Technological Regimes and Catching Up in the Product Space[1]

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Abstract

This paper proposes a micro-founded model of countries' diversification trajectories in the product space. We argue that the type of technological regime under which countries operate conditions their export performance and diversification trajectories. In particular, repeated simulations show that countries with firms operating under an entrepreneurial regime expand their export basket faster when most other countries are characterized by a routinized regime. Simulations also show that catching-up trajectories in the product space are less likely when all countries operate under the same technological regime.

Key words: product diversification, technological regimes, product space, agent-based model
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1. Introduction

A country's economic development is closely related to its capacity to successfully export an increasing number of products (Teza et al., 2018). This fact can be illustrated by Hong Kong, Taiwan, South Korea, and Singapore. Indeed, their economic catch-ups were based on the successful development and export of electronic products in which they had no expertise in the 1960s (Nelson and Pack, 1999). The World Bank (1993) acknowledges the role of the state, and especially of industrial policies, in the emergence of the East Asian miracle.

The virtues of product diversification have already been highlighted by economic theory. For instance, according to Romer (1987), an increasing variety of intermediate goods fosters economic growth due to higher specialization of their producers. Furthermore, Hausmann, Hwang, and Rodrik (2007) show that countries exporting goods associated with high productivity levels grow faster. Taking China as an example, Rodrik (2006) documents that in 1992, the country was successfully exporting goods "associated with an income level […] more than six times higher" than its own (p. 6), which largely explains the country's subsequent success story. On the demand side, Aoki and Yoshikawa (2002) and Saviotti and Pyka (2008) show that increases in the variety of consumer goods allow a country to overcome the consumer satiety that would otherwise hamper economic growth.

More recently, it has been proposed that countries do not diversify at random. In particular, Hidalgo et al. (2007) propose a tool for mapping countries' diversification paths. This tool is a network of "relatedness" between products — also called "product space" — in which countries develop new exports primarily in the products that are more closely related to those that they already successfully export. This observation permits to highlight the singular pattern of East Asian development, as these countries have succeeded at building advantages in the export of poorly related products. Since Hidalgo et al.'s (2007) contribution, several other papers have tried to propose models of countries' movements over the product space. However, in our view, none of these have succeeded at developing a single framework that explains both the stylized facts of related diversification and the existence of outliers, like East Asia.

One of the main theoretical models is provided by Hausmann and Hidalgo (2011). They propose that countries are endowed with specific capabilities and that they export products that require a set of capabilities compatible with their own. This framework allows the authors to identify a new form of development trap. Countries with a low number of capabilities will find virtually no marginal benefit from developing new capabilities, as it is rather unlikely that one additional capability would permit them to become exporters of new goods. However, Hausmann and Hidalgo (2011) do not propose a theory of capabilities acquisition and loss - a prerequisite for a dynamic framework.

Neffke et al. (2018) developed the idea of capabilities further by extending the resource-based view of the firm (Barney, 1991) to regions. According to these authors, economies are endowed with a number of distinctive resources that local firms learn to use over time, hence the development of advantages in related products. Observing that regions sometimes develop expertise in rather unrelated goods, they indicate that unrelated diversification happens when firms from other regions establish themselves in a new location. By doing so, these firms bring new resources and capabilities into the region. Neffke et al.'s (2018) framework is thus more flexible than the one proposed by Hausmann and Hidalgo (2011), as it takes into account the appearance of unrelated diversification.

In our view, the capabilities/resources perspective of Hausmann and Hidalgo (2011) and Neffke et al. (2018) suffers from several weaknesses. First, it postulates that countries or firms export all the goods that are compatible with their endowment. This assumption supposes perfect information about what is feasible, and it ignores the high degree of uncertainty related to the development of new products. On the contrary, historical accounts of the development of electronics in East Asian economies often mention the importance of entrepreneurship, learning, and business strategy — in particular, to overcome barriers for exporting new products (Nelson and Pack, 1999, Hobday, 1994). Second, so far, the capability perspective does not constitute a theory of capabilities building and it does not consider the fact that the set of capabilities required for producing a given good evolves over time.

An alternative to the capabilities framework is proposed by Desmarchelier et al. (2018). They build a simulation model in which countries are made up by firms that evolve over the product space. Firms decide which goods to produce based on the size of their export market. The model succeeds at generating a number of stylized facts, namely, the increasing market shares of East Asian countries, the path dependence of countries' exports, and a decline in overlaps between East Asian economies' respective export baskets. Nonetheless, this model also presents a number of limitations. In this framework, market shares are equally distributed between firms operating in the same export market, and countries' numbers of firms are constant in size, which limits simulation of catch-up processes.

A key element toward the integration of related and less-related diversification into a single framework has been proposed recently by Pinheiro et al. (2018). They provide empirical evidence that unrelated diversification is more frequent in countries that reach intermediate levels of income per capita, while such type of diversification is rather infrequent in rich or poor countries. As already mentioned, Nelson and Pack (1999) and Hobday (1994) (among others) invoke entrepreneurship as a key factor for explaining rapid economic catch-up through relatively unrelated products. Therefore, the observation of unrelated diversification in intermediate income countries could be the result of these countries having a particularly high entrepreneurial spirit. This spirit could then diminish as their internal markets mature. A recent contribution by Reinstaller and Reschenhofer (2019) is bringing support to this hypothesis, as they find that a wider breadth of firms' technological search favors countries' propensity to develop comparative advantages in less related products.

In this context, the present paper proposes a theoretical model of countries' development over the product space based on entrepreneurship theories. In particular, we focus our attention on the technological regime literature (e.g., Nelson and Winter, 1982; Malerba and Orsenigo, 1997) and propose that the diversification trajectories of some middle-income economies into less-related goods could be the product of a difference in technological regime with the rest of the world. The model is based on firms with micro-foundations. Repeated simulations support this assumption as they show that countries governed by an entrepreneurial regime expand their export basket faster when most other countries are operating under a routinized regime. Further, we show that such catch-up trajectories over the product space are less likely when all countries operate under the same technological regime.

This paper contributes to the literature on export diversification in several ways. First, we establish a bridge between the product space literature and the concept of the technological regime. In particular, we show that changes in technological regimes can affect the shape of the product space. These regimes can thus constitute a theoretical basis for future models and conceptual works on the evolutions of the product space.

Our second contribution is a theoretical explanation of the empirical puzzle of the relatively unrelated diversification of middle-income countries. All things being equal, we find that the routinized regime is more favorable for diversification, hence the fact that most countries rely on local diversification. However, as noted by Hidalgo et al. (2007), developing countries are more involved in groups of products located at the periphery of the product space. Thus, once these countries have extended their activities to all the neighboring products, they necessarily need to aim for less-related variety to pursue their economic catch-up, in accordance with Pinheiro et al. (2018)'s observation of a relatively less related diversification of successful intermediate income countries. Our proposition is that the entrepreneurial regime is well suited to achieving this goal, but only when most other countries are operating under a routinized setting. According to our simulations, the key advantage in this case resides in the more dynamic demography of firms when the economy is entrepreneurial.

The rest of the paper is organized as follows. In Section 2, we discuss the literature on technological regimes and argue that this concept — originally proposed for characterizing industries — can be applied at the country level. We build the theoretical model in Section 3, and Section 4 is devoted to the presentation of simulation results. Section 5 concludes.

2. Linking Technological Regimes and the Product Space Literature

This section is organized in two parts. First, we highlight how the concept of technological regime enriches the discussion on countries' diversification path into more or less related products. Secondly, we bring elements in support of the application of technological regimes at the country level, since this concept is frequently used to characterize industries than countries.

2.1 Definition and relevance of the concept of technological regimes

The concept of the technological regime has been mostly used to describe how innovations take place within an industry. It was first defined by Nelson and Winter (1982) as "technicians' beliefs about what is feasible or at least worth attempting" (pp. 258–259). As defined, a technological regime is a dynamic concept, as the beliefs it refers to can change from one industry to another, as well as from one epoch to another. These beliefs condition the direction of technological progress, hence the emergence of "natural trajectories", like "the exploitation of latent economies of scale" or "mechanization" (pp. 259–260). Applied to the product space, the concept of the technological regime could explain why countries or firms choose to remain in the same location, or to re-orient their activities toward the export of a more- or less-related alternative.

Winter (1984) proposes a more operational definition of the technological regime as a way to characterize who primarily innovates in a given industry, as well as the main form of innovation, that is, radical or incremental. In reference to the traditional distinction between Schumpeter's Mark I and Mark II models (Malerba and Orsenigo, 1997), Winter distinguishes two regimes. In the "entrepreneurial regime", innovations are mainly performed by new entrants (i.e., the entrepreneurs), and they are relatively infrequent and often radical. In the "routinized regime", innovations are performed by incumbent and large firms, and they are more frequent but more incremental. With the help of a simulation model, the author finds that productivity increases faster under the routinized regime. Moreover, market shares are more concentrated under this regime. The entrepreneurial regime exhibits the opposite patterns: less stable market shares and productivity increases through irregular shocks.

Transposed onto the product space, performing a radical innovation can be compared to expanding activities into less-related goods, which is what was observed by Pinheiro et al. (2018) for some intermediate income countries. Indeed, through the building of a relatedness index these authors found that although most variety expansions occur in closely related products, in 7.2% of the cases countries develop new comparative advantages in products below the mean of relatedness of their export set. In particular, this probability is higher in middle-income countries. Through the lens of the technological regime, developed and poor countries can be mainly characterized by routinized regimes, while countries at intermediate income levels may exhibit patterns of entrepreneurial regimes.

2.2 Technological regimes at the country-level

In the literature, technological regimes have been presented mostly as industry-specific. Alternatively, we propose that they could be useful concepts at the country level. An example of the industry-specific perspective is Malerba and Orsenigo (1997), who claim that "Schumpeterian patterns of innovation are technology-specific" (p. 89). Their view is based on collecting data on innovation opportunities, appropriability conditions, cumulativeness (i.e., the extent of knowledge spill-overs), and the knowledge base (i.e., tacit or explicit knowledge sources) in the main industries of Germany, France, the UK, Italy, the USA, and Japan. Their conclusion is thus based on a set of relatively similar countries, in which many industries are already mature. Moreover, opportunity and appropriability conditions are arguably strongly determined by country-level regulations.

In Winter's model (1984), the two technological regimes were actually both applicable to the same sector, but at different stages of its development: the sector is entrepreneurial in its early stages, and then becomes a routinized regime as it matures. The same sector could be routinized in developed countries, while displaying entrepreneurial characteristics in a developing country because the sector is not yet mature in such a country.

Another argument in favor of applying technological regimes at the country level is provided by the literature on "comparative capitalism" (Deeg and Jackson, 2007), which identifies ways in which national institutions influence firms' behaviors in different countries. Taking this perspective, Baumol et al. (2007) distinguish four types of capitalism: state-guided, oligarchic, "big firm" or oligopolistic capitalism, and entrepreneurial. The main difference between the two latter varieties of capitalism resides in the characteristics of the main innovative agent: large and established companies in the oligopolistic case, and "smaller, younger firms" (pp. 86–87) in the entrepreneurial case. Clearly, these two categories of capitalism are the country equivalent of the notion of technological regime.

The literature on national innovation systems also provides numerous examples and historical accounts on the importance of institutions in shaping firms innovation behaviors and the structure of competition in national markets (Freeman, 1995; Lundvall, 2016). For instance, Mowery and Rosenberg (1993) highlight a strong bias towards military innovations in the United States' R&D efforts. Furthermore, Chesnais (1993) puts forth that the French educational system and large public R&D centers favor the emergence of an "oligopolistic core" in the country's industry (p. 192). Hobday (1995) points out the importance of institutional arrangements in the emergence of national champions in consumer electronics in East Asian economies. Examples of such arrangements include the obligation to establish joint-ventures for foreign firms wishing to run operations in the country, or the granting of subsidies to firms that reach certain export targets. These examples show that similar sectors might operate under different technological regimes in different nations.

The theoretical discussion presented in this section highlights that the notion of the technological regime can be extended to the country level and that it can be a useful concept in explaining countries' diversification trajectories over the product space. We develop this idea further in the next section by building a theoretical model of export diversification.

3. A Model of Technological Regimes over the Product Space

The model built in this section is based on elements found in Winter (1984) model of technological regimes and in Desmarchelier et al. (2018) model of export diversification over the product space. We present its building blocks , starting with the product space, followed by the behavior of the firms and the modeling of technological regimes. Micro-foundations of the behavior of the firm are based on its search for the optimal location in the product space.

3.1. The product space

In Desmarchelier et al. (2018), the product space is used as a topography for the individual firm's exploration, in a similar manner to the "sugarscape" in Epstein and Axtell's (1996) artificial societies model. The economy is populated by artificial firms that may move from one product to another over the product space. An export value is then assigned to each product while the objective of the firm is to gain the best exports. Both the product space and the export values are updated at each time step based on world trade data. We build our model on the same principles.

With the four-digit SITC Revision 2 trade data provided by the Observatory of Economic Complexity[2], we construct the product space of each year from 1995 to 2014. The product space is formed by the 771 product categories traded by the 145 countries with a population over 2 million. Following the methodology proposed by Hidalgo et al. (2007) and Hausmann et al. (2013), the product space consists of a 771×771 symmetrical matrix of proximity coefficients $\phi_{i,j}$ between all products, labeled i and j.

Let $P\left(RCA_i \geq 1/RCA_j \geq 1\right)$ be the probability that a country exhibits a comparative advantage at least equal to *1* in product i given that it already has a similar advantage in the export of product j. Then, the proximity between two products ($\phi_{i,j}$) is defined as:

$$\phi_{i,j} = \min\left[P\left(RCA_i \geq 1/RCA_j \geq 1\right), P(RCA_j \geq 1/RCA_i \geq 1)\right] \quad (1)$$

The more likely it is for a country to exhibit a comparative advantage in both goods i and j at the same time, the higher $\phi_{i,j}$. This matrix can be represented in the form of an undirected network with the products standing as its 771 nodes, and a maximum of 296,449 links among them, represented by the $\phi_{i,j}$ coefficients. The product spaces of 1995 and 2014 are displayed in Figure 1. The higher the probability $\phi_{i,j}$, the closer to each other the nodes of products i and j are. For readability, only nodes with links larger than 0.55 ($\phi_{i,j} \geq 0.55$) are displayed . This filter allows to highlight the changes affecting the core of the product space from 1995 to 2014, but a more exhaustive version of these two product spaces is presented in Appendix 1. Both product spaces in Figure 1 are displayed using the Force Atlas algorithm of the Gephi software.[3]Also, the node size is proportional to the product's degree centrality. We consider the constraint $\phi_{i,j} \geq 0.55$ only to improve the readability of Figure 1 by displaying the strongest links; however, all nodes will be included in the computer simulations presented later in the paper, regardless of their connectivity with the rest of the product space.
In Figure 1, colors stand for the one-digit SITC classification. The correspondence between colors and this classification is provided in Table 1. As in Hidalgo et al. (2007), we observe that products belonging to the same category have a tendency to cluster. For instance, in both 1995 and 2014, the core of the product space is dominated by machinery and transportation equipment (yellow) and manufactured goods (blue). However, despite this common point, the product space has evolved to some degree throughout the timespan considered. Indeed, the correlation coefficient between the weighted degree centralities of the two product spaces is of 73% (please refer to footnote 8 for the calculation of products' centralities). Example of evolution of the product space includes the yellow nodes – located at the center - which seem more closely integrated with blue and other nodes in 2014. Also, the small cluster of yellow products on the left has broken apart. These observations advocate for updating the product space at each time step of the model.

[2] https://atlas.media.mit.edu/en/resources/data/ (last access, Nov. 28, 2018).
[3] https://gephi.org/

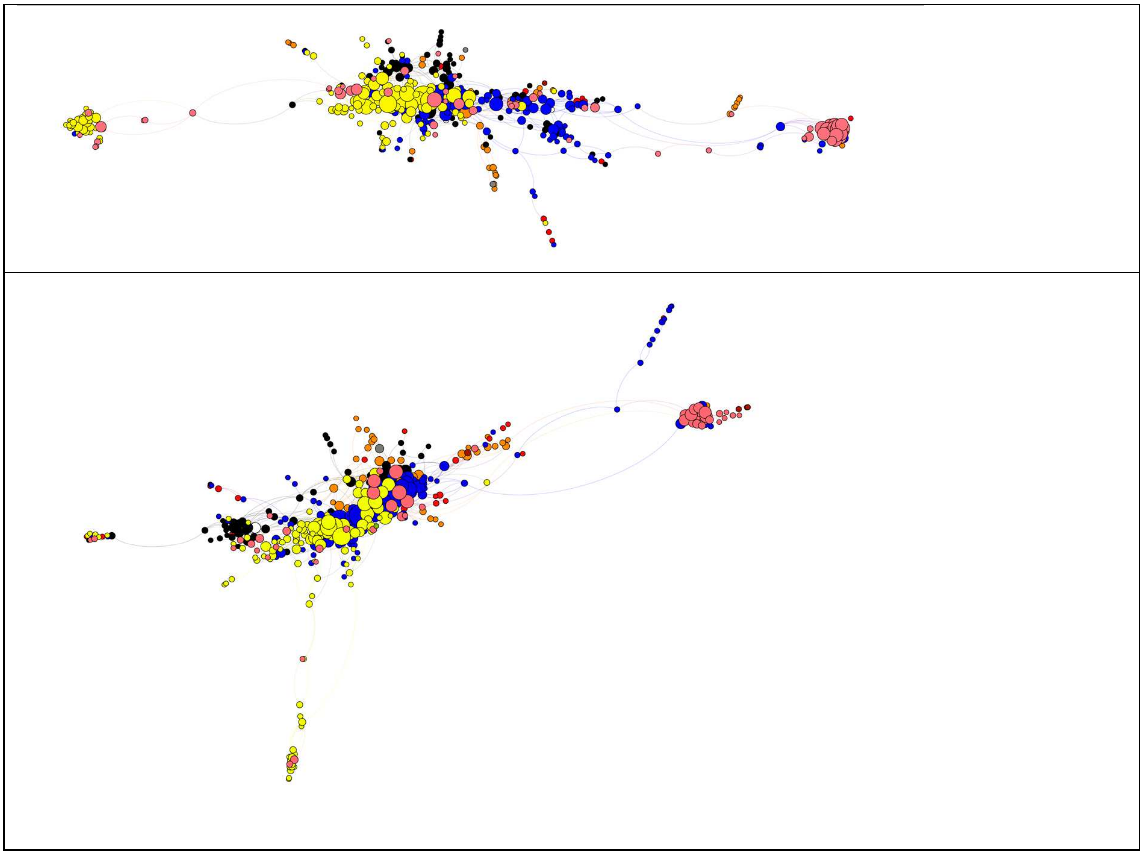

Figure 1: The product space in 1995 (upper part) and in 2014 (lower part)

Table 1: Correspondence between nodes colors and the SITC classification (Rev. 2 at one digit)[4]

Category	Color	Description	Number of Nodes (%)
0	Orange	Food and live animals chiefly for food	12.06
1	Brown	Beverages and tobacco	1.43
2	Red	Crude materials, inedible, except fuels	13.23
3	White	Mineral fuels, lubricants, and related materials	2.08
4	Gray	Animal and vegetable oils, fats and waxes	2.33
5	Black	Chemicals and related products	12.19
6	Blue	Manufactured goods	24.25
7	Yellow	Machinery and transport equipment	20.36
8	Pink	Miscellaneous manufactured articles	11.41
9	Green	Commodities and transactions not classified elsewhere in the SITC	0.65

[4] Source: https://unstats.un.org/unsd/tradekb/Knowledgebase/50262/Search-SITC-code-description (last access, Nov. 30, 2018).

3.2. Firms' and countries' initialization, and population dynamics

As in the data used for building the product space, the model comprises 145 countries. Each country c is initially endowed with $N_{c,i,t=0}$ firms producing the good i, with $N_{c,i,t=0}$ being the closest integer to Equation (2).

$$N_{c,i,t=0} = MS_{c,i,1995} \times 1000 \times \frac{\Omega_{i,1995}}{\overline{\Omega}_{1995}} \qquad (2)$$

In equation (2), $MS_{c,i,1995}$ is the market share of country c in product i computed from the SITC data in 1995 (the starting year). Likewise, $\Omega_{i,1995}$ is the real export value of good i in 1995 and $\overline{\Omega}_{1995}$ is the average export value in the same year. $\Omega_{i,t}$ values are the observed total exports of the good i in the real world at time t, in constant US dollars. We use the US GDP deflator, base 100 in 1995, to deflate nominal data. $N_{c,i,t=0}$ is thus given by the market share of the country, adjusted depending on the differences between the export value of the product and the average observed in that year. Without such adjustment, each product would have 1,000 firms and the model would initially count 771,000 firms. Actually, the model counts 768,359 firms at $t = 0$. The adjustment procedure is necessary to ensure that large export markets are populated by a number of firms which is large enough, while small markets are not overpopulated. Otherwise, such markets would play the role of giant attractors or repulsors, which could distort the model's outputs.

As in Winter (1984), firms are heterogenous in size, with firm f size determined by its respective capital stock $k_{f,t}$. Initial capital stocks are drawn from a normal distribution given by Equation (3).

$$k_{f,t=0} \sim \mathcal{N}(\overline{K}_{i,t=0}, 0.25 \times \overline{K}_{i,t=0}), \text{ with } \overline{K}_{i,t=0} = \frac{\Omega_{i,1995}}{0.16 \times 1000 \times {}^{\Omega_{i,1995}}/_{\overline{\Omega}_{1995}}} = \frac{\overline{\Omega}_{1995}}{0.16 \times 1000} \qquad (3)$$

$\overline{K}_{i,t=0}$ is the average capital stock of the firms producing the good i at time $t = 0$. Its formula ensures a zero-profit condition on average across firms when the broad depreciation rate of capital is set at 16%. Assuming a depreciation rate of capital of 5%, this is consistent with a "normal" rate of return of the firm on its capital of 11%. Indeed, with $\pi_{f,t}$ the profit of firm f at time t and $K_{i,t}$ the sum of the capital stocks of all firms involved in the market of good i — regardless of their country — then $\pi_{f,t}$ is given by the following equation:

$$\pi_{f,t} = \frac{k_{f,t}}{K_{i,t}} \times \Omega_{i,t} - 0.16 \times k_{f,t} \Leftrightarrow \pi_{f,t} = \frac{k_{f,t}}{N_{i,t} \times \overline{K}_{i,t}} \times \Omega_{i,t} - 0.16 \times k_{f,t}$$

Setting up $\pi_{f,t} = 0$ implies the following:

$$\Rightarrow \overline{K}_{i,t} = \frac{\Omega_{i,t}}{0.16 \times N_{i,t}}$$

Acknowledging that $N_{i,t} = 1000 \times \Omega_{i,1995}/\overline{\Omega}_{1995}$, we obtain the formula for $\overline{K}_{t=0}$ in Equation (3). Note that we use the same depreciation rate as in Winter (1984). Equation (3) suggests that the average capital is the same across industries.[5]

Firms reinvest all their profits exceeding the 16% depreciation rate in capital goods[6]. The most profitable firms grow faster than the others, and gain increasing market shares. At the other end, firms making losses (i.e., less than 16% return) see their capital stock decreasing. Firms with $k_{f,t}$ that falls below a certain threshold (determined at the market level, see Table 2) are going bankrupt and they are removed from the model. Thus, in contrast to Desmarchelier et al. (2018), the population of firms is dynamic in the model.

The population of firms in each country also evolves because the model includes a mechanism of entry of newly created firms. In each country, at each time step, the number of new entrants in product i - noted $X_{c,i,t}$ - is determined by a Poisson distribution such as $P\big(X_{c,i,t} = n\big) = \frac{e^{-\mu} \times \mu^n}{n!}$, with μ a function of $N_{c,i,t}$ (see Table 2 for details). This mechanism favors large economies and it implies that countries with a large number of firms in a given market will see their position becoming stronger over time in this market.

3.3. Firms' search routine

Each firm engages in a search activity with a probability $P1$. This search can be either innovative or imitative. As such, a searching firm engages in an innovative search with a probability $P2$. Imitative search thus occurs with a probability $(1 - P2)$. In line with the variety of capitalism literature, both $P1$ and $P2$ are fixed at the country level (see Table 2). In this section, i stands as the good currently exported by a firm *f*, and j will refer to an alternative good. Firms are all searching simultaneously in the model, so we do not consider cases of sequential decision-making between competing firms.

An innovative search is performed as follows. At first, the firm *f* producing good i observes the D closest goods to i in the product space. Note that a higher D parameter increases the potential for less-related diversification. Then, the firm chooses the location that maximizes its potential exports between its current location i and these D closest alternatives j as in Equation (4). The firm assesses perfectly the size of the market at time t, but it does not have information about the number of other potential entrants and their sizes. That is, the firm makes a decision assuming there will be no other entry or exit of firms, and based on past data: $K_{j,t-1}$, the total capital stock involved in the production and export of good j in $t - 1$. Finally, if an alternative j is selected, then the firm succeeds at switching its production from i to j with a probability $\phi_{i,j,t}$. This probability is the conditional probability provided by the product space of the period t.

[5] Appendix 3 shows that using the same average capital across industries is not having significant effect on the model's behavior.

[6] Included in the depreciation rate is a normal return of capital to the owner.

$$Max_{i,j}\left[\frac{\mathrm{k}_{f,t}}{K_{i,t-1}}\times\Omega_{i,t}, Max_j\left(\frac{\mathrm{k}_{f,t}}{K_{j,t-1}+\mathrm{k}_{f,t}}\times\Omega_{j,t}\right)\right] \qquad (4)$$

An imitative search also increases the potential for unrelated diversification[7]. It is meant to represent cases of technological assimilation, such as those observed in the East Asian economies during their phases of rapid catch-up (Nelson and Pack, 1999; Hobday, 1994). An imitative firm selects the good j exported by another firm selected at random among those operating in a G7 country.

If $\frac{\mathrm{k}_{f,t}}{K_{j,t-1}+\mathrm{k}_{f,t}}\times\Omega_{j,t} > \frac{\mathrm{k}_{f,t}}{K_{i,t-1}}\times\Omega_{i,t}$, then the imitator moves to the export of j with a probability $\phi_{i,j,t}$. Imitation can thus involve the export of goods that are poorly related to the country's current export basket. Note however that imitation does not necessarily imply that the country will be successful in this new product, because national firms' creations in a given market depend positively on the number of national firms already operating in this market. From that perspective, it will be difficult for a country with only one firm operating in a market to grow in this product. Also, as in Hidalgo et al. (2007), we consider that a country succeeds at exporting a product only when its comparative advantage in that good exceeds a value of 1. All these elements ensure that unrelated diversification remains an exceptional case.

3.4. Representing technological regimes

So far, we have built a model combining elements from Winter (1984) and Desmarchelier et al. (2018). We can now use it to simulate different technological regimes over the product space and observe their consequences on countries' catch-up trajectories. We simulate three scenarios: one in which all countries are characterized by a routinized regime, another one where all countries are entrepreneurial, and finally a hybrid situation in which all countries are routinized except Brazil, Russia, India, and China (referred as BRICs thereafter), which are entrepreneurial. This latter case, hereafter referred to as the "hybrid regime", thus integrates the intuition that middle-income economies are more likely than others to be entrepreneurial.

Technological regimes are represented by different values for the key parameters influencing firms' entries, exits, and innovation activities. Parameter values are detailed in Table 2.[8] Compared with the routinized configuration, in the entrepreneurial regime firms enter and leave the model more frequently. Their innovations are less frequent (lower $P1$ parameter) but potentially more radical because of a higher D parameter. Finally, regardless of the technological regime, we postulate that G7 firms are more likely to choose innovation over imitation, because they are supposed to be closer to the technological frontier.

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[7] By "unrelated," we mean "less related," that is, diversification into products with a relatively low $\phi_{i,j}$ value in the product space. In this context, unrelated diversification means that the firm is not constrained by its neighborhood.

[8] A sensitivity analysis testing for a wide array of values for parameter $P1$ is presented in Appendix 2.

Table 2: Model parameters under different technological regimes

	Routinized Regime	Entrepreneurial Regime
Search probability $P1$	$P1 = 0.3$	$P1 = 0.15$
Innovation probability $P2$	G7 countries: $P2 = 0.9$	G7 countries: $P2 = 0.9$
	Other: $P2 = 0.7$	Other: $P2 = 0.7$
Bankruptcy threshold	$0.2 \times \overline{K}_{i,t}$	$0.5 \times \overline{K}_{i,t}$
Entry parameter μ	$\mu = 0.01 \times N_{c,i,t}$	$\mu = 0.05 \times N_{c,i,t}$
Movement parameter D	$D = 5$	$D = 10$

Note: $\overline{K}_{i,t}$ is the average capital stock of the firms producing the good i at time t. $N_{c,i,t}$ is the number of firms in country c that are exporting product i at time t.

In summary, the model combines the parameters calibrated in Table 2, data from the real world and simulated outputs. Data from the real-world are the following:

- $MS_{c,i,1995}$, the market share of a country *c* in product *i* in *1995*.
- $\Omega_{i,t}$, the export value – or the size of the exports market - of the product *i* at time *t*.
- $\phi_{i,j,t}$, the proximity coefficient between products *i* and *j* at time *t*.

Concretely, product spaces ($\phi_{i,j,t}$) and export values ($\Omega_{i,t}$) are stored in 20 files, one per year from 1995 to 2014. At the beginning of each time step, all $\phi_{i,j,t}$ and $\Omega_{i,t}$ are cleared from the random access memory of the computer, and the new values are loaded from these files before the agents of the model make any decision.

All other variables at the country level and at the product level are simulated outputs. These include $MS_{c,i,t}$ (for $t > 1995$), as well as the number of firms, the capital stock per country or per export market, and the intensity of competition in each of the 771 markets.

4. Simulation Results

This section is divided into three parts. First, we assess the ability of the model to produce realistic results. Then, we verify if the simulations' outputs are coherent with the technological regimes literature. Finally, we focus our attention on the catch-up process. In particular, we assess if the hybrid regime provides BRIC countries with a competitive advantage. Each of the simulated scenario is repeated 30 times with different seeds for computing random draws. Further, simulations run 20 time steps, one time-step per year from 1995 to 2014.

4.1. Relevance of model assumptions

Prior to detailing the model's behavior under the three technological regimes, we propose an initial assessment of its validity using real data. The objective is to verify if the simplifications from our assumptions do not generate unrealistic outcomes. Figure 2 compares countries' simulated exports in time step 20 in the three regimes with countries' exports observed in the empirical data in 2014. To recall, the model has been initialized with real-world data in 1995 and then it ran freely during 20 time steps. The results suggest a good match in all technological regimes, except that simulated exports tend to be lower than real ones for the largest exporters.

It could be argued that such a good match is due to the use of real export data ($\Omega_{i,t}$) for the products. Using these data undeniably provides conditions for respecting the scale of values of world trade. However, firms are autonomous in the model, and as such, they constantly change their exported products. Also, there are many firms' entries and exits in the model. It follows that letting the model run for 20 time steps could have produced important deviations from the 45°-line, despite respecting the scale of economic activity overall. In terms of countries' export variety, that is, the number of products in which countries exhibit revealed comparative advantages higher or equal to 1, we observe an overall correspondence between empirical and simulated values. In this case, the entrepreneurial regime produces values that are generally lower than real-world data, while the routinized regime tends to produce larger ones.

Another way to assess the relevance of the model is to make the product space endogenous and to compare the simulated spaces with the real ones. In this experiment, we proceed as follows. First, the product space for 1995 is loaded for initializing the model. Then, instead of loading the subsequent real-world product spaces sequentially, the $\phi_{i,j,t}$ coefficients are updated within the model at the end of each time step according to the evolution of countries' simulated revealed comparative advantages. The corresponding distributions of weighted degree centralities among the 771 products are provided in Figure 3[9]. It appears that the centrality values are more concentrated around the average under the routinized regime than the entrepreneurial case. This observation suggests that firms find it easier to create new products in the routinized scenario. While a Kolmogorov-Smirnov test indicates that simulated distributions are different to the real one in 2014[10], they remain plausible, especially because the real distribution is between those produced by the three regimes. Overall, this observation is supporting the idea that technological regimes can influence on the shape of the product space.

Having shown that the model is producing plausible results, we now move to the assessment of its capacity to account for different technological regimes.

[9] The degree centrality of a node is the total number of links that connect it with the other nodes of the network. In this paper, we use the proximity coefficients $\phi_{i,j}$ as weights in the computation of this centrality measure. Following the formula proposed by Opsahl et al. (2010), the weighted centrality C_i^{α} of a product i is computed as follows:

$$C_i^{\alpha} = \sum_{j \neq i} \left(k_{i,j,}^{1-\alpha} \times \left(\phi_{i,j} \right)^{\alpha} \right)$$

In this equation, $k_{i,j}$ is a link between products i and j, and α is a tuning parameter. The higher this parameter, the higher the importance of $\phi_{i,j}$ over $k_{i,j}$. In this paper, we used $\alpha = 0.5$.

[10] The maximum distance statistic between the distribution in the entrepreneurial case and the one in 2014 is $D = 0.2179$. Distance between the distribution in the routinized regime and the one in 2014 is $D = 0.1933$, and it is $D = 0.076$ in the case of the hybrid regime. In all three cases, the Kolmogorov-Smirnov test concludes a significant difference with real data in 2014 with a P-values lower than 0.05.

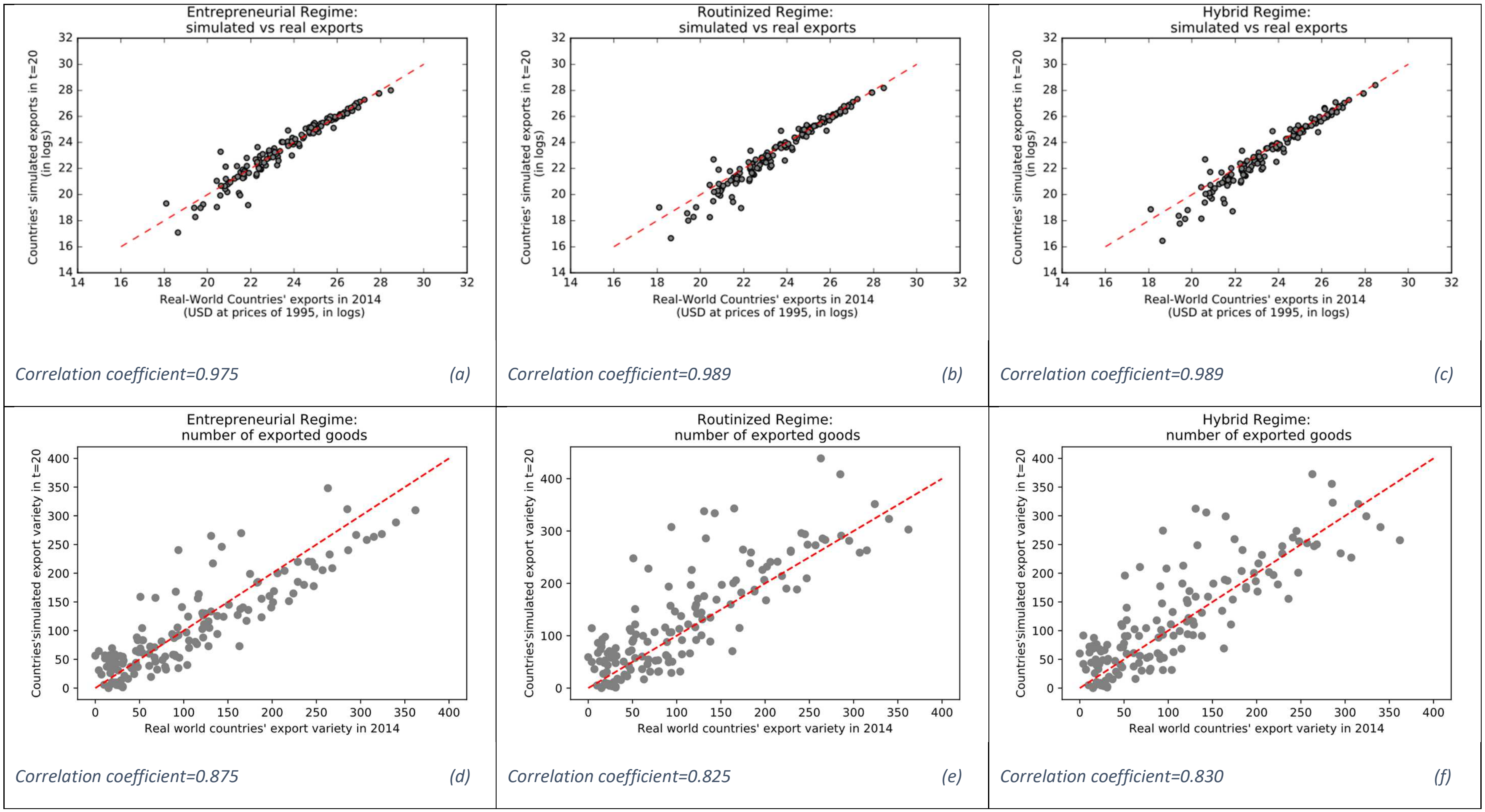


Figure 2: Comparison between simulated values (av. over 30 simulations) and real ones in 2014 for countries' exports and export variety. Dashed lines stand for the 45° line

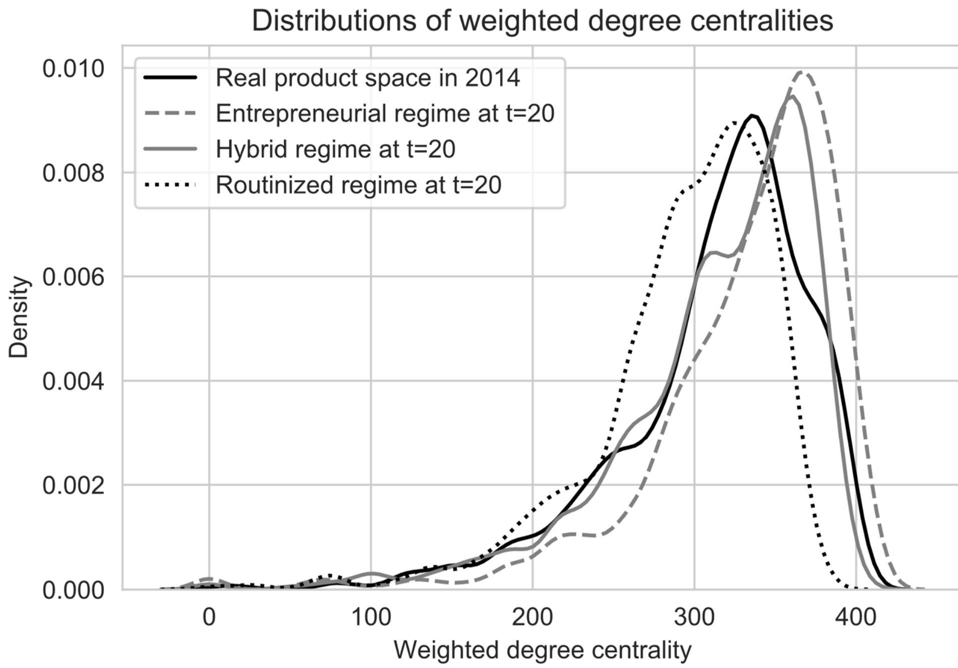


Figure 3: Distributions of weighted degree centralities of simulated product spaces and the real one in 2014

4.2. Simulation of technological regimes

Table 3 compares the input data at $t = 1$ with the variables generated by the model at the country level at $t = 20$ in the three technological regimes. All three regimes produce economic growth, since the average number of firms per country, the average number of exported goods, the average capital stock, the average total exports, and countries' exports-to-capital ratio, are higher in $t = 20$ than in $t = 1$.

It appears that countries' populations of firms grow faster in the entrepreneurial regime. Indeed, the average country has 7997 firms when $t = 20$ in this configuration, against 6013 in the routinized regime, and 6347 in the hybrid regime. Hence, easier entry conditions overcome the large number of bankruptcies under this regime. It can be noted however that the standard deviation across countries increases through time in all regimes, which suggests that lagging economies are having difficulties to catch up the leading ones, particularly under the entrepreneurial setting. Similarly, differences between countries in terms of total exports increase over time in all technological regimes, especially in the hybrid regime – which has to be expected because we introduced differences between countries in this regime.

Table 3: Descriptive statistics across countries in the model

	Nb. of firms				Nb. of exported goods				Capital Stock (in billion USD of 1995)			
	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)
Mean	5299.02	7997.88	6013.92	6347.53	92.68	106.48	131.76	122.14	534.00	648.00	562.00	575.00
St. dev.	12109.08	17176.99	13665.49	15199.27	88.69	79.09	100.29	90.47	1230.00	1340.00	1280.00	1410.00
Median	666	1120.3	800.6	793.13	56.27	83.33	102.37	92.87	64.80	105.00	77.50	74.00
Kurtosis	22.42	19.56	22.29	30.92	-0.12	0.01	-0.25	-0.45	22.76	18.65	23.62	36.21
Skewness	4.36	4.08	4.35	4.97	0.97	0.87	0.77	0.71	4.39	3.97	4.44	5.32

	Total Exports (in billion USD of 1995)				Exports to capital ratio			
	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)
Mean	41.60	102.00	100.00	101.00	0.077	0.156	0.178	0.174
St. dev.	104.00	210.00	229.00	247.00	0.021	0.015	0.015	0.015
Median	4.60	18.50	14.00	12.60	0.081	0.156	0.179	0.174
Kurtosis	26.28	18.99	24.43	36.94	0.54	79.98	119.89	117.18
Skewness	4.74	3.99	4.50	5.37	-0.59	-7.69	-10.44	-10.25

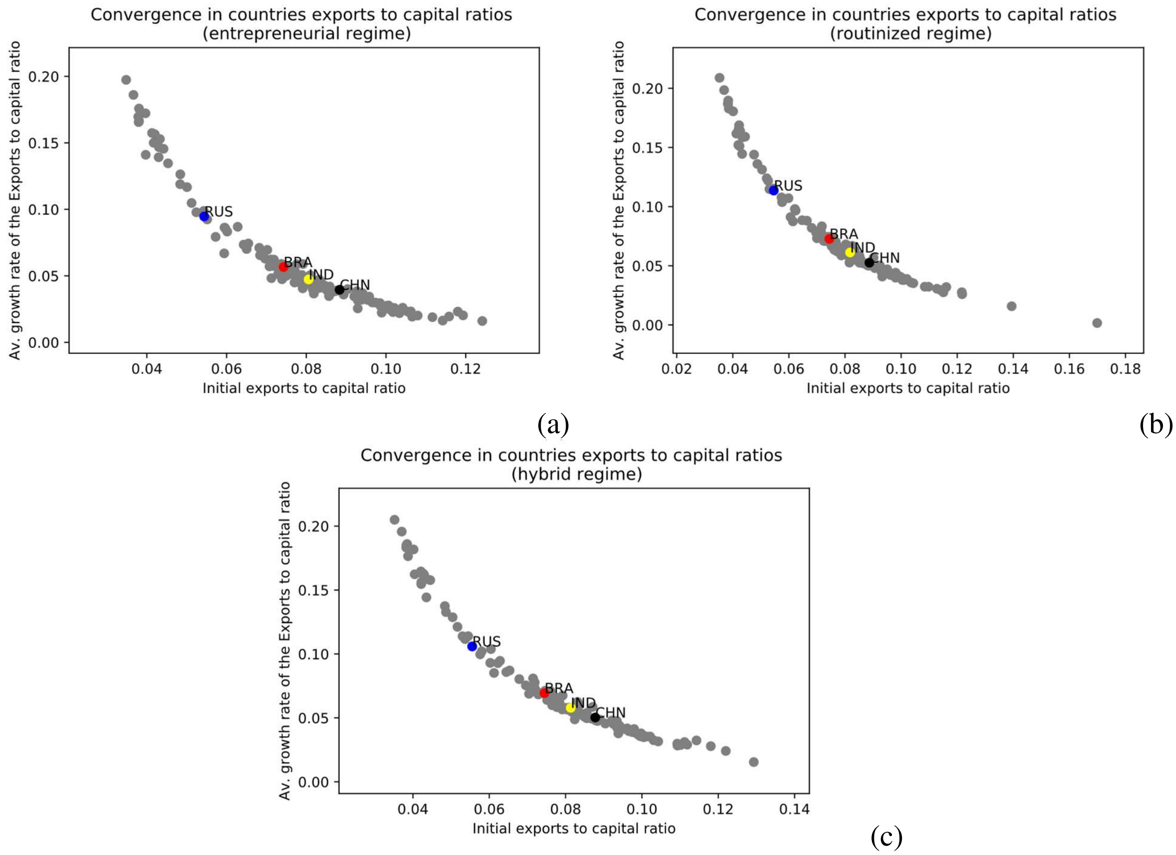
As in Hidalgo et al. (2007), we measure countries' export variety by counting the number of products in which they have a revealed comparative advantage higher or equal to 1. Surprisingly, Table 3 shows that the larger number of firms under the entrepreneurial regime does not imply a larger basket of exported goods. Indeed, while all three regimes begin with the same export variety, at around 92 products per country on average, the routinized regime generates an average variety of 131.76 products in time step 20 against 106.48 and 122.14 products under the entrepreneurial and hybrid settings, respectively. We explain this result as follows: under the entrepreneurial regime, firms are more inclined to develop activities in unrelated diversity, but developing advantages in such products is difficult as they remain out of reach for most of the other firms operating in the country. It is thus relatively harder for countries to develop new comparative advantages in the entrepreneurial regime. Besides, the routinized regime generates the highest exports to capital ratio at t=20. Therefore, as in Winter (1984), this regime may seem more favorable to long-term economic growth. Note however that the routinized regime also exhibits the lowest average capital stock, and the lowest average total exports at $t = 20$.

Absolute inequalities between countries remain or even deepen throughout simulation runs, as standard deviation and skewness coefficients remain particularly high in all cases. However, in per unit of capital terms, convergence is taking place, since exports-to-capital ratios display a lower standard deviation and a higher negative skewness at t=20 in all technological regimes (Table 3). This convergence is illustrated in Figure 4, in which we observe that, in all technological regimes, countries with the lower exports-to-capital ratios at t=1 are those with the highest average growth rate of this ratio in subsequent periods. The Appendix 3 highlights that this convergence is driven by firms' accumulation of capital and by their search for profitable exports.

In Winter (1984), the key results in terms of characterizing the technological regimes were that both productivity growth and market concentration are higher under the routinized regime. In our model, we can use the ratio of exports-to-capital at the country level as a proxy for productivity (per unit of capital). Table 3 shows that, as in Winter (1984), productivity grows faster under the routinized regime, since the mean exports to capital ratio is the highest in this configuration.

Market concentration is assessed in Table 4, which shows the evolution of the number of firms and of the capital stock per product, as well as the Herfindahl-Hirschman index (HHI) per product. In line with Winter (1984), we find that, in our model, the routinized regime generates increasingly concentrated markets, as it is the only technological regime in which the HHI is, on average, higher at $t = 20$ than at $t = 1$. On the other hand, the entrepreneurial configuration produces more competitive markets.

Table 4 shows that the entrepreneurial regime is the one in which products are on average exported by the highest number of firms, and using the highest capital stock. While we found in Table 3 that absolute differences across countries are persistent, there is a tendency towards equalization of the capital stock across products, since the standard deviation and skewness of its distribution are lower at $t = 20$ than in $t = 1$ in all technological regimes. Equalization can be explained by the equation (4), which makes all products substitutable for firms: if one product is more attractive than another, then firms will try to reach it. Thus, for a sufficiently long-time horizon, we can expect markets to reach relatively equal exports-to-capital ratios. Factors that prevent this situation from happening are the different $\phi_{i,j,t}$ coefficients between products, firms' limited information - that is firms' D parameter - as well as the constant updating of $\Omega_{i,t}$ values.



(a) (b) (c)

Figure 4: Convergence in the three technological regimes

Table 4: Descriptive statistics across products in the model

	Nb. of firms				Capital stock (in billion USD of 1995)				HHI			
	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)	in t=1	Entrepreneurial Regime (t=20)	Routinized Regime (t=20)	Hybrid regime (t=20)
Mean	996.57	1504.14	1131.02	1193.76	110	126	106	110	0.015	0.012	0.017	0.014
St. dev.	3412.77	4126.30	3238.89	3317.19	392	362	328	331	0.067	0.043	0.063	0.051
Median	364	556.37	403.83	429.07	36.5	45.3	35.1	37.7	0.0027	0.0020	0.003	0.003
Kurtosis	285.36	148.38	179.88	167.67	280.61	201.94	226.28	222.06	133.14	105.31	86.86	114.91
Skewness	14.95	10.53	11.54	11.12	14.80	12.12	12.93	12.79	10.73	9.17	8.48	9.50

In summary, the technological regimes in the model are producing results which are consistent with Winter (1984). As such, most outputs of the model give an advantage to the routinized regime, that is, the regime of incremental, highly related, innovations. This conclusion makes Pinheiro et al.'s (2018) findings puzzling. Indeed, if highly related diversification brings higher growth, then what advantage could intermediate income economies find in diversifying into relatively unrelated products? In the next section, we tackle this question by studying entrepreneurial countries' catch-up processes when all other countries are routinized. So far, the hybrid regime brings results in between those of the two archetypal technological regimes. In the next section, we isolate the BRIC countries and the G7 countries to assess the consequences of this dual configuration for these countries.

4.3. The hybrid regime and its consequences for BRICs and G7 countries

A reason for the long-lasting absolute difference in terms of export variety between economies can be found in our hypothesis that, for a country, firms' entries in a given market are a positive function of the number of national firms already operating in that market. As we observed that populations of firms are growing faster under the entrepreneurial regime than in the routinized regime, we postulate that intermediate economies could catch up the leading ones while being entrepreneurial when all other economies (i.e., both the poorest and the richest) are operating under the routinized regime. This intuition needs to be tested, because countries need to have a critical number of firms operating in a given market for exhibiting a comparative advantage. Table 3 already presented outcomes of the hybrid regime for all countries. In this section, we concentrate the analysis on the BRIC countries – i.e. the only entrepreneurial economies in the hybrid setting – and the G7 countries, which are the main targets of firms' imitation strategies in the model.

Figure 5 displays the differences between the hybrid regime and the entrepreneurial regime (left panels) and between the hybrid and the routinized regimes (right panels) for the BRIC countries. Figure 6 provides the same information for the G7. In these figures, positive numbers indicate that the hybrid regime outperforms, while negative numbers reveal its underperformance compared with the entrepreneurial or routinized regimes. Interestingly, Figures 5 (a) and (b) reveal that the BRICs see their populations of firms growing faster in the hybrid setting. For instance, China has on average 8,000 more firms at $t = 20$ than in the entrepreneurial regime (a) and 25,000 more firms than in the routinized regime (b). Being the sole entrepreneurs is thus bringing a clear demographic advantage. Developing a comparative advantage in a new product requires a critical mass of companies exporting this product. We have seen that such a critical mass is easier to achieve in goods that are closely related to the country's exports basket, but the scale of the demographic advantage offered to the BRICs by the hybrid regime should allow them to over-perform both the entrepreneurial and the routinized regime in terms of exports variety. This is what is observed for China and Russia (Figure 5 c and d). However, Brazil exports around 30 products less at $t = 20$ than in the routinized setting, and India does not benefit from the hybrid regime until $t = 12$ (d). We explain this difficulty by the fact that, in the model, the demographic advantage of these two countries is too weak in front of routinized competitors.

Figure 5 (e) shows that all four countries succeed at getting higher exports to capital ratios in the hybrid regime than in the entrepreneurial regime. However, all countries under-perform compared with the routinized regime (Figure 5 f). Thus, a large export basket does not imply larger exports to capital ratios. To explain this under-performance, we compute the average growth rates of countries' capital stock and exports in Table 5. We observe that, in all four countries, exports are growing the fastest in the hybrid regime. This is also the only regime in which the BRIC countries see their exports grow faster than world exports. The growth of BRIC countries' capital stock is also the highest in the hybrid regime. In Table 5, it becomes evident that the decline of the exports to capital ratio of these countries in the hybrid regime compared with the routinized setting is above all the result of a particularly slow capital accumulation in the routinized version of the model.

Figure 6 and Table 5 reveal the consequences of the hybrid regime for the competing economies. To recall, in this setting, G7 economies are routinized. Given the demographic advantage of operating under an entrepreneurial setting, it is no surprise that G7 countries are losing firms compared with the entrepreneurial regime (Figure 6 a). Accordingly, they are nearly unaffected compared with the routinized situation (b). Sharper dynamics emerge when we look at countries' exports variety. Indeed, most of G7 members are exporting a lower variety of products in the hybrid regime compared with both the entrepreneurial (c) and routinized (d) situations. The higher competition created by entrepreneurial economies is thus costly for the routinized ones. Besides, the hybrid regime produces a lower growth rate of exports, and even a negative growth rate of capital stock- in G7 economies in the model (Table 5). The consequence is a lower exports-to-capital ratio compared with the routinized setting (Figure 6 f).

In summary, we first established that the routinized regime generally outperforms the entrepreneurial regime. This result is consistent with the empirical observation that most countries expand their export varieties into closely related products. Then, we have found that the entrepreneurial regime can foster countries' catching-up process if most other countries remain routinized. This suggests that some developing countries succeed at developing comparative advantages in relatively less related products because they are entrepreneurial, while the rest of the world find it beneficial to be routinized. Finally, we find that the leading routinized economies are suffering from this entrepreneurial competition. Differences of technological regimes between countries could thus be a driver of commercial tensions.

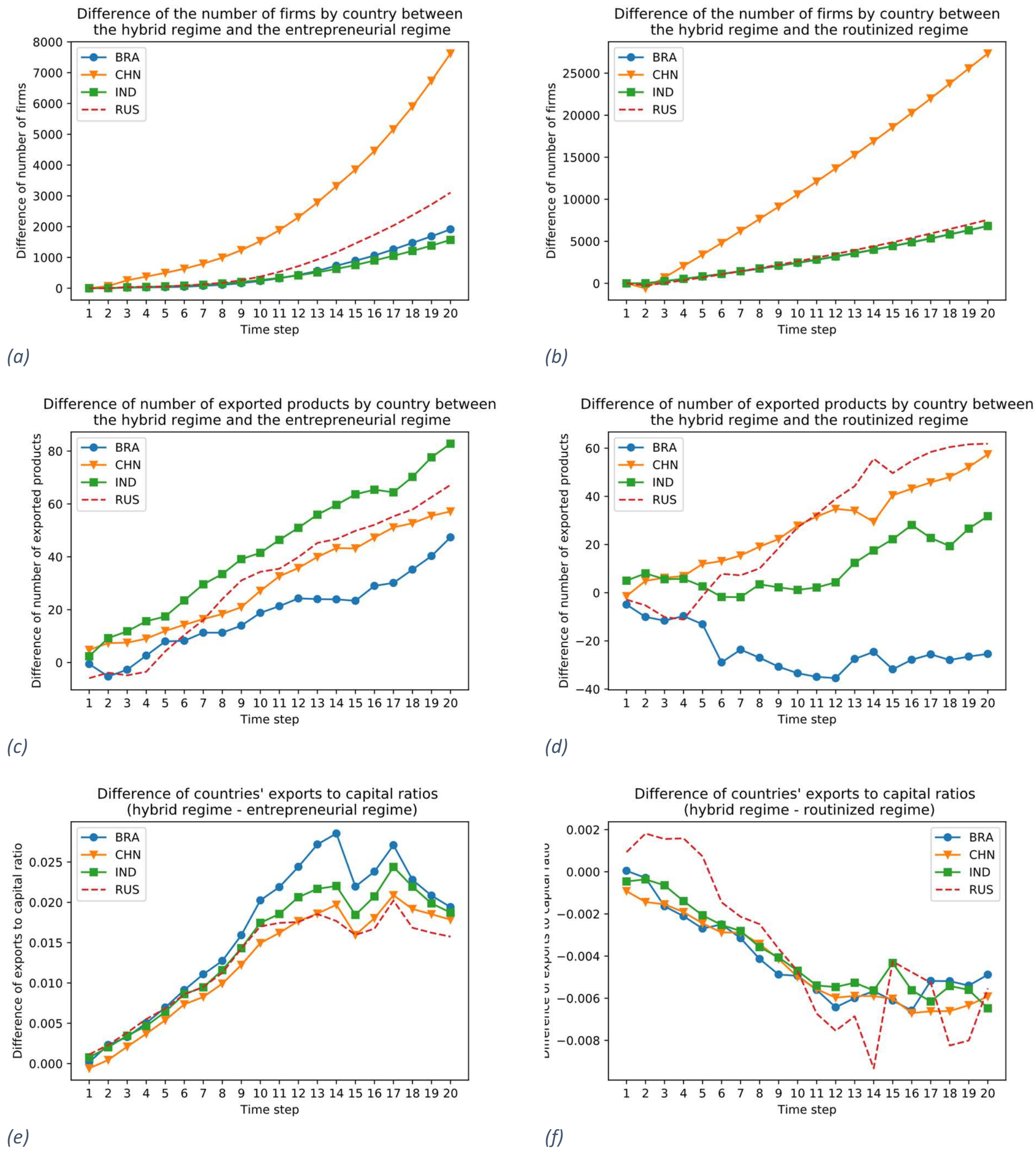
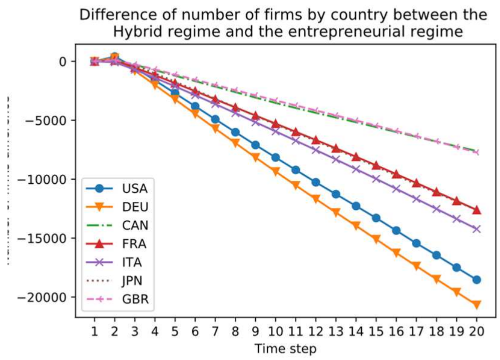
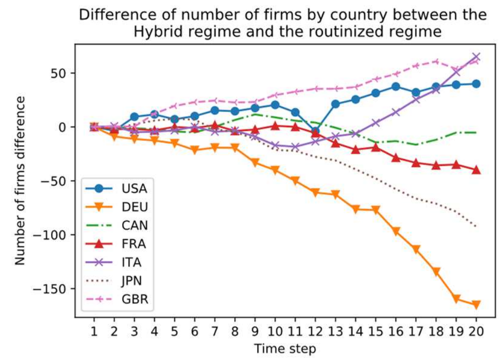


Figure 5: Effect of the hybrid regime on BRICs' numbers of firms, export variety, and exports to capital ratio.



(a)



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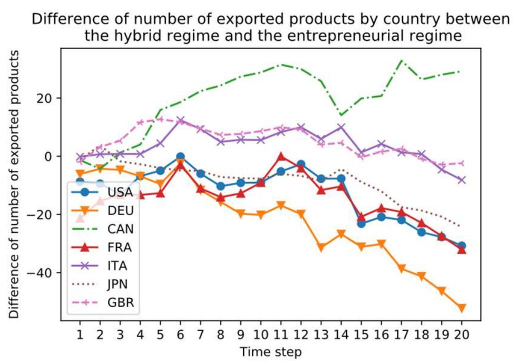

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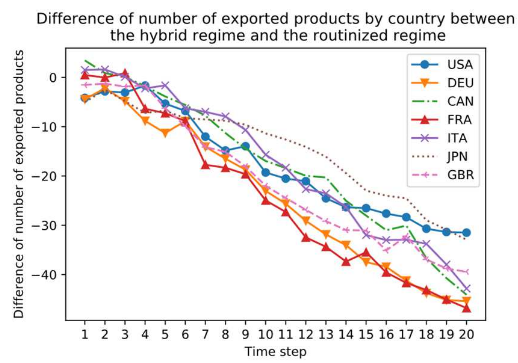

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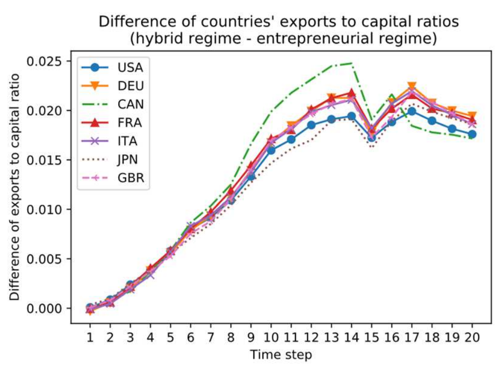
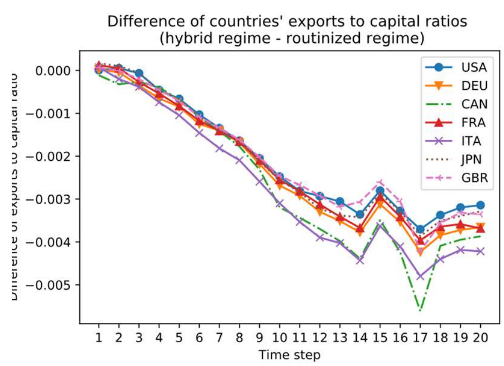


(e)



(f)

Figure 6: Effect of the hybrid regime on G7 countries' numbers of firms, export variety, capital stock and exports value.

Table 5: Average yearly growth rates of BRICs and G7 countries in different technological regimes

	Growth rate of exports (%)			Growth rate of capital stock (%)		
	Entrepreneurial regime	Routinized regime	Hybrid regime	Entrepreneurial regime	Routinized regime	Hybrid regime
Brazil	8.7336	8.4367	17.0884	1.4431	0.4744	4.2525
China	4.2574	5.9918	8.8785	0.1714	0.3579	1.9203
India	7.6741	6.8553	14.4347	1.5142	0.329	4.0076
Russia	10.2909	12.121	17.6376	0.2846	0.2319	2.2611
United States	5.2652	5.8976	5.2181	0.532	0.1881	-0.047
Germany	4.9757	5.7482	4.9512	0.3518	0.0000	-0.275
Canada	8.2441	8.4886	7.4465	0.8635	0.2686	-0.039
France	6.4298	6.3247	5.5045	1.0323	0.2057	-0.062
Italy	6.7911	5.4596	4.6189	1.655	0.1295	-0.164
Japan	5.0066	5.4969	4.7626	0.6325	0.189	-0.073
United Kingdom	6.5981	6.8554	6.11	0.7109	0.1168	-0.108
World	7.2142	7.0682598	7.0956	1.0699	0.2645	0.3906

5. Conclusion

This paper proposes a theoretical model to account for countries' exports diversification. In contrast to the resource-based perspective adopted by existing models in the literature (Hausmann and Hidalgo, 2011; Neffke et al., 2018), our framework is grounded in entrepreneurship theory. Drawing on Winter's (1984) model of technological regimes, we postulate that export diversification is the consequence of specific businesses' strategies, namely, more or less radical innovation and imitation.

Simulations show that countries are in general more successful at diversifying their exports when their businesses innovate in a routinized manner, that is, when their product innovations are frequent and incremental, hence highly related to existing products. This is coherent with most observations that countries expand their activities over the product space through highly related products (Hidalgo et al., 2007). However, this strategy can hamper the economic development of countries if they are mostly involved into the export of products that are isolated at the periphery of the product space. In this situation, the escape solution consists of developing activities into more unrelated products. Such a trajectory is documented in Pinheiro et al. (2018), who find that successful catch-ups of middle-income economies involve the export of new and poorly related products. Our model offers a potential explanation of how this occurs by exploring the implications of the entrepreneurial regime (Winter, 1984) in terms of the diversification trajectory over the product space. This regime is characterized by a more dynamic demography of firms, and by more radical, but less frequent, innovations.

The entrepreneurial regime provides firms with more opportunities to explore less-related products than the routinized regime does. However, we find that the entrepreneurial regime does not necessarily favor product diversification, because it makes it more difficult for countries to obtain a critical mass of firms operating in new — and poorly related — markets. Interestingly, the entrepreneurial regime favors product diversification in a hybrid situation in which most other countries remain routinized. To put it another way, entering into new and less-related markets would require countries to adopt an outlier strategy.

Hausmann and Rodrik (2003) also emphasize the importance of entrepreneurship in the discovery and learning of "what one is good at producing" (p. 605). In their view, such a discovery is an episodic, almost random event because, especially in developing countries, a poor legal environment makes it easy to copy the discovery at lower cost. It is thus important for governments to act as a rent provider in order to encourage entrepreneurial behaviors. Government is at best an exogenous variable in the framework that we are sketching in this paper, but it can be an important reason for the emergence of an entrepreneurial regime in countries that otherwise would remain locked into undesirable areas of the product space. The structural reforms initiated by China since the 1970s, with a mixture of liberalization and protection, in particular in favor of technology transfers to national firms, may be the most emblematic of such policies applied by the four BRIC countries in terms of the emergence of a dynamic entrepreneurial environment.

On a more general perspective, the product space remains primarily an empirical construct. As such, theoretical foundations and models are necessary to understand its evolutions and their implications for countries' development. The present paper suggests that technological regimes are a candidate framework, as endogenizing the product space did generate plausible degree distributions in our simulation experiments. The concept fo technological regime nonetheless encounters important limitations. Indeed, the question of either technological regimes are country-specific or industry-specific is still debatable, and there is – to our knowledge – still no accepted theory of countries or industries transition from one regime to another. We believe that further developments in that direction would prove valuable to the building of theoretical foundations to the product space.

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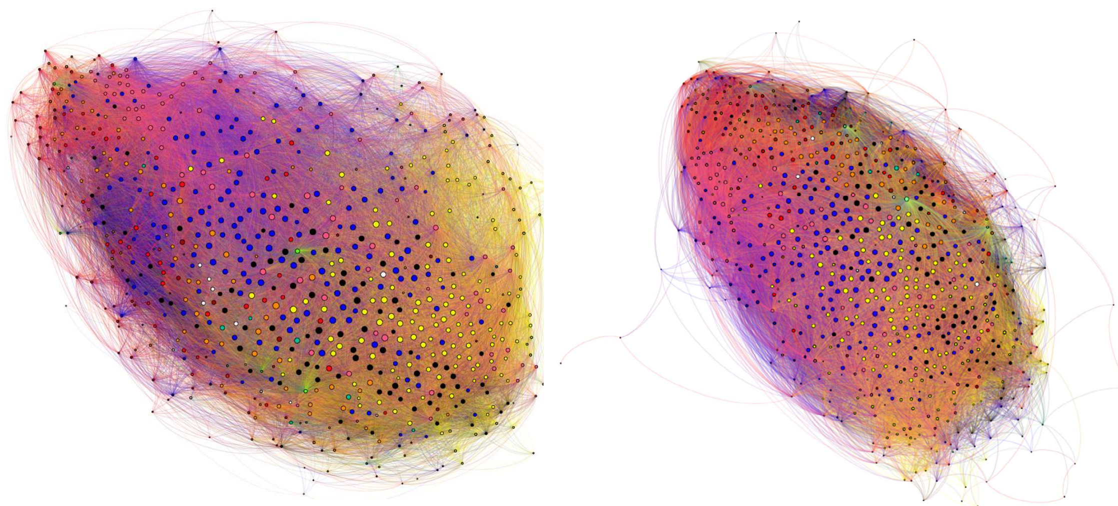
Appendix 1

Figure 7 presents the product spaces in 1995 and in 2014 when keeping all links such as $\phi_{i,j} \geq 0.25$. Like in Figure 1, products belonging to the same category/ color tend to cluster. However changes affecting the product space are harder to grasp than in Figure 1, where a tighter filtering of links is applied.



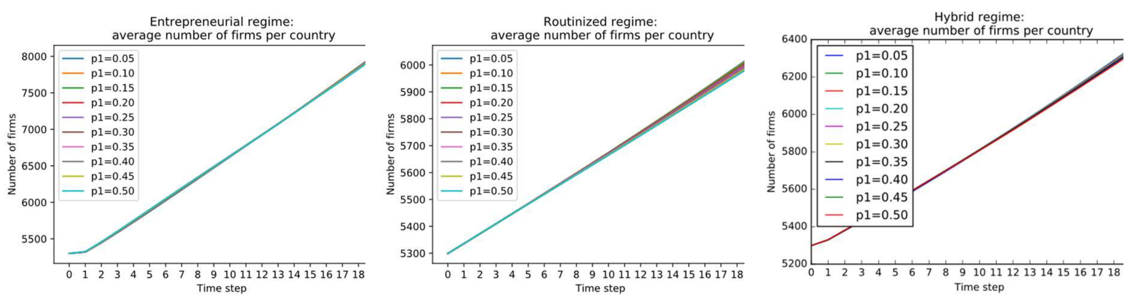
(a) (b)

Figure 7: The product space in 1995 (a) and in 2014 (b), using all links such as $\phi_{i,j} \geq 0.25$

Appendix 2

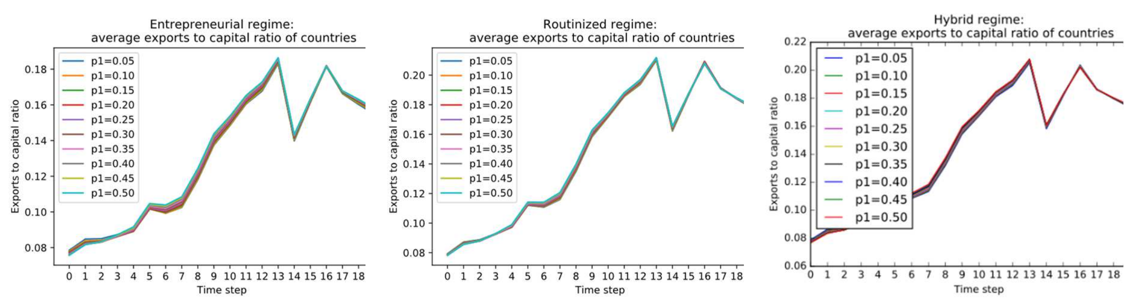
The results reported in the core of the paper about the three technological regimes show that the model's behavior is not erratic when its key parameters are modified. To further test for the model's robustness, we run it with 10 different values of $P1$, the parameter controlling the probability of firms' search, such as $P1 \in [0.05, 0.50]$. This experiment is conducted in all three technological regimes configurations. All Figures in this appendix are averages over 30 simulation runs, each performed using a different seed for computing random draws.

Figures 8 and 9 reveal that changing the value of $P1$ does not affect significantly the average number of firms per country, nor does it influence the average exports to capital ratio. Hence, conclusions of the paper regarding these two variables are supported: the number of firms is growing faster in the entrepreneurial regime, while the routinized regime presents an advantage in terms of exports per unit of capital.



(a) *(b)* *(c)*

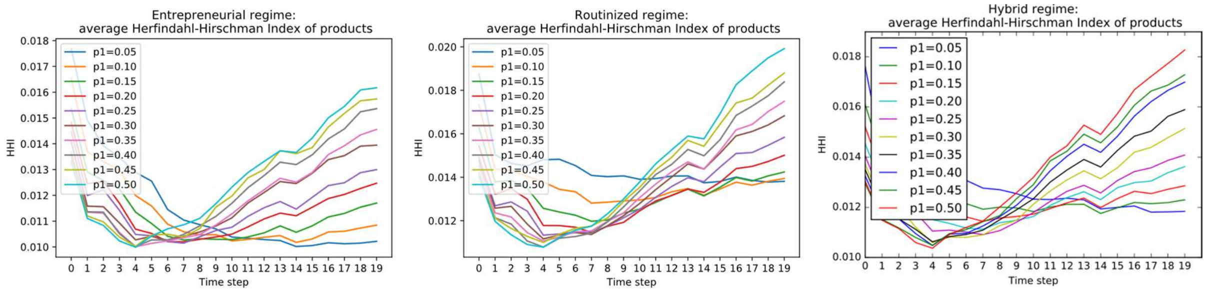
Figure 8: Effect of P1 on the average number of firms per country



(a) (b) (c)

Figure 9: Effect of P1 on the average exports to capital ratio

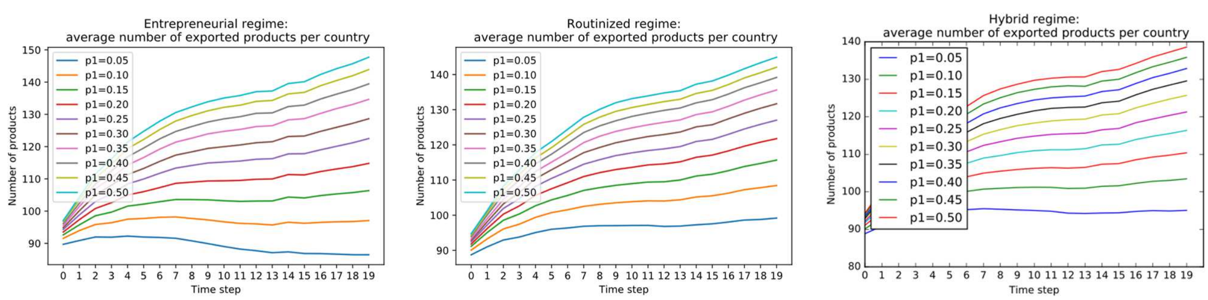
Increasing firms' search probability has a sharp effect on the Herfindahl-Hirschmann index (HHI) as shown in Figure 10. We observe two phases: a decline of the HHI – i.e. an increase in competition – during the first time steps of the model, and then a tendency of increasing market concentration. For a given value of $P1$, this concentration is more pronounced in the routinized regime than in the other two regimes. In this respect, the entrepreneurial setting is the configuration that exhibits the highest levels of competition. The present sensitivity analysis reveals that the parameter $P1$ is having an important influence on these dynamics: the higher it is, the higher the market concentration at $t = 20$.



(a) (b) (c)

Figure 10: Effect of P1 on the average Herfindhal-Hirschmann index (computed over all markets in the model)

Regarding countries' export varieties, the core of the paper revealed an advantage for the routinized regime. More frequent incremental movements of firms over the product space make it easier for a country to build new competitive advantages. Figure 11 mostly supports this conclusion. It shows that increasing firms' search probability ($P1$) increases countries' average export basket in the three technological regimes. The routinized regime exhibits the highest varieties for the lower values of $P1$, but increasing $P1$ erodes this advantage, such that the routinized regime becomes slightly outperformed by the entrepreneurial one for $P1 \geq 0.4$. Note however that performing radical innovation so frequently is certainly not a realistic situation.



(a) (b) (c)

Figure 11: Effect of P1 on the average export variety of countries

Overall, we can say that this complementary analysis suggests that the model is robust to changes in parameters' values.

Appendix 3

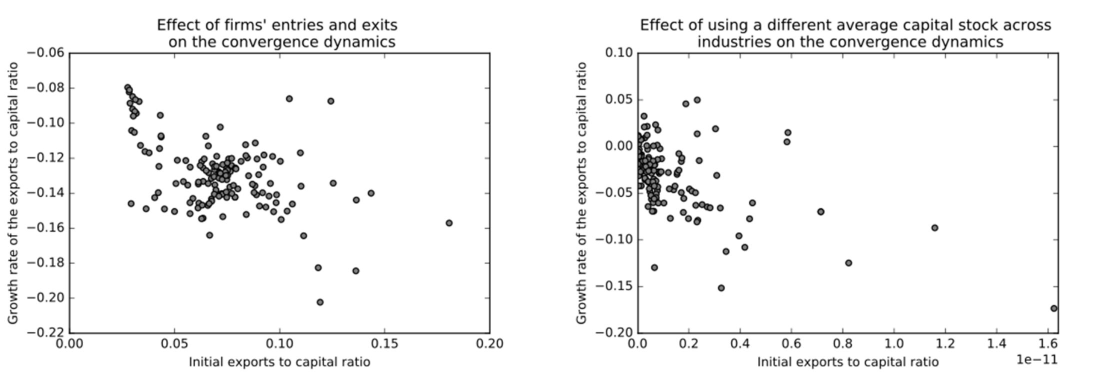
This appendix aims at exploring the drivers of the convergence dynamics displayed in the Figure 4 of the main text.

We can summarize the model into three building blocks:

- Firms' entries and exits from the model
- Firms' capital accumulation process
- Firms' search algorithm

To test the effect of each block on countries' convergence, we abandon the updating of the product space and of products' export values. Also, we deactivate all three blocks. Running the model in these conditions does not produce any dynamics: the numbers of firms and of exported goods per countries remain constant, so is their exports to capital ratio.

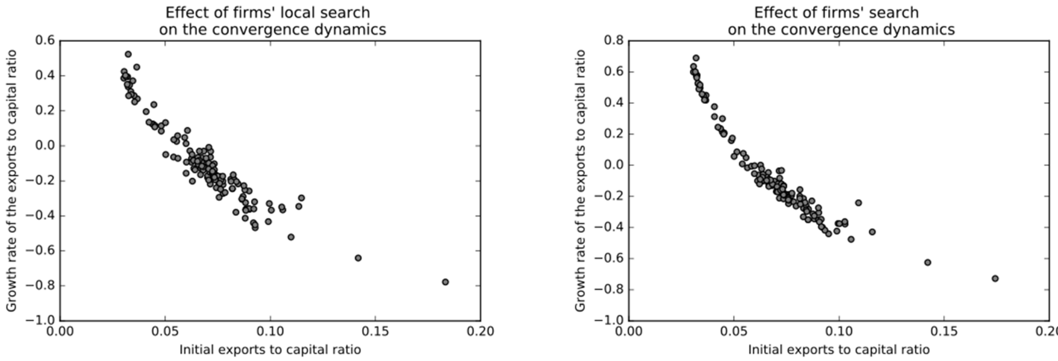
Figures 12 (a) and (b) present the convergence pattern that emerges when firms' entries and exits have been reactivated. In Figure 12 (a), like in Equation (3), $\overline{K}_{i,t=0} = \frac{\overline{\Omega}_{1995}}{0.16\times1000}$, while in Figure 12 (b), $\overline{K}_{i,t=0} = \frac{\Omega_{i,1995}}{0.16\times1000}$. Therefore, the average capital stock is heterogeneous across sectors in the scenario depicted in Figure (b), while it is homogenous in Figure (a). These figures reveal that dynamic populations of firms allow for evolving exports and capital stocks at the country level, but without producing convergence. Besides, Figure 12 (b) reveals that the convergence in Figure 4 is not the product of the hypothesis of homogeneous average initial capital stock across sectors.



(a) (b)

Figure 12: Effect of firms' entries and exits on the convergence of countries' exports to capital ratio, when (a) $\overline{K}_{i,t=0}$ is homogenous across sectors, (b) $\overline{K}_{i,t=0}$ is heterogeneous across sectors.

Figures 13 (a) and (b) show the effect of firms' searches on the emergence of convergence across countries: allowing firms to search for better locations over the product space seems a sufficient condition for convergence, even when searches are occurring only locally, that is without imitation (Figure 13a). As might have been expected, the convergence pattern looks stronger when firms are allowed to perform imitative search (Figure 13b). Finally, Figure 14 reveals that capital accumulation is a strong driver of convergence. We thus conclude that the convergence in the model is due to firms' search behaviors and to capital accumulation.



(a) (b)

Figure 13: Effect of firms' search behavior on the convergence dynamics across countries. (a) Firms can perform only local (i.e. innovative) search, (b) firms can perform both local and distant (i.e. imitative) searches.

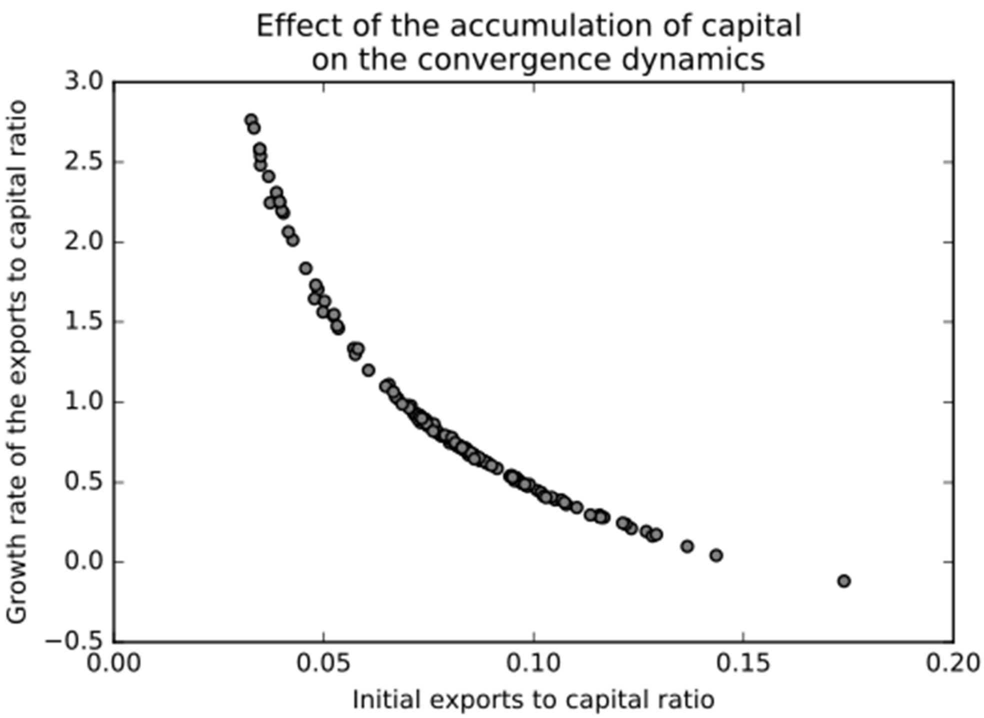


Figure 14: Effect of firms' accumulation of capital on the convergence across countries