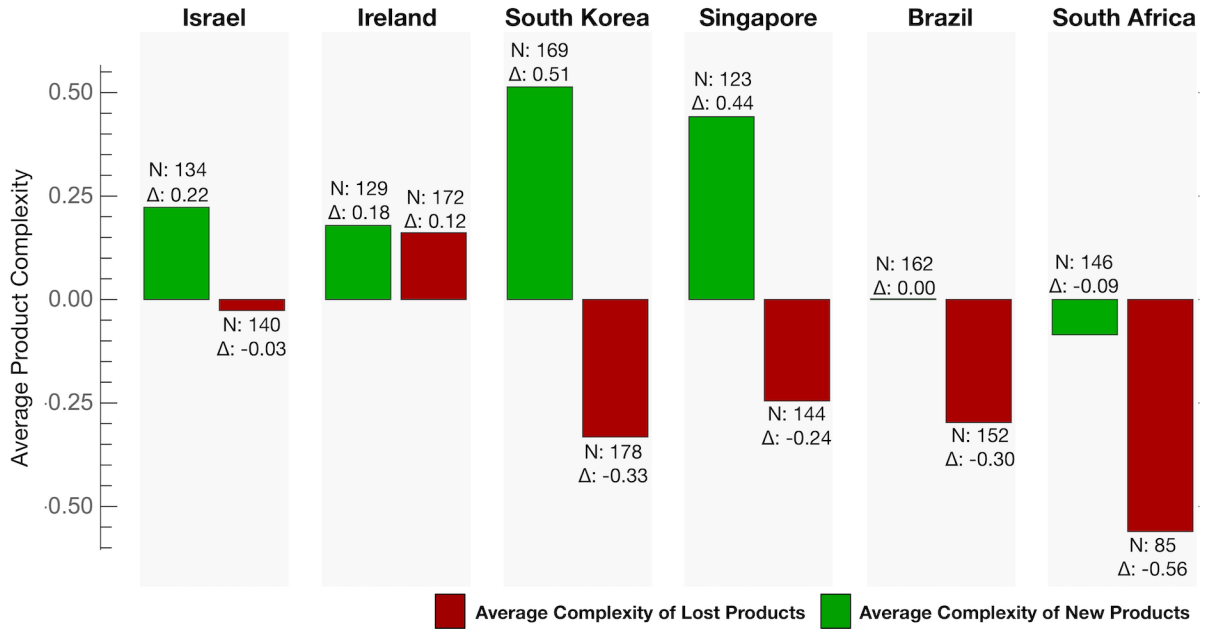

Figure 4. Average complexity of product entries and exists of South Korea, Singapore, South Africa and Brazil. The red bars indicate the average complexity of lost products of a country, the green bars indicate the average complexity of adopted products of the respective country (Δ), the number of entries and exits by each country is also indicated (N).

re-evaluate the sectors to be aided. At the beginning of the 1960s, the sectors of wigs, toys, plywood, cement, fertilizers and synthetic fibbers were prioritized. In the early 1970s, heavy industries, such as chemical, steel and machinery industries, were prioritized. By the end of the decade South Korea already had a sophisticated shipbuilding and steel industry. There was, then, a new wave of import substitution policies that arguably made the production of automobiles and, later, of electronics possible. In the mid-1980s, South Korea already had a technology-intensive autonomous industry that produced automobiles parts and high-technology goods, such as computers, memory chips, electronics, and semi-conductors for exports (Amsden, 1989, Chang, 1990).

Apart from deciding the sectors and the private companies to be aided, the Korean government played an important role in deciding which companies would maintain their benefits, following an approach of 'carrots and sticks' (Rodrik, 2008a). This was arguably pivotal to avoid the so-called problem of rent-seeking, which means obtaining protection without delivering the technological progress and competitiveness required by economic development. Probably one of the most important strengths of the Korean developmental state consists in its ability not to only pick winners, but also to weed out losers. The automobile industry is a good example of this process: half a dozen auto makers were set up in Korea with

the help of direct and indirect state subsidies, today only one solely Korean car firm survived, Hyundai (Studwell, 2013). It did so through the adoption of a successful practice that included the enforcement of conditionalities to those companies that were to be helped and the establishment of a close relationship between the bureaucratic and private elites (Evans, 1995).

According to Lee (2013), Korean firms experienced a lengthy period of learning by assimilating and adapting foreign technologies in the 1960s and 1970s before beginning to conduct in-house R&D in the mid 1980s. Initially, like any other developing country, South Korea specialized in long-cycle technology-based sectors and low-value-added productions, such as textiles and wigs. To do so, it mostly relied on OEMs assemble-types and adopted tariffs and subsequent devaluations of its currency. Later, it progressively shifted towards shorter-cycle technology-based sectors, producing high-end and high-value-added products. During this process, local firms adopted a stage-skipping strategy, which meant producing their own products so they could avoid importing expensive products. In the 1980s, the company LG Electronics, for example, did a 'detour'. Instead of replicating the Japanese high-definition analogue TV technology it moved straight to produce high-definition digital TV. It is important to note that for the success of such products in the global market, a strong intervention of the central bank in its currency market arguably helped South Korea to maintain a competitive currency and promote its industrial exports. Singapore followed similar policies (World Bank, 1993) and several studies highlighted that pro-competitive exchange rate management in East Asia were important in promoting manufacturing exports (Dornbusch & Park, 1999; Rhee & Song 1999; Rodrik 2008,b). Throughout most of the second half of the 20th century, the Korean developmentalist state kept both exchange rates and interest rates at levels compatible with the promotion of structural change as a strategy to avoid losses in the competitiveness of its industries.

Singapore

Similar to South Korea, Singapore also rapidly changed its productive structure and climbed up the S-curve of productive sophistication by dropping simple and adopting complex products (see **Figure 4** and Singapore's product space in the **appendix**). The success story of Singapore has been presented by many authors as a case of market-driven success: minimal price distortions, openness to international trade, technology and investment flows, fiscal and monetary prudence, and high savings and investment (Yue, 2005). However, as many other authors argue, Singapore is also a good example of how state planning and government

intervention in the economy can create national competitive advantages through smart industrial policy (Wade, 1990).

The catching up of Singapore, which became independent in 1965, was roughly classified by Goh (2006) as labour-intensive in the 1960s, export-oriented in the 1970s, cost-competitive in the 1980s, and enterprise development-oriented in the 1990s (the decade in which Singapore advanced the most in the S curve). The first phase of industrialization was mainly based on the use of cheap labour as a pragmatic means of solving the severe unemployment problems of the country. This was followed by the adoption of the strategy common to Asian countries at the time: adopting an export-oriented industrialization model. To attract more multinational companies (MNCs), the small island nation relied on its strategic trading location, invested in physical infrastructure and a growing skilled workforce. By the 1980s industrialization was established in advanced sectors, such as electronic parts manufacturing, construction and building engineering, logistics, and finance (Yue, 2005). Yet, due to its FDI driven model, in contrast with other successful countries of the region like South Korea, Singapore did not create competitive domestic firms in the early industrialization stages.

As Singapore became more economically developed, its cost-competitive advantage diminished comparatively, and countries like China, Indonesia, and Thailand started to offer better operating costs. In the 1990s, the country changed its development strategy once again, this time focusing on the strength of local enterprises. To do so, industrial policies were introduced by the government to maximize the potential for economic growth through enterprise development. The government invested in public research and encouraged private companies to be more entrepreneurial in order to gain niche competitive advantages in the global economy dominated by large and oligopolistic players (Goh, 2006). Additionally, several national plans, such as the SME Master Plan (1998) and the Technopreneurship 21 (1999), were launched (Yue 2005). This attempt to promote indigenous R&D is still in place and is crucial to understand Singapore's recent economic success.

While showing different trajectories, both Singapore and South Korea applied smart industrial policies that combined market and state forces, local and foreign knowledge, to rapidly climb up the steep parts of the S curve. Next, we analyse two other countries with great improvements driven by access to external knowledge sources and the adoption of new digital technologies: Ireland and Israel. While Ireland significantly gained from FDI of foreign tech companies aiming to attend European markets, Israel established a dynamic tech start-up scene of local companies. Both approaches helped these economies to reduce the reliance on simple products and move into complex, knowledge-based activities.

Ireland

Ireland is a success case in Europe that transformed its productive structure towards more complex products. Since joining the European Community, in 1973, the country has been aided by the European Structural Funds, which aimed at promoting the development of both physical and social infrastructure of the member countries (McCarthy, 2001). This implementation of industrial policies promoted the diversification of the economy through exports. The Irish government decided to develop and implement an industrial focused policy, aimed at attracting foreign investors from the most dynamic sectors of the world economy at the time: computing, chemistry, and petrochemicals. The implementation of such a strategy was carried out by the Industrial Development Authority (IDA). The IDA was successful in attracting a number of international banner companies, such as Intel, IBM, Motorola, and Microsoft (Godoi, 2007). As a result, the Irish economy shifted from an agrarian and traditional manufacture to a high technology and international services-based economy in only a few decades. It became one of the most distinguished exporters of software globally and it is highly competitive in sectors such as chemicals, information, and communications technology (ICT), which represented 35% of the national exports in 2014.

Scholars have argued that the success of the Irish industrial policies was only possible by virtue of the establishment of a favourable macroeconomic environment. This was a positive externality of the Irish policy to reduce unemployment. At the beginning of the 1980s, Ireland presented quite a high inflation, interest rate, and current account deficit (Dornbusch et al, 1989). Although attempts to reduce inflation and stabilise the local economy began to be made by the Irish government starting in 1979, when the country joined the European Monetary System (EMS), improvements only began to be more noticeable after the second half of the 1980s (Detragiache & Hamman, 1999). The main economic goal of the Irish government was to stabilize nominal wages and to allow benefits related to a stable nominal exchange rate and rising productivity to be reflected in employment growth. Along with the wage policy, the government promoted two large devaluations of the Irish pound in the exchange rate mechanism of the EMS in 1985 and 1993 (Walsh, 1999). This contributed to a significant reduction in relative hourly earnings and significant improvement in the competitiveness of manufacturing industries. While by the end of the 1970s, Ireland's economy was mainly based on an abundant labour force, at the beginning of the 21st century the Irish economy became competitive in more capital and technology-based products.

Israel

The Israeli IT industry is also a significant success story. During the 1950s and the 1960s, the Israeli state adopted long-term planning and traditional industrial policies that were protectionist, in order to foment specific sectors and industries, such as textiles and defence. Scholars noted that the development of high-tech industries was not an explicit goal, but a positive externality of an increasing demand of technology to advance the national defence industry. In that context and period of time, science-and-technology (S&T) policies resulted mainly from public research institutions efforts, while research-and-development activities in the civilian industrial sectors were almost null (Breznitz, 2007).

The private sector started to play an important role after the creation of a public agency, the Office of the Chief Scientist (OCS). Although the OCS was launched in 1968, resources for the agency only started to be more abundant in the 1980s (Breznitz and Ornston, 2013). The industrial policies promoted by OCS focused almost entirely on developing capabilities to create new R&D-based products. The state's R&D policies started to consider private firms as the main agents of R&D and the state itself as the grantor of capital for R&D activities. Therefore, the agency disseminated R&D know-how from the university and defence sectors to the civilian industrial sectors; promoted the development of R&D capabilities in the private market; and coordinated talks among private and public R&D representatives. As a result, in less than 20 years, Israel climbed the S curve of productive sophistication like no other country, emerging as a key player in global IT technology, with local companies pioneering 'many hardware and software market niches, such as voice over Internet protocol (VoIP), encryption, printed circuit board inspection, antiviral protection, digital printing, and firewalls' (Breznitz, 2007, p.41). Currently, the Israeli economy is mostly based on the high-tech industry, which relies on strong links with capital markets, a wide range of taxation and customs treaties, as well as international trade agreements with large partners, such as the EU, the US, and some Asian countries (Getz & Segal, 2008). According to OECD (2020), Israel was the country that most invested in R&D in 2018, i.e. 4.9% of its GDP, while South Korea, which ranked second, invested 4.5%, and the average of investment presented by OECD's countries was as only 2.3%. Finally, the Tel Aviv area was ranked the 7th world's most influential start-up ecosystem in 2020 (Startup Blink, 2020).

What do the success cases have in common?

Many countries tried to climb up the S curve productive sophistication, but our empirical analysis shows that very few actually succeeded. The success cases Ireland, Israel, Singapore, and South Korea all relied on smart industrial policies to made use of new technological opportunities, often related to digital technologies, software, and electronics. To do so, these countries relied not only on the state to promote development, but also heavily on private agents, suggesting that a smart combination of state and market forces are necessary to climb up the ladder of productive sophistication. In some cases, the state acted more directly, like in South Korea, in others, such as in Singapore and Israel, private sector agents increasingly became more central. All success countries have been able to implement industrial policies in an efficient manner. The Korean government, for example, not only granted credits, but also monitored whether supported private enterprises met their goals. Finally, domestic companies from all these successful countries learned from foreign companies and technologies to make qualitative leaps towards the internal generation of innovation and more complex products.

6. Why did other countries fail? The cases of Brazil and South Africa

The success cases show that market forces alone cannot explain the success of countries to move up the S curve of productive sophistication, but industrial policies and state support also have been involved. However, this does not mean that the existence of industrial policies per se guarantees successful economic catch-up and sophistication. Indeed, there are also many cases in which industrial policies failed, led to inefficiencies, misallocations, and corruption.
Two examples in this regard are Brazil and South Africa, which have significant strengths in R&D, who did apply applied industrial policies, and have been noted for their large developmental potentials (Cassiolato & Lastres, 2009; Becker, 2014), yet also have struggled to overcome structural constraints, failed to implement coherent and smart industrial policies, and did not move up the ladder of productive sophistication on a nationwide scale. Indeed, recent research on Brazil showed that government expenditures between 2003 and 2012 have mainly gone to rather simple products and protected existing industries than targeted new and more complex products (Machado 2019). In this regard, research on economic complexity has shown that moving into the wrong type of products at the wrong moment can lead to development traps if countries mainly focus on simple products (Hidalgo et al., 2007; Hausmann et al., 2014; Alshamsi et al., 2018, Hartmann et al., 2019a, 2019b). So not any type of industrial policies will be successful, but rather smart industrial policies that target the right

industries in the right moment and are well designed and implemented (Rodrik 2008a, 2008b). Brazil and South Africa are two countries that have failed to move up the ladder of economic sophistication and implement successful industrial policies. What distinguished their policies from the more successful cases discussed above?

Brazil

Throughout the 20th century, Brazil was among the countries with the highest average annual growth rates in the world (Evans, 2005). While Brazil grew on average 5% per year between 1900 and 1994, Argentina grew 3.5%, Korea 4.5% and Taiwan 5.2% (Maddison, 1995). As a result, the country managed to develop a considerable number of low to medium tech industries. Yet analyzing more disaggregated data helps to understand why, despite this remarkable GDP growth, Brazil has never fully caught up. For starters, periods of fast economic expansion were usually followed by periods of stagnation or even recession. This tendency led Palma (2009) to call these countries 'waddling ducks', in comparison to the 'flying geese' from Asia. Moreover, even though some complex industries, such as petrochemical and aircrafts, did flourish, Brazil was unable to gain comparative advantages into a more varied set of complex products. Primary goods never ceased to be the core of its exports and continue to be a substantial driver of its economy. It is noteworthy that phases of more assertive economic policies corresponded with periods of advances in terms of structural change.

During the government periods of Getulio Vargas (1930-1945; 1951-54), investments in infrastructure were essential for the consolidation of the Brazilian industrialization and led to the creation of some industrial companies, such as the National Steel Company. Juscelino Kubitschek's years in office and the Targets Plan in 1956 resulted in the consolidation of the Brazilian basic and heavy industry and there was a 'deepening in sectors such as automotive, shipbuilding, heavy electrical equipment and machinery (…). With regards to basic industries, the plan particularly addressed industries such as steel, non-ferrous materials, heavy chemicals, petroleum, pulp and paper' (Rocha 2015, 8). Finally, the period of military rule (1964-1985) was important in terms of the promotion of structural transformation. The National Development Plan (PND) (1972-74) aimed at producing durable goods and infrastructure, whereas and II PND (1975-79) prioritized the areas of energy and capital goods (Rocha, 2015). Despite all this, Brazil has not climbed the technological ladder for several reasons. Among them, too many sectors have been targeted, which in practice diluted the effects and the incentives were quite indiscriminate (Lago, 2014).

The Brazilian state was inefficient in avoiding rent-seeking, as its mechanisms to 'weed losers out' were much weaker than in the case of South Korea, for example. Additionally, even before its commercial and capital liberalization in the early 1990s, Brazil had never established a rigid and effective control on the type of FDI entering the country and how it was allocated. The fact that only 6% of MNCs in South Korea were wholly owned subsidiaries, compared to 60% in Brazil, indicates the degree of state control over foreign direct investment (Chang, 1993). Finally, in 1981, the Brazilian debt-export ratio was almost 4 times larger than in South Korea (Sachs, 1985), which indicates the country was unable to convert foreign borrowing into endogenous technology creation.

The debt and inflation crisis during the 1980s and early 1990s resulted in a halt of structural advances in the country. After the economic turmoil, Brazil did not resume its path of economic diversification and sophistication, but faced a strong early deindustrialization process (Palma, 2009, Carvalho & Kupfer 2011). This was associated with the trade and financial liberalizations, which had severe adverse consequences, such as the end of the tacit control of its Dutch disease (Bresser-Pereira, 2019). Moreover, there is evidence that recent industrial policies, such as PITCE, PDP and PBM, were ineffective in promoting economic complexity, as they disproportionately aided simpler economic activities than complex ones (Machado, 2019). The ultimate result of this centenary process of advances and setbacks was an incomplete industrialization and a lack of advanced technological capabilities in recent growth sectors, such as electronics or digital technologies, into which most of the success cases diversified.

South Africa

In many ways, South Africa has presented a similar path of structural change like Brazil. Supporting industrial development was a key component of the government approach to economic development throughout most of the second half of the 20th century. This changed in the 1990s with the adoption of the recommendations from the Washington Consensus (Zalk, 2014). At the beginning of the 2000s, even though the country has grown substantially, it has been facing a premature deindustrialization (Palma, 2014), partially caused by the growing competition of manufacturing goods from China (Edwards & Jenkins, 2015, Zalk, 2014, Fotoyi et al., 2016), and partially due to internal inconsistencies, such as a tendency to have an overvalued currency and high real interest rates.

The support for industrial development has long been linked to the extraction of minerals and other primary goods. The term Minerals Energy Complex (MEC) has been used

to describe the strong relationship between the minerals sector and the energy sector (Zalk, 2014). The post-war apartheid state drew on mineral rents and levers of the state to embark on ambitious projects in the energy and chemical sector, which led to the establishment and growth of Sasol and Mosgas (later PetroSA) (Fotoyi et al, 2016). Although the MEC was crucial for the South African economic progress, a number of other industries, such as automobiles, grew outside it. As in the case of Brazil, the Import Substitution Industrialization (ISI) in South Africa came to an end in the late 1970s, as a result of the oil crisis and emerging debt problems. Another similarity between South Africa and Brazil is an extremely high level of income and wealth inequality, which resulted in attempts by the elite of reproducing consumption patterns from the middle class of the developed world that was mostly fulfilled by imports (Fotoyi et al, 2016).

In 1994, democratization was followed by economic liberalization processes. The lowering of tariffs and opening of borders resulted in the restructuring and closure of many industries. There was also a change in the nature of economic policies. The Reconstruction and Development Programme (RDP), launched in 1994, for instance, did not put any particular emphasis on industrial structure (Fotoyi et al., 2016). In the 2000s, as it was the case for most of the developing countries, the increasing Chinese demand for commodities made South Africa exports increasingly focused on (processed) raw materials, whereas imports from China were mainly consumer products and capital goods. There was a strong crowding out effect of exports by China, which meant that South Africa (as well as Brazil) exported less manufactured goods to the US, EU and their regional markets (Edwards and Jenkins, 2015). Moreover, South Africa used the recent boom in capital inflows not just to finance an increase in foreign exchange reserves, but also to promote a large current account deficit. Finally, there was a strong appreciation of the Rand, especially between 2003 and 2006, which has reduced the competitiveness of local manufacturing goods (Frankel et al., 2008). By 2007, when the South African government made the decision to resume the adoption of targeting industrial policies and implemented the National Industrial Policy Framework (NIPF), there were already signs of a manufacturing industry in crisis. Scholars argued that 'The process of economic restructuring had only been positive in certain industries while others were in free fall and on the brink of collapse' (Fotoyi et al., 2016, 6).

The commodity boom had seen the currency strengthen to a level that made much of South Africa's industry uncompetitive. 'The growth in the mining sector provided some stimulus for local industry but increasingly the conglomerates operating in the manufacturing sector were becoming international players with global sourcing strategies, which usually

meant procurement from China or other markets' (Fotoyi et al., 2016, 6). However, the launch of NIPF coincided with the outbreak of the global financial crisis of 2008. The outset of the crisis in connection with South Africa's other structural and macroeconomic problems led to the domestic economic crisis and the deepening of the process of its early deindustrialization process, which had started in the 1990s (Palma, 2014). According to the World Bank, the manufacturing value added (% of GDP), has declined from 21.6 in 1990, to 11.7 in 2018.

Both Brazil and South Africa largely missed opportunities in new growth sectors, such computer parts, electronics, and digital technologies. Interestingly, though, both the success cases South Korea and Singapore as well as the less successful cases South Africa and Brazil did lose comparative advantages in low complexity products (See also **Figure 4**). Yet, while the South Korea and Singapore entered into highly complex new products, South Africa and Brazil only managed to enter into new products with an intermediate level of complexity (see **Figure 4**). In consequence, there was a significant divergence processes productive sophistication of these countries. Brazil and South Africa have also been negatively affected by commodity price fluctuations and the threat of a Dutch disease (Bresser-Pereira 2019). Another issue that requires more in-depth analysis in subsequent research are the effects of extremely high levels of inequality and social stratification in South Africa and Brazil (Gorshkov et al., 2013; Hartmann et al., 2019c). Extreme levels of inequality can arguably lead to a lack of mutual learning and cooperation between different groups of the society—i.e. industry and company owners, the civil society and workers, science and technology, and different social classes— which hampers the ability of these countries to implement smart industrial policies, become learning societies, and move up the ladder of productive sophistication (Cimoli et al, 2009; Lundvall et al., 2011; Stiglitz et al., 2014).

7. Discussion

In this article we quantified the stages of productive sophistication 116 countries between 1970 and 2010 and showed that most countries have failed to move up the steep part of the S curve of economic sophistication. Moreover, we compared countries that have successfully overcome the intermediate development trap—i.e. South Korea, Singapore, Israel, and Ireland— with less successful cases, such as South Africa and Brazil. Our results indicate that smart industrial policies (not every industrial policies) are necessary, although not sufficient, to overcome the gravitation towards simple products and transform the entire economy towards more complex and knowledge-based activities.

In this article we combined the more quantitative perspective of economic complexity research with the more qualitative perspective from case studies on catch-up and development. Research on the product space of international trade has made great advances in understanding the structural pattern and dynamics of economic diversification and sophistication processes. In this regard, the S curve of productive sophistication discussed helps to understand the gravitational forces towards more simple or complex parts of the product space. The S curve of productive sophistication could be read as an empirical high-resolution picture of structural development problems that have haunted development economists since many decades. For instance, the failure of large emerging economies to move closer to complex products in the 'S' space illustrates structural problems in the drive to maturity phase as explained by Rostow (1971). Moreover, the idea of gravitational forces in the S curve is close to Myrdal's notion of cumulative causation and divergence processes of development.

It must be noted that S curves of knowledge diffusion or business cycles tend to imply that after some considerable investment efforts, diffusion processes start to accelerate, and are almost an automatic process afterwards. While the data reveals an S shaped curve, this process is not automatic process, though, as our case studies show, but great effort at intermediate levels is necessary to climb up the steep parts of the S curve. Indeed, starting from similar positions of intermediate levels of economic complexity some countries have managed to rapidly catch-up while others did not. Thus, a window of opportunity opens, but not all economies are able to ensure smart industrial policies and bring together both market and government forces necessary to climb up the ladder.

This connects with some methodological and qualitative limitations of the S curve that shall be discussed subsequently. Firstly, the S curve is mainly a descriptive picture on how the productive structures of countries move closer to more complex products during the process of economic development (Pinheiro et al., 2018). But as mentioned this is not an automatic development process and the S curve itself does not fully explain why some countries successfully catch-up while others do not. Moreover, two countries with a similar average level of economic complexity or closeness to complex products can have quite different productive structures and, thus, different constraints and opportunities. These are the main reasons why this article has reviewed several cases of success and failure, in order to argue that a combination of the quantitative strengths of economic complexity research and qualitative insights of industrial policy research can benefit from each other.

Thirdly, while it is clear that a trend exists, there is also a significant amount of variance along the S curve. For instance, there is a group of oil producing countries that show a

comparatively high closeness to complex products in comparison to countries with similar (intermediate) levels of economic complexity. Moreover, there is a quite large set of countries with a similar average closeness of their productive structure to complex products, yet large differences in economic complexity. At the same time, there is also a considerable number of countries with rather similar average levels of economic complexity, but large differences in closeness to complex products. All of these examples of variance arguably require their own in-depth analysis. Within this article we mainly focussed on the last examples in which countries with relatively similar initial levels of intermediate economic complexity showed divergent paths.

Fourthly, the S curve is based on export data and associated classification of goods. This provides important information on the competitiveness of countries in tradable goods and may to a certain extent also be able to proxy the overall productive capabilities and knowledge intensity of a country. However, it does not depict services and moreover does not depict current significant transformations of the digital age.

Finally, the average country-level data and perspective in this article does not consider the large differences within countries. Indeed, some regions in many, if not most developing and emerging economies, are able to produce sophisticated goods, while other regions in the same country lag behind. These data limitations constitute, in our view, promising paths for future research, and do not affect the main results of this article. Indeed, we expect a similar S curve behaviour and need for smart industrial policies at the regional level as well. Nonetheless, these considerations require further research on the differences at the national and regional level.

The qualitative case studies on Korea, Singapore, Israel and Ireland in this article, though, showed that quantitative research on economic complexity can benefit from existing knowledge in development studies about why some countries were able to overcome structural constraints of development, while others were not. In the process of structural change and moving up the ladder of productive sophistication, social, political, and institutional factors do play an essential role, yet are hard to measure and may require in-depth cases studies to be of practical use for policymakers. Our cases studies show that to escape the gravitational forces of underdevelopment and moving up the ladder, smart industrial policies are necessary that promote both market and state forces, internal and external learning. It is hard to imagine how a country can move into completely new industries, requiring new infrastructures, institutions, and skills without smart industrial policies and state support. Equally it is hard to imagine how countries can achieve and sustain competitive advantage in complex industries without

innovative and competitive companies. Countries need to design and implement industrial policies to move into the right moment into the right sectors and move up the S curve of productive sophistication.

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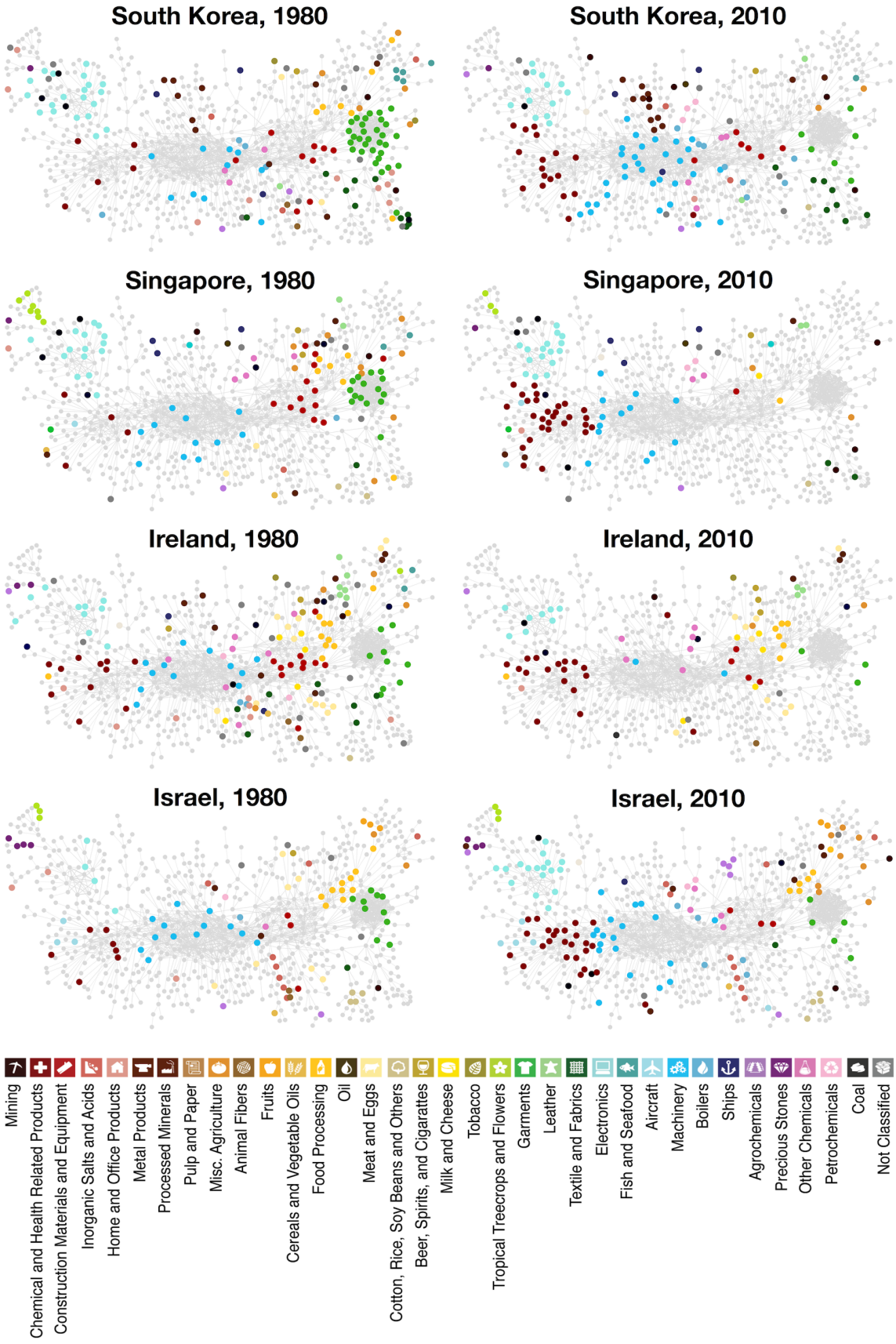
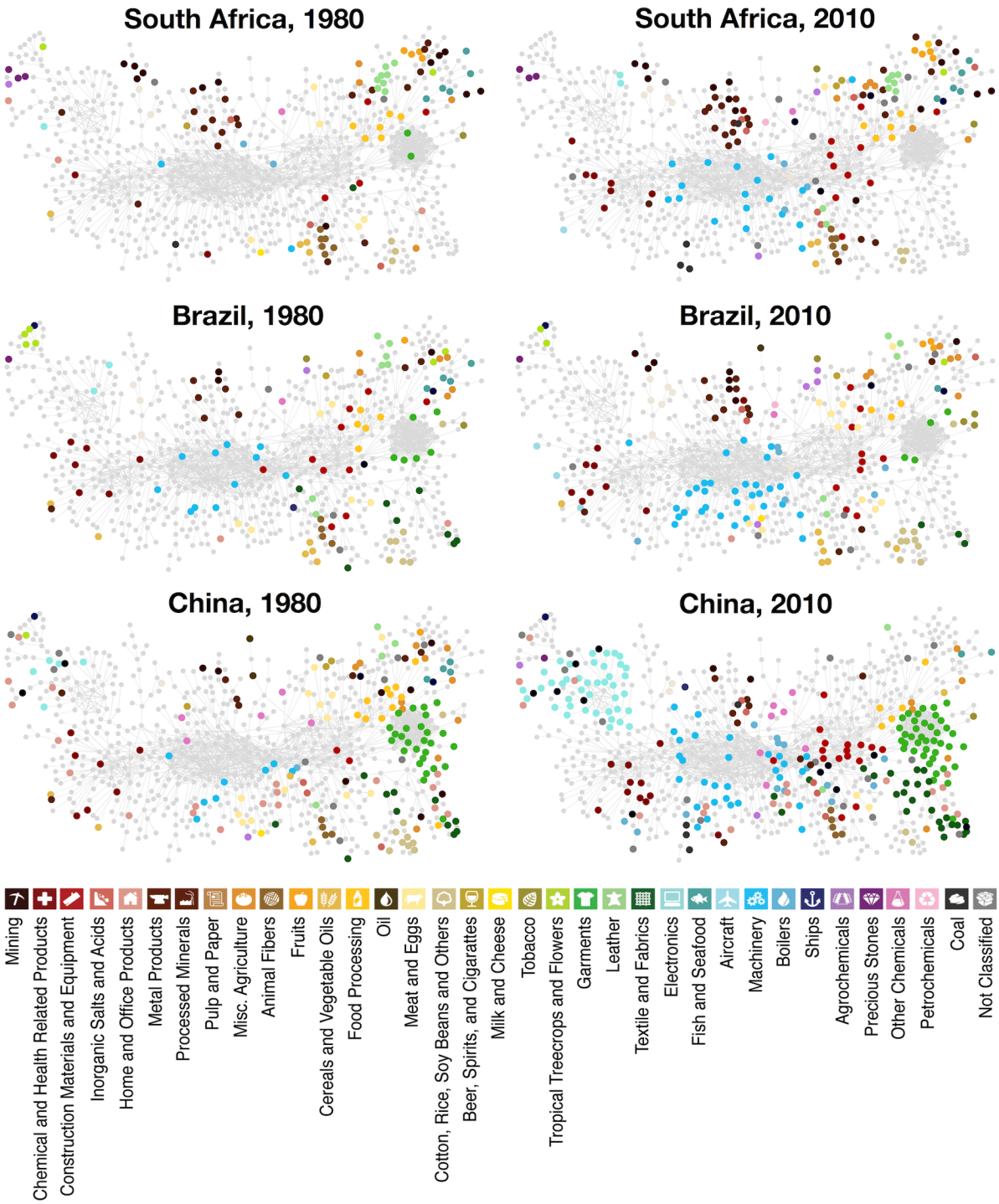
Appendix – Supporting Figures



Data sourced from The Observatory of Economic Complexity: https://oec.world/en/, own illustration with Wolfram Mathematica



Data sourced from The Observatory of Economic Complexity: https://oec.world/en/, own illustration with Wolfram Mathematica