Xi'an Jiaotong-Liverpool University

Research Institute for Economic Integration

Working Papers Series

(RIEI WP series)

Product Space and the Development of Nations: AModel of Product Diversification

by

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Working paper number: 2016-01

Notes:
Original version: 3 Mar 2016

Product Space and the Development of Nations: A Model of Product Diversification

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February 2, 2016

Abstract

In a recent series of contributions, Hausmann and Hidalgo (2007 [18]; 2009 [17]; 2011 [15]) propose an outcome-based product space where development traps can emerge quite easily due to low connectivity between products. We extend this model - notably by building on micro-foundations - to take into account cases of leapfrogging and increasing connectedness in the product space. Firms optimize their position in the product space with respect to our proposed fitness landscape. Although we might expect these elements to prevent development traps, lock-ins still emerge, but through a different channel. Indeed, the main driver of poor performance is now the lack of economic opportunities for countries that start in a neighborhood with fierce competition, or populated by goods with low export values.

Keywords: Product Diversification, Network, Fitness Landscape, Development Trap, Agent-Based Modeling

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1 Introduction

The great divergence of income per capita between countries and/or regions since the advent of the Industrial Revolution is one of the most complex and challenging stylized facts to be explained by growth theorists. This divergence is not a binary situation of equally rich countries on one side and equally poor countries on the other side of the spectrum of wealth: there are numerous alternatives, such as the emergence of convergence clubs (Galor, 1996[13] and Phillips and Sul, 2009[33]), growth "miracles" (Nelson and Pack, 1999[31]) and growth "disasters" (Diamond, 2011[10]). On theoretical grounds, this wide variety of trajectories suggests the presence of multiple equilibria. The source of these equilibria is to be found in the non-convexities of the macroeconomic production function, resulting from external effects arising, for instance, from either knowledge externalities (Romer, 1986[35]) or the accumulation of human capital (Lucas, 1988[28]) or increasing specialization in the production of intermediate goods (Romer, 1987[36]). The equilibrium toward which a country is gravitating depends on several factors, such as the quality of its institutions, its initial endowment in terms of capital per capita or the occurrence of external shocks, which can make a country leave a basin of attraction for another one (Azariadis and Stachurski, 2005[6]).

A new factor explaining growth and potential lock-in in sub-optimal equilibria has been proposed by Hausmann, Hidalgo and their co-authors in a recent series of contributions (2007[18]; 2009[17]; 2011[15]; 2013[16]). Their approach consists of computing a product space from disaggregated data of international trade. This space takes the form of a network, whose vertices represent the traded products and whose links, or edges, are the countries' conditional probabilities of having a revealed comparative advantage in a specific product given the comparative advantage it has in producing the other goods in the product space. Countries are then located on this network, and their movements over time are observed and simulated.

This new approach shifts the attention from a quantitative perspective to a qualitative one: what matters for economic growth is not only the diversity of the production set, such as in Romer (1987[36]), but also the type of goods that a country is producing. Arguably, a country has more options for developing new specializations if it is producing machine tools than if it is focusing on cultivating vegetables (Hidalgo et al., 2007[18]). The conditional probabilities act as do externalities in growth theory: when facing a null probability - i.e., no externalities available any more - a country has no easy option for further development, and it stays stuck in an undesirable periphery; i.e., a local and sub-optimal equilibrium.

In addition to its theoretical appeal, this new approach is a methodological breakthrough, as it stands in between network science and growth theory. This should allow for a new range of empirical and theoretical investigations, such as the identification of new sets of stylized facts about countries' growth experiences. Maps of the product space are an innovative tool to study the product set of a nation and for finding patterns of specialization (e.g., Kali et al., 2013[21], Hamwey et al., 2013[14]). Likewise, this approach provides a measure and analytic framework for product relatedness and diversification (e.g., Lo Turco and Maggioni, 2015[40]; Poncet and Waldemar, 2015[34]). More ambitious uses aim to employ it not only as a descriptive measure but also as a predictive tool for growth trajectories (e.g., Hausmann et al., 2013[16]); however, this is the path followed by fewer studies and to which we aim to contribute.

Despite these intrinsic qualities, the proposed approach, at least in its current formulation, faces some limitations. In our view, the main limitation to be found in Hidalgo et al. (2007[18]) is that the simulation model built for studying countries' adaptation in product space is lacking micro-foundations. In this model, countries increase their production sets time after time via a percolation process (Silverberg and Verspagen, 2005[37]) by producing goods that are close enough to their existing ones. This process is coherent with the idea of technological trajectories (Dosi, 1982[11]), but it cannot represent the observed patterns of leapfrogging[1] occurring in some catch-up economies. Hidalgo et al. (2007[18]) also draw strong conclusions about the emergence of development traps,[2] as they find that starting from the periphery of a product space makes it difficult for countries to develop new specializations.

Our objective in this paper is twofold. First, we refine Hidalgo et al.'s model by adding to its micro-foundations: notably, firms endowed with economic-driven motivations and the ability to perform small jumps (i.e., leapfrogging) in the product space. These motivations consist of maximizing a fitness landscape that we define upon the previously mentioned product space. Also, although the dynamics of an economy' s location in the network have been studied following Hidalgo et al.' s model, we have not learned much about changes in the network topology itself. In our paper, the product space evolves to take into account the fitness landscape. In addition, leapfrogging is introduced by extending the search of the firm in the fitness landscape from a single location in the product space to a wider reachable neighborhood.

Secondly, we address the question of the emergence of development traps. Indeed, the theoretical literature on fitness landscapes (Kauffman and Levin, 1987[24]; Kauffman, 1993[22] and 1995[23]) suggests that leapfrogging allows populations of agents to perform well when confronted with multiple optima. These small jumps can be assimilated with the genetic operators (crossovers, mutations, etc.) used for optimizing complex functions or landscapes (Holland, 1975[19]). We thus might expect them to prevent the emergence of development traps.

Repeated simulations applied to the East Asian car and electronic intermediate industries show that, even when allowing for leapfrogging, development

[1]Leapfrogging is a strategy of economic catch-up by skipping stages of technology evolution (see Lee and Lim, 2001[26]).

[2]In this paper, a development trap is defined as a process where the long run outcome (GDP in the case of nations) is subordinated to the initial conditions, as in Azariadis and Stachurski (2005[6]).

traps still occur, but via a different mechanism than that identified by Hidalgo et al. Indeed, the possibility of small jumps implies that agents stop moving as a result of the poor economic opportunities offered by their neighborhood, rather than the technical properties of their products. This result responds directly to the previously mentioned theoretical contributions analyzing the optimization of complex landscapes: in the present case, small jumps are not preventing poor solutions because firms avoid well-fitting locations where there are already too many competitors. Competition thus now plays a crucial role in the emergence of lock-ins. This finding links countries' economic success with the idea of first-mover advantage.

The remainder of this paper is organized into four parts. In Section 2, we present Hidalgo et al.'s product space and build such a space for the East Asian car and electronic intermediate industries. In Section 3, our model is outlined and assessed for its relevance with regard to the evolutions of countries' specializations on this product map. The fourth section addresses the question of the emergence of development traps. We then conclude this paper with a discussion.

2 The Outcome-Based Product Space

In endogenous growth theory, a growing diversity of intermediate products implies faster economic growth due to the positive externalities emerging from greater specialization (Romer, 1987[36]). Hidalgo et al. (2007[18]) enrich this idea with the concept of proximity: countries mainly increase their production sets by developing their activities into new products that are technically close to their existing ones. From this perspective, initial conditions become essential in explaining countries' growth paths: those starting by producing goods technically close to a wide range of other products benefit from an important growth potential. In contrast, countries mainly producing isolated products are very likely to be stuck in that production domain, or at least they experience comparatively slower growth.

The crucial point for empirical analysis is to measure this "proximity" in a systematic way. Hidalgo et al. (2007[18]; 2013[16]) have proposed an outcome-based approach, where the proximity of two products is computed as the minimum of the pairwise conditional probabilities of a country exporting one of the two goods, given that it exports the other. Formally, let i and j be two distinct products, their proximity $\phi_{i,j}$ is given by $\phi_{i,j} = min\{P(RCA_i \geq 1/RCA_j \geq 1), P(RCA_j \geq 1/RCA_i \geq 1)\}$, with $P(RCA_i \geq 1/RCA_j \geq 1)$ the conditional probability of a country having a revealed comparative advantage (RCA) at least equal to 1 in the export of product i, given that it has already such an advantage in the export of product j.

The result of these computations is a symmetrical matrix of $\phi_{i,j}$ values, which can be represented in the form of a network - or a map - illustrating products' proximities. This "product map" or "product space" can then be used for studying the evolution of countries' production sets. Hidalgo et al. (2007[18]; 2013[16]) consider the product space as fixed and propose a simulation model of countries' movements. In this model, they postulate that countries expand their production to nearby products and they show that if the product space is adequately well connected, all countries can reach its core and richer parts, although at different speeds. However, a disconnected product space is likely to generate traps; that is, situations in which countries are stuck in the periphery of that space.

In our view three elements constitute important limitations of Hidalgo et al.'s model: (1) a fixed product space, (2) only expanding countries' production sets, and (3) countries that only try to reach the center of the product space. We justify these assertions by computing product spaces from the export values for 11 East Asian countries from 1992 to 2011, as reported in the UN Comtrade database of Standard International Trade Classifications (SITC), Revision 3 (United Nations, 1991[30]).[3] The main reason driving this choice of countries is that East Asia experienced rapid growth during this period (Young, 1995[41]; Nelson and Pack, 1999[31]). The product space itself and countries' positions on it are thus expected to display profound changes between 1992 and 2011.

With regard to the choice of commodities, we focus our attention on two sections of the Comtrade database: SITC Section 7 (machinery and transport equipment) and Section 8 (miscellaneous manufactured articles), since the majority of intermediate goods traded in East Asia belong to these two sections, which are primarily used in the transportation and electronics industries. When looking for patterns of specialization, Hidalgo et al. (2007[18]) identified these products as important in the productive structure within the East Asia Pacific region. Data were collected up to the 5-digit level, the finest level. Sections 7 and 8 include 653 and 442 basic headings, respectively. Among these, 346 heading represent intermediate goods:[4] 276 in Section 7 and 70 in Section 8.

As we observe important variability in countries' $RCAs$ from year to year, we compute the averages over five-year periods. Figure 1 represents the four product spaces in the form of 346×346 symmetrical matrices. These four product spaces are modular, since we observe distinct blocks of relatively high proximity values. This modularity is consistent with the general understanding of the evolution of technologies through combinations of existing artifacts (Arthur and Polak, 2006[4]; Arthur, 2009[3]). This modularity is evolving from $1992-1996$ to $2007-2011$, which suggests important structural changes over time. A way to quantify these changes is to look at the evolution of

[3]These countries are China, Hong Kong, Indonesia, Japan, Malaysia, Taiwan, the Philippines, Korea, Singapore, Thailand, and Vietnam. Since the export values are reported in US dollars, we deflate these values by using the annual price index for intermediate manufacturing materials provided by the US Bureau of Labor Statistics.

[4]We identify intermediate goods using the lists provided in Athukorala (2005[5]), Kimura and Obashi (2010[25]), and Sturgeon and Memedovic (2011[39]).

the distributions of the products' weighted degree centralities over the four product maps.[5] The distributions of these centralities over the five-year periods are displayed in Figure 2. We observe a slight increase in the average centralities from period to period up until 2002 – 2006, and then a sharp decrease in 2007 – 2011. These numbers suggest that the cores of the maps for 1992 – 1996 and 2007 – 2011 are likely to be different, whether as a result of changing market conditions or due to technical change. We thus propose to remove the hypothesis of a fixed product space.

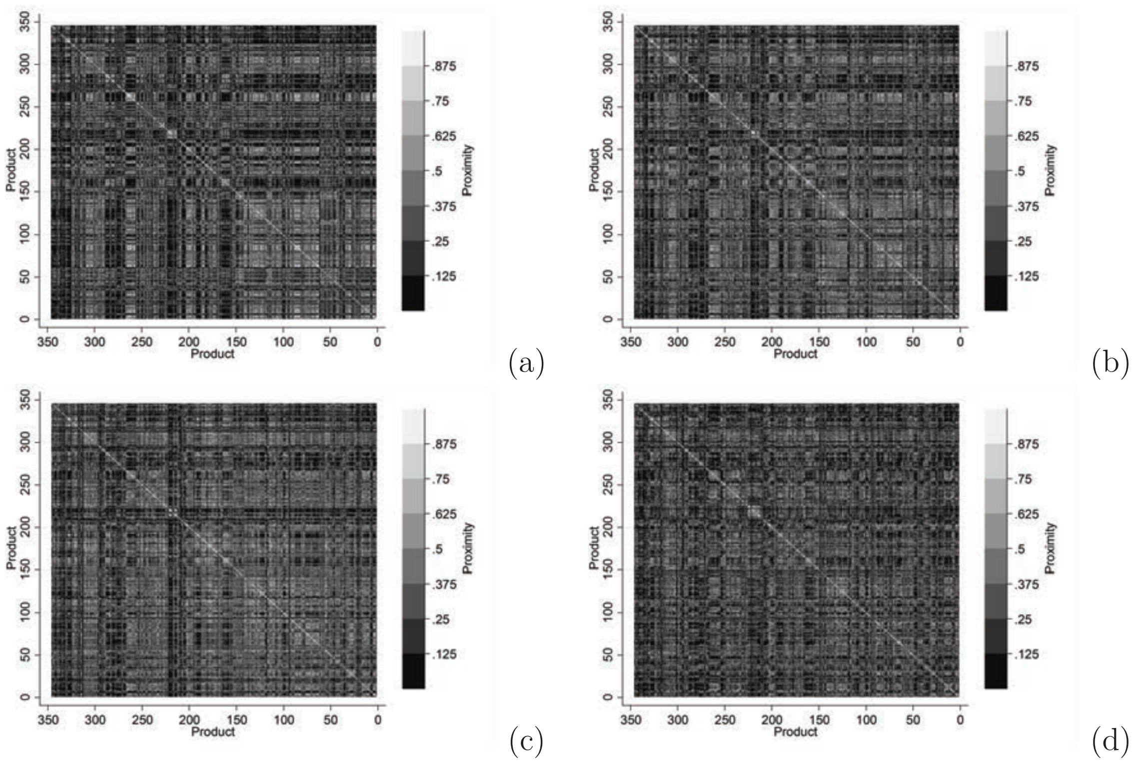


Figure 1: Product maps computed for (a) 1992 – 1996, (b) 1997 – 2001, (c) 2002 – 2006, (d) 2007 – 2011. The maps are symmetrical and consist of 346 products.

[5]Since proximity measures $\phi_{i,j}$ are not binary numbers, they can be used as weighting coefficients when computing products' degree centralities. We follow Opsahl et al.'s proposition (2010[32]) by computing $C_i^{W\alpha}$, the weighted centrality of a product i, as follows:

$$C_i^{W\alpha} = k_i^{1-\alpha} \times \left(\frac{S_i}{k_i}\right)^{\alpha}$$

k_i is the number of links between the product i and all the other products j of the map, S_i is the sum of the proximities $\phi_{i,j}$ associated with these links, and α is a tuning parameter. In Figure 2, $\alpha = 0.5$.

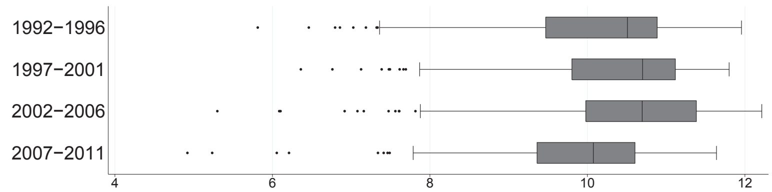


Figure 2: Weighted degree centralities in the product space.

Table 1 gives the number of products i for which the countries of our population exhibit $RCA_i \geq 1$. We note that Japan and Taiwan export fewer products in $2007-2011$ than in $1992-1996$, and that all countries experience periods of decline in the number of exported products. These observations suggest that the assumption of an ever-expanding product variety - or a constant variety in the case of an equilibrium - found in Hidalgo et al. (2007[18]) and in some models of endogenous growth (Romer, 1987[36]) is not realistic.

	CHN	HKG	IDN	JPN	MYS	TWN	PHL	KOR	SGP	THA	VNM
1992-1996	130	95	72	235	55	131	43	58	87	51	65
1997-2001	147	102	116	252	38	104	20	79	103	75	63
2002-2006	176	88	138	257	57	48	28	72	101	112	106
2007-2011	166	108	118	203	98	56	64	62	145	104	86

Table 1: Number of products for which the considered country exhibits an $RCA_i \geq 1$.

With regard to the general idea that all countries try to reach the core of the product space, Figure 3 shows the evolution of China's position over time. We voluntarily fix the product space at its $2007-2011$ configuration to improve comparability. In order to maintain good readability, only links with values $\phi_{i,j} \geq 0.55$ are displayed. Vertices stand for the products and their size is proportional to the sum of the exports of the 11 countries (we present the average for each five-year period). From $1992-1996$ to $2007-2011$, China leaves the core of the product space - i.e., the more densely connected part of the map - for exporting products situated in a periphery; that is, at the right side of the product space. This movement is the opposite of what would have been predicted by Hidalgo et al. (2007[18]), but their intuition regarding countries developing advantages in new products close to their existing productions remains valid. Indeed, China's exports are not uniformly distributed over the product map. The same goes for the other countries (for example, see Japan's positions in Figure 4).

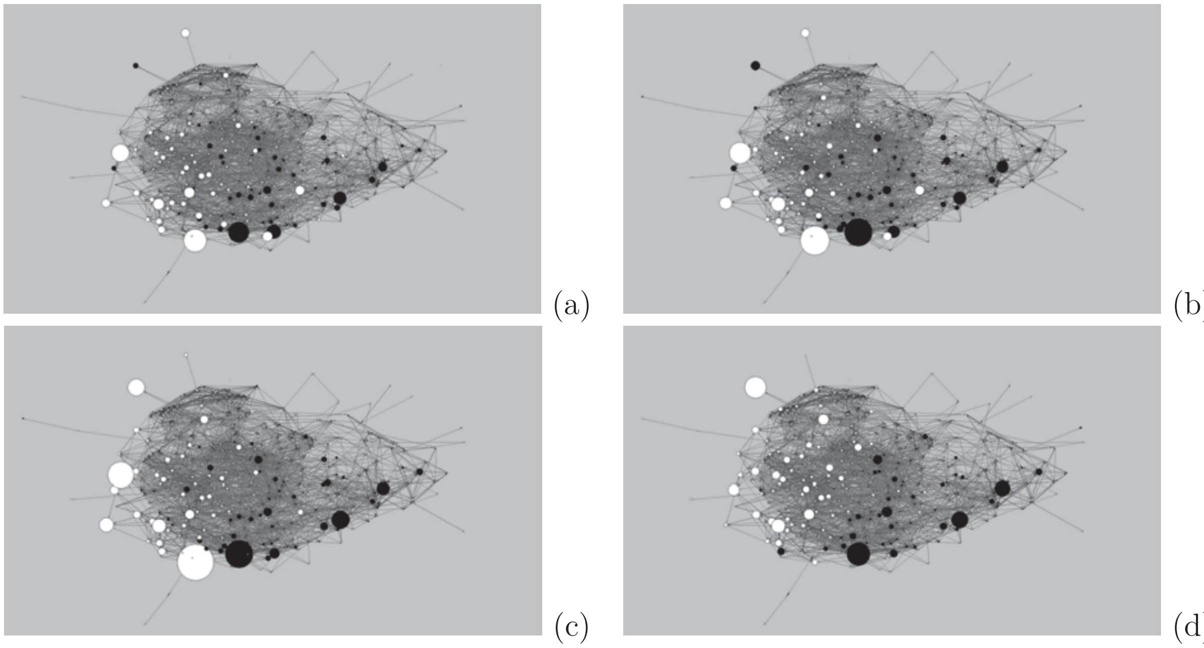


Figure 3: China' s positions (black vertices, i.e., $RCA_i \geq 1$) over the product space (a) $1992 - 1996$, (b) $1997 - 2001$, (c) $2002 - 2006$, (d) $2007 - 2011$. White vertices represent products in which China has an $RCA_i < 1$. The sizes of the vertices are proportional to the total value of exports of all countries.

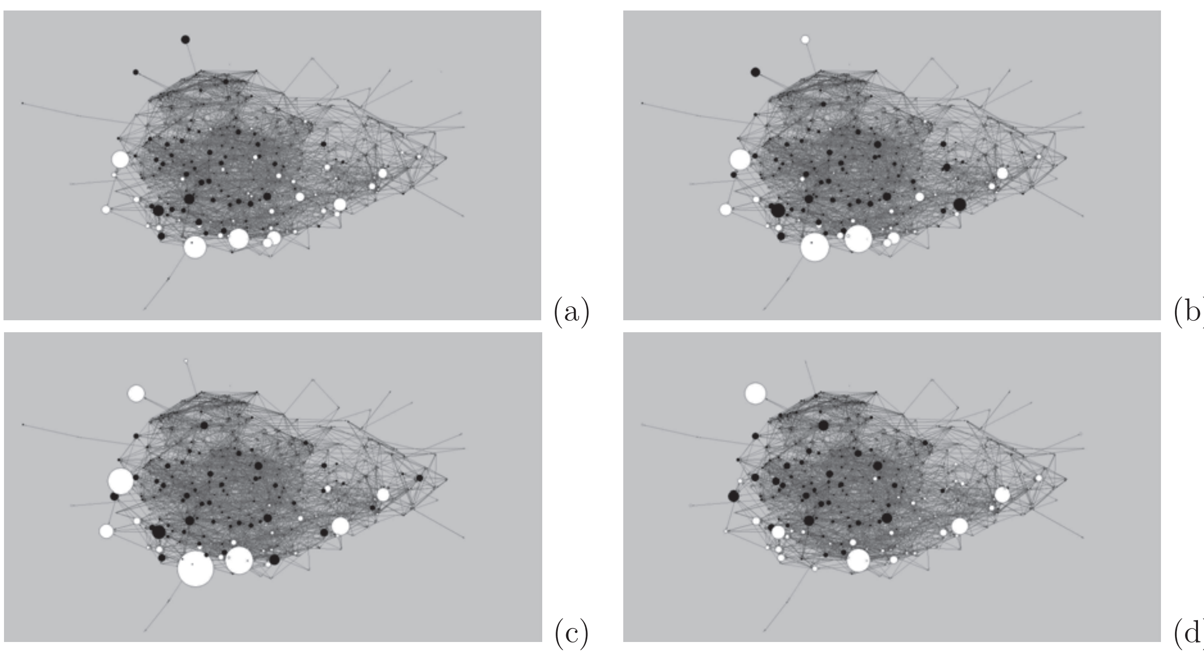


Figure 4: Japan' s positions (black vertices, i.e., $RCA_i \geq 1$) over the product space (a) $1992 - 1996$, (b) $1997 - 2001$, (c) $2002 - 2006$, (d) $2007 - 2011$. White vertices represent products in which Japan has an $RCA_i < 1$. The sizes of the vertices are proportional to the total value of exports of all countries.

In addition to including an endogenous product space, we propose to amend Hidalgo et al.'s model in two directions for explaining countries' movements over time: (1) we add other explanatory factors to the one of proximity between products, (2) we build on micro-foundations.

The intuition for new factors comes from the evolution in countries' positions (Figures 3 and 4). In particular, China is developing specializations in products at the periphery, which may suggest a strategy of avoidance of competition, since the core of the product space is populated by more countries than the periphery. Competition might thus play a repulsive role in countries' exports decisions. The need for micro-foundations was acknowledged by Hausmann and Hidalgo (2011 [15]). They postulate that producing each type of good requires different sets of capabilities. In their model, capabilities are attributed at random and countries are producing all the products that they can. Although the resulting countries-products network displays relevant properties, the fact that the model is based on two random matrices; i.e., the products-capabilities matrix and the countries-capabilities matrix, limits its explanatory power. For instance, the observation of convergence clubs (Durlauf and Johnson, 1995[12], Phillips and Sul, 2009[33]) suggests that capabilities are not randomly distributed in the real world. In addition, this hypothesis makes it difficult, if not impossible, to study the evolution of countries' production structures since the attribution of capabilities is not based on theory or a country' s actions.

3 A Complex Adaptive System of Countries' Product Diversification

Holland and Miller (1991[20]) propose to represent economies as complex adaptive systems. These systems are defined by three characteristics: (i) a network of interacting agents; (ii) dynamic aggregate behavior that emerges from agents' actions and interactions; and (iii) this aggregate behavior can be described without detailed information on individual agent's behavior. This definition fits well with the question of product diversification of countries, as it is an aggregate and dynamic phenomenon that can be described in itself, but is the product of the actions and interactions of microeconomic entities: the firms. We thus propose to disaggregate each country in our sample as a sub-national population of firms. Holland and Miller also define agents as being self-motivated: for every action available to the agent in its environment, a value is assigned (which may represent performance, utility, payoff, fitness, or similar) and the agent behaves to optimize this value over time.

This idea of a value is missing in Hidalgo et al.'s contribution (2007[18]), as the motivation of a country for changing its production structure is not explained, if any motivation can exist at this level of aggregation. One way to think about such a motivation is to use the concept of the fitness function or landscape. Fitness landscapes are common in models of adaptation in biology (Kauffman and Levin, 1987[24]; Holland, 1975[19]) and they have been successfully applied to the question of the evolution of technologies (Solé et al., 2013[38]; Desmarchelier et al., 2013[9]). We thus propose to amend the model by building a fitness landscape upon the product space.

3.1 Fitness Landscape

The initial product space of our model is the one for East Asian countries in its $1992 - 1996$ version (Figure 1 (a)). Because this space is symmetrical, we only keep the half matrix situated below the main diagonal. This space will determine how difficult it is for firms - and consequently for countries - to switch from one location to another. We now focus on building a landscape of fitness values upon the product space. These values will provide a motivation for firms to change their location, which will in return affect countries' production structure.

Several models of adaptation already exist in the economic literature. Some adopt a random fitness landscape (March, 1991[29]; Levinthal, 1997[27]) but others opt for a more economically-grounded landscape. For instance, Chang and Harrington (2006[8]) build a profit landscape, and Desmarchelier et al. (2013[9]) use the average distance between locations on the product space and consumers' preferences. We follow a similar strategy by using the export value of each location of the product space. Let i and j be the indices of the rows and columns of our two-dimensional product space, and k stands for one of our 11 Asian countries. Also, let $Exports_{k,i}$ stands for the exports of country k for product i if and only if $RCA_{k,i} \geq 1$ in the year considered. Similarly $Exports_{k,ij}$ represents the exports of country k for products i and j if both $RCA_{k,i} \geq 1$ and $RCA_{k,j} \geq 1$. Then $Fit_{i;j}$, the fitness of location $(i; j)$, is computed by the following procedure:

- If $i = j$ then $Fit_{i;j} = \sum_{k=1}^{11} Exports_{k,i}$
- If $i \neq j$ then $Fit_{i;j} = \sum_{k=1}^{11} (Exports_{k,i,t} + Exports_{k,j,t})$

These computations produce five landscapes; i.e., one per year, including 1992 and 1996, we compute the average. The resulting landscape is displayed in Figure 5 and shows many local optima. This kind of landscape is typically difficult to optimize by agents with information only about their immediate environment (Kauffman and Levin, 1987[24]; Solé et al., 2013[38]). It implies a strong probability of lock-in, and therefore agents' initial positions must be carefully chosen.

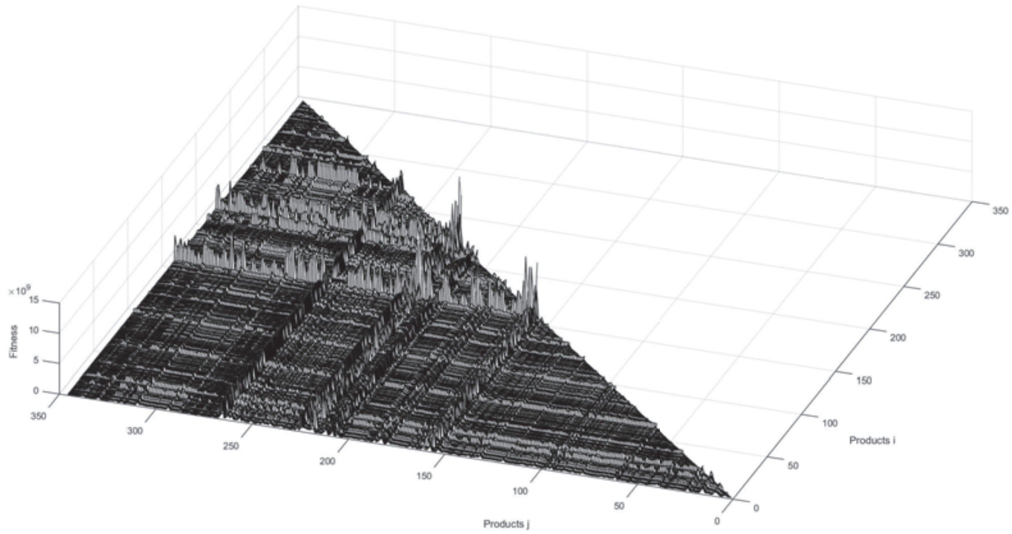


Figure 5: Fitness landscape of the model

3.2 Firms and countries' initial conditions

The model includes the 11 Asian countries. By assumption, we consider that a country k has at least one of its firms producing the good i if $RCA_{k,i} \geq 1$ in our data for $1992 - 1996$. However, the total number of firms per country is decided by two different set-ups.

In the first set-up, we allow for scale difference between countries. Every time $RCA_{k,i} \geq 1$ for a country in our data from $1992 - 1996$, we randomly create between 1 and 5 firms h producing the good i in country k. These firms can produce two goods at the same time: for each one of the new firms, we randomly draw an integer $j \in (1; 346)$. If j corresponds to another product than i for which $RCA_{k,j} \geq 1$, then h produces goods i and j, otherwise h produces only i.[6] It follows that initially all countries of the model have the same positions on the product space as the real countries to which they refer in $1992 - 1996$. For instance, China and Japan's starting positions are those described in Figures 3(a) and 4(a). This set-up introduces significant differences between countries in terms of opportunities for development: Japan exports 5.46 times more goods in our sample than the Philippines does in $1992 - 1996$ (see Table 1). Consequently, Japan has on average 5.46 times more firms, and thus far more opportunities for developing new comparative advantages.

The second set-up for initial conditions cancels this scale effect as we attribute 500 firms to each country. As in the previous case, these firms are exporting goods for which the country that they belong to exhibits $RCA_{k,i} \geq 1$ in $1992 - 1996$. We now move to the description of firms' adaptive behavior..

[6] We make sure that firms always start in the lower half of the matrix of the product space matrix.

3.3 Firms' exploration behaviour and environment dynamics

At each time step, every firm tries to move in the product space. Following our previous discussion of motivation and competition, the direction of this movement is influenced by both the fitness landscape (Figure 5) and the level of competition (the location of the rest of the firms in the neighborhood).

Firms' movement algorithm is as follows:

- Select randomly a location $(i'; j')$ of the product space within the immediate Von Neumann neighborhood with a maximum walking distance of 5 or 10 (depending on the simulation set-up). The walking distance represents the idea of leapfrogging. The larger the maximum distance, the further the firm can jump on the product space.
- We note $N_{i';j'}$, the number of firms producing $(i'; j')$. If $\frac{Fit_{i';j'}}{N_{i';j'}+1} > \frac{Fit_{i;j}}{N_{i;j}}$ then the firm tries to move to $(i'; j')$. It succeeds in moving if $U(0;1) \leq \phi_{i';j'}$, with $U(0;1)$ a random draw in a uniform distribution. The higher $\phi_{i';j'}$ is, the easier the move to this location. As in Hidalgo et al. (2007[18]), the product space conditions the ease with which agents can develop new specializations, but now movements are the result of agents with a clear motivation to optimize their fitness value.

This algorithm is very simple. It states that firms have very limited information about selling opportunities and that they try to maximize their potential market. As such, the sum of exports acts as an attractor to the firm, while they try to avoid competition at the same time. Countries' positions on the product map are updated at every time step depending on the movements of their firms.

After firms and countries have moved, the product map - i.e., the model's matrix of proximity values $\phi_{i;j}$ - is updated by re-computing every conditional probability $\phi_{i;j}$ via the aforementioned formula: $\phi_{i,j} = min\{P(RCA_i \geq 1/RCA_j \geq 1), P(RCA_j \geq 1/RCA_i \geq 1)\}$. In some cases, we also allow for economic growth; that is, for an exogenous increase of the values of the fitness landscape. Three cases are possible: no growth, growth of the fitness at the rate $g = 2\%$ of all products or only for selected ones.

In total, we run the model with eight different set-ups (summarized in Figure 6), each one has been repeated 100 times with different seeds for performing random draws.[7] Every simulation run lasts for 50 time steps, which proved to be sufficient for countries to reach a stable position.

[7] Countries' initial specializations are decided by our empirical data, and are thus quite similar from one simulation run to another. It follows that 100 simulation runs per scenario is enough for to obtaining stable average results.

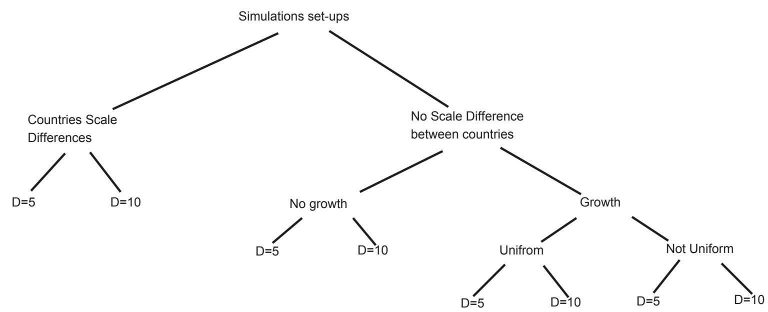


Figure 6: *
Summary of the simulations' set-ups.
D stands for firms' maximum walking distance, or leapfrogging.

3.4 Assessing for the Relevance of the Model

Before using the model to discuss about the emergence of development traps, we propose to assess for its relevance with regard to the three stylized facts identified in Ssection 2: (i) the product space is dynamic; (ii) each country can experience short periods of decline in the variety of its exports, and (iii) countries can develop new advantages in products located in the periphery of the product space.

(i) Figure 7 shows the average distributions over 100 simulation runs of products' weighted centralities for the simulated product spaces at $t = 50$ (i.e., the last time step of the model). Since the initial space is that of $1992 - 1996$ (Figure 2), each scenario sees an increase in the connectedness of its product space. This general movement is coherent with the general trend observed between 1992 and 2006 in Figure 2, but not with the decrease happening during $2007 - 2011$. We can arguably attribute this later phenomenon to external events; for instance, the 2008 economic crisis and the 2011 earthquake and tsunami in Japan.

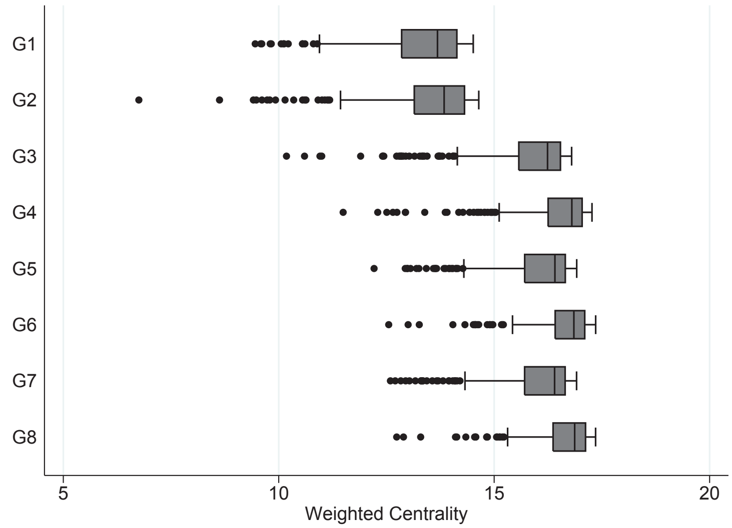


Figure 7: *
Average distributions of weighted degree centralities in simulated product spaces (100 simulations per distribution) at $t = 50$.

$G1$ and $G2$ represent the scenarios with scale differences between countries and with $D = 5$ and $D = 10$ respectively. $G3$; $G4$ stand for the scenarios without scale difference nor economic growth, and with $D = 5$ and $D = 10$ respectively. $G5$; $G6$ are the scenarios without scale difference, with uniform economic growth, and with $D = 5$ and $D = 10$ respectively. $G7$; $G8$ represent the scenarios without scale difference, with differentiated economic growth, and with $D = 5$ and $D = 10$ respectively.

Distributions in Figure 7 also reveal that an increase in firms' walking distances from 5 to 10 always increases the connectivity of the product space. Cancelling scale differences between countries has an even bigger effect in that direction. However, economic growth, whether uniform or not, does not seem to have any effect on product connectivity.

(ii) To the best of our knowledge, decline in export variety is not possible in Hidalgo et al.'s model (2007[18]). Figure 8 shows the evolution of the number of products per country in two typical simulation runs with different initial settings. We observe that the model allows for a growing variety of products in every country, but also that all countries experience short periods of decline. In accordance with the observation on Figure 7, removing the initial scale difference between countries and increasing firms' walking distances reduces the differences in terms of product varieties.

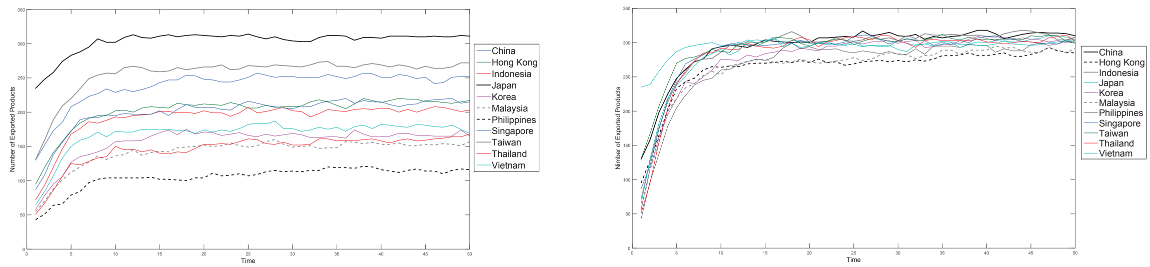


Figure 8: Evolution of the number of products per countries in a typical simulation run. Left: Simulation with scale difference and a walking distance of 5. Right: simulation without scale difference and with a walking distance of 10.

(iii) For maintaining comparability with previous observations for Japan and China (see Figures 3 and 4), we use the product space of $2007-2011$ to present their typical simulated positions at $t = 50$ (see Figure 9). In these simulations, China and Japan do not have initial scale difference, which can explain their similarities. It is interesting to note that even though the two countries have enough firms to produce all goods of the product space, they are not doing so. There are slight differences between the two countries, as we observe that China is a bit more involved than Japan in the right side periphery, whereas Japan is slightly more involved in the central products. The significant overlap between the exports of these two countries is not consistent with the available data for $2007-2011$, but strict comparison with reality has to be treated with caution. Indeed, the model does not allow for external perturbations (e.g., earthquakes), and also it does not includes realistic growth settings, nor the effects of specific government policies. It is nonetheless interesting to note that countries tend to spread both in the center and the periphery of the map, which is something that Hidalgo et al. did not allow for (2007[18]).

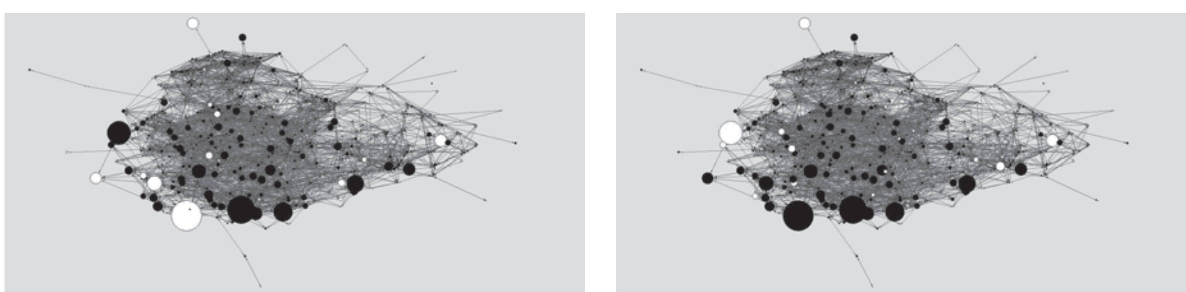


Figure 9: China and Japan's simulated final positions (respectively left and right) at $t = 50$ reported in the $2007 - 2011$ product map.

4 Implications for the Development of Nations

The use of a fitness landscape allows the measurement of countries' overall fitness over time. This fitness has an economic meaning: it is a measure of countries' export performance. We can thus use it as a proxy for economic opportunities and failures, or traps, under various simulation settings. Our objective is to refine Hidalgo et al.'s conclusions (2007[18]; 2011[15]; 2013[16]) on the emergence of development traps. Indeed, two elements of our model could, a priori, work against the emergence of traps: (i) the product space is dynamic and moves toward higher connectivity, (ii) we allow for leapfrogging. Simulation results presented in this section are averages over 100 simulation runs, each one computed with different seeds for random draws.

4.1 Countries' performances with initial scale differences

We start our analysis with the two scenarios in which countries have initial scale differences (see the schema in Figure 6): country k is doted with a random number of firms - between 1 and 5 - producing product i if $RCA_{k,i} \geq 1$ in $1992 - 1996$. Leading economies at that time, like Japan, are thus very likely to start with more firms than others, and thus to benefit from higher adaptability.

Figure 10 shows the evolution of countries' fitness when firms' maximum walking distance (D) is set at $D = 5$ (left side) and $D = 10$ (right side). We observe that the best fitted countries at $t = 0$ (Japan, followed by China and Taiwan) are invariably the best performers at $t = 50$, regardless of the walking distance. On the opposite side, the Philippines, Malaysia and Thailand are always lagging behind other countries. They encounter a trap: their fitness grows more slowly and stabilizes more rapidly than the other countries as a result of unfavorable initial conditions in terms of the size and spread of their population of firms. This conclusion is the opposite of the principle of "advantage of backwardness" (Aghion and Howitt, 2006[2] p. 276) found in Schumpeterian models of endogenous growth. Indeed, in these models, the more a country lags behind the technological frontier, the greater its potential for a high speed catch-up.

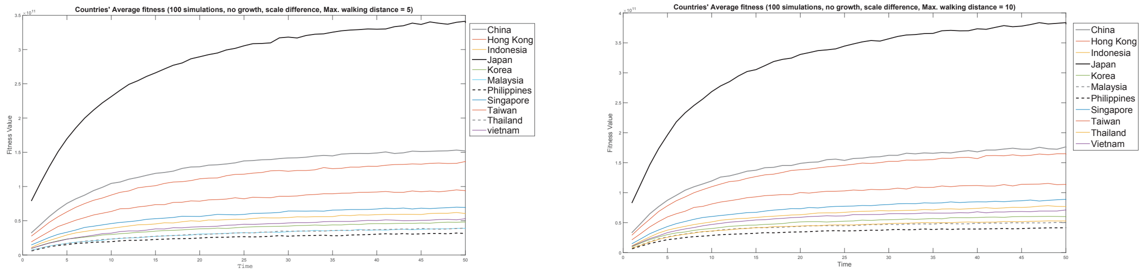


Figure 10: Evolution of countries' fitness (averages over 100 simulation runs) with initial scale differences between countries. Left:$D = 5$. Right $D = 10$

If the numbers of firms is the main factor explaining countries' lock-ins into sub-optimal equilibria, then developing pro-business institutions, like the establishment of good property rights, might prove to be a viable escape solution (Acemoglu et al., 2005[1]; Baumol et al., 2007[7]). Likewise, FDI and access to international markets via capital account liberalization may help to remove capital constraints and level the ground for the exploration of the fitness landscape. All these would provide a positive scale effect to the country. But aside from the scale differences between populations of firms, what is the specific role of firms' initial spread throughout the product space for explaining the performance of countries?

4.2 Countries' performances without initial scale difference

Removing the initial scale difference between populations of firms provides quite different results. At first, Figure 11 shows that there are no obvious relationships between fitness at $t = 0$ and $t = 50$. For instance, although Japan and China are still the leaders, Thailand, which is among the worst performers in the scale difference scenarios, and one of the countries with the lowest initial fitness, succeeds in becoming the fourth best at $t = 50$, both for $D = 5$ and $D = 10$. Another interesting case is that of Singapore: the country produced a relatively wide variety of products in $1992 - 1996$ (see Table 1), but it finds itself with a low initial fitness and the second lowest at $t = 50$.

Figure 11 also shows the emergence of "clubs": when $D = 5$ Japan and China are competing with each other and are well above the rest of the population, while a core regroups all the other countries except Malaysia and Singapore, which lag behind. Increasing the maximum walking distance reduces the final differences and the distinctions between these clubs. We note the case of Korea, which succeeds in competing with Japan and China when $D = 10$, although it was producing only 58 products in $1992 - 1996$ (see Table 1). As might be expected, allowing for a uniform exogenous growth does not change these observations (Annex, Figure 13). However, what is more surprising is that similar results are found when only goods i for which Singapore and Malaysia exhibit $RCA_{k,i} \geq 1$ are allowed to grow (Annex, Figure 14).

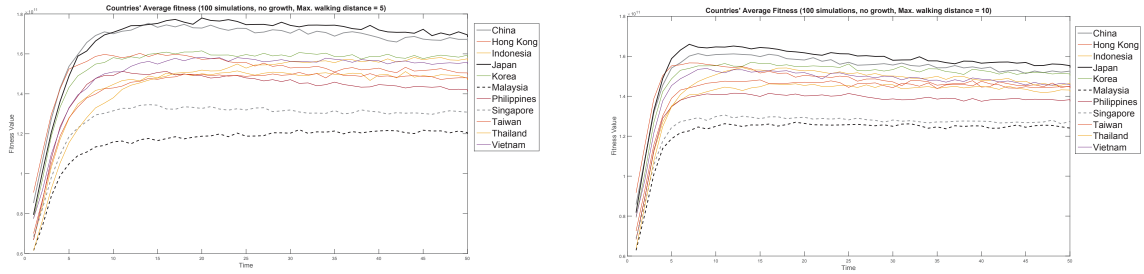


Figure 11: Evolution of countries' fitness (averages over 100 simulation runs) without initial scale differences between countries or economic growth. Left: $D = 5$, Right: $D = 10$.

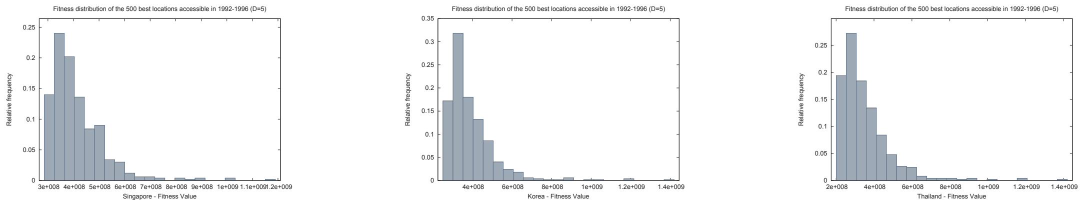
These observations of countries with poor initial conditions that succeed in performing well at $t = 50$ might suggest that initial conditions are not important for explaining a country's performance. In fact, we do observe the emergence of traps, since the results are similar between scenarios. For instance, Thailand is always the fourth best performer at $t = 50$, while Malaysia and Singapore are always the worst. Looking at fitness or at the number of products at $t = 0$ is arguably not appropriate for assessing countries' initial conditions, as firms can obtain information about products located beyond their immediate neighborhood thanks to the parameter of walking distance. We have also to take into account potential competition when assessing a locations' fitness.

We take into account these elements (walking distance and the pressure from competitors) via the following computation: for Korea, Singapore and Thailand, our three countries of interest in the preceding analysis, we divide the fitness of the products for which $RCA_{k,i} \geq 1$ at $t = 0$ (i.e., in $1992-1996$) by the number of countries also exhibiting $RCA_{k,i} \geq 1$. We also perform the same computation for all products situated in the Moore neighborhood within a walking distance $D = 5$ of this product i. The reason why we choose a Moore neighborhood is that it covers products that are reachable after several movements when firms are walking within a Von Neumann neighborhood. It thus provides a better understanding of potential attractors lying in the surrounding area. We then keep the 500 best locations[8] and display their fitness distributions in Figure 12 for all three countries.

Singapore initially exports a higher variety of goods (see Table 1) and starts the simulations within a more favorable neighborhood on average (see the means in Figure 12). However, Korea and Thailand's environments offer a higher maximum fitness, and the distributions of their fitness values are more positively skewed than that of Singapore, meaning that they present a longer tail toward high fitness values. Further, the higher kurtosis of the neighborhoods of Korea and Thailand imply that these tails are fatter than that of Singapore. Here, we echo Hidalgo et al.'s argument (2007[18]) against

[8]This number is sufficient, since each country has only 500 firms and can produce a maximum variety of 346 products.

the literature on product variety: what matters for countries' long-run performance is more the "qualities" of the products than their quantities. This is why Thailand and Korea always perform better in our simulations than Singapore does when we remove the initial scale difference in terms of firm numbers. However, we differ from Hidalgo et al. in the sense that we measure the quality of a product by the fitness of its reachable neighborhood rather than by its own fitness.



mean $= 4.1363e + 008$	mean $= 3.9177e + 008$	mean $= 3.5271e + 008$
median $= 3.8822e + 008$	median $= 3.5561e + 008$	median $=3.1157e + 008$
maximum $= 1.1704e + 009$	maximum $= 1.3942e + 009$	maximum $=1.3942e + 009$
skewness $= 2.5566$	skewness $= 3.1884$	skewness $=2.9255$
kurtosis $= 10.555$	kurtosis $= 15.591$	kurtosis $=13.647$

Figure 12: Distributions of the average fitness (over the number countries producing the considered good) of the 500 best locations reachable in 1992−1996 for Singapore (left), Korea (middle), and Thailand (right).

5 Discussion

In this paper, we propose a refinement of Hidalgo et al.'s recent outcome-based product space framework (2007[18]; 2009[17]; 2011[15] and 2013[16]). We extend this framework in two directions: (i) countries are now represented by populations of autonomous firms, each firm trying to maximize its potential revenue from exports; (ii) we also use export values from Comtrade datasets for computing a fitness landscape defined upon the aforementioned product space. This landscape provides firms with a way to assess the relative advantages of changing their specialization; i.e., their location on the product space.

We then simulate the evolution of South-East Asian countries' specializations in terms of exports of intermediate goods in the electronic and car industries. Our main objective is to study the interaction between initial conditions and long-run economic performance; in particular, the emergence of development traps. Hidalgo et al. (2007[[18] and 2011[15]) indeed emphasize the existence of such lock-ins with their model.

A first conclusion of our simulations is that countries with a larger initial population of firms are less likely to experience development issues. Indeed, having more firms implies a higher capacity for exploration and adaptation on the product space. When removing this initial scale difference between countries' populations of microeconomic agents, our results echo Hidalgo et al.'s conclusion (2007[18]) that contrary to the argument advanced by product variety models of endogenous growth (Romer, 1987[36]), what conditions economic growth is the properties of products rather than their variety. As such, a country exporting a relatively low initial range of products can perform very well in the long run, while others with a relatively high initial variety can fall into a trap. However, we differ from Hidalgo and colleagues when defining these properties. In the case of Hidalgo et al., the relevant property conditioning economic growth is the proximity of the goods that a country exports to a wide variety of other products. Following their view, countries develop new specializations through a process of percolation that always occurs by moving to neighboring products. However, in our view, the economic opportunities offered by a product's reachable neighborhood are more important. We thus advance that firms are motivated by economic perspectives and that they can move on the product space by performing more or less wide "jumps" on it.

Economic history provides numerous examples of countries that have quickly changed their production and exports by skipping stages of technology development. This tends to sustain the idea that technical proximity between products is not fundamental in explaining countries' specialization choices. As an illustration, Lee and Lim (2001[26]) document that Samsung skipped the $1-16$ kbits D-RAM to enter directly into 64 kbits in early 1980s. Similarly, Hyundai skipped the carburetor-based engine that was standard at that time by proposing a new electronic injection-based engine. According to the authors, these firms were mainly motivated by the expected increase in profits. This Korean example is interesting, as it justifies our idea of walking distance, our micro-foundation at the firm level and the computation of a fitness landscape providing firms with expectations about their potential sales opportunities.

From this perspective, traps can emerge through two mechanisms. The first one is exogenous: the value of the walking distance, which is associated with the capacity of firms to "jump" from one product to another. However, this distance proved to play only a marginal role, since all countries start by producing several goods, more or less widespread over the product space. The second mechanism is endogenous: the evolution of economic opportunities within the product space. Aside from economic growth, these opportunities are influenced by the intensity of the competition between firms, and therefore also between countries, for producing the various goods that compose the product space. It follows that specialization opportunities are limited for latecomers. Although pessimistic, this conclusion is coherent with the observation of regional specialization: for instance, Asian economies are mainly specialized in electronics; that is, in relatively new industries (Hidalgo et al., 2007[18]) in which they could benefit from a first mover advantage, thanks to rapid leapfrogging (Lee and Lim, 2001[26]).

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6 Annex

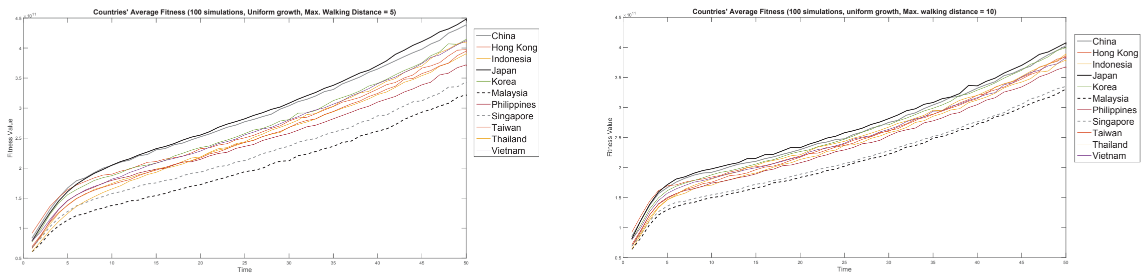

Figure 13: Evolution of countries' fitness (averages over 100 simulation runs) without initial scale differences between countries, and with a uniformly distributed economic growth. Left: $D = 5$. Right $D = 10$

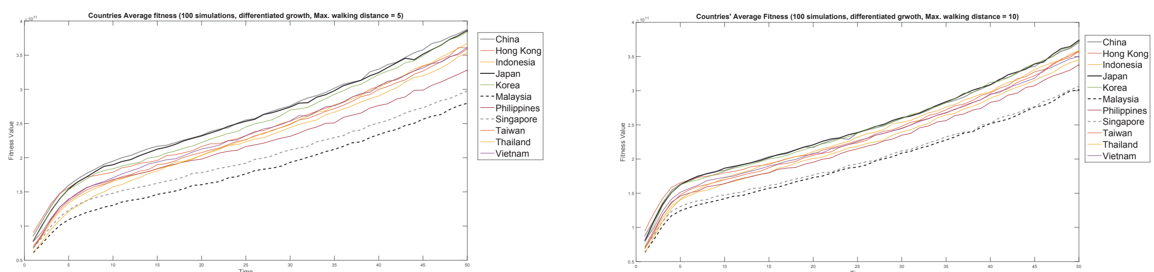

Figure 14: Evolution of countries' fitness (averages over 100 simulation runs) without initial scale differences between countries, and with a differentiated growth advantaging Singapore and Malaysia. Left:$D = 5$. Right: $D = 10$