The Dynamics of Economic Complexity and the Product Space over a 42 year period

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CID Working Paper No. 189
December 2009

Working Papers
Center for International Development
at Harvard University

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Abstract

How does the productive structure of countries' changes over time? In this paper we explore this question by combining techniques of networks science with 42 years of trade data and find that, while the Product Space remains relatively stable during this period, the dynamics of countries' productive structures is characterized by a few highly dynamic economies. In particular we identify Brazil, Indonesia, Turkey, Malaysia, Thailand, Korea, Singapore and China, as countries that transformed their productive structures considerably during these four decades, albeit following different trajectories. For instance, the economic complexity of Korea, Singapore and China was relatively high at the beginning of the observation period and continued to increase during these forty two years, moving these countries into the top spots of the economic complexity rankings for the beginning of this millennium. Brazil, Indonesia and Turkey, on the other hand, transformed their productive structures significantly during the same period of time, but did so starting from a less sophisticated foundation. We conclude the paper by moving from this and other observations into the policy implications of this view of economic development and argue that the government involvement in the private sector should be to help catalyze market activities and solve coordination problems that emerge naturally when countries try to accumulate capabilities. This represents an alternative to more traditional views of the role of government that postulate, in their extremes, that the public sector should either have no involvement in private sector activities or, on the other hand, substantial ownership of the means of production.

PACS: 89.75.-k, 89.65.Gh, 89.65.-s, 89.75.Fb, 89.75.Hc

Keywords: Economic Complexity, Capabilities, Networks, Product Space, Structural Transformation, Economic Development

Introduction and Theory

The wealth of a nation is tightly connected to its *productive structure*, which is defined as the set of products and services that a nation can deliver. During a great part of the twentieth century, however, traditional economic theory did not consider the productive structure of countries as a relevant ingredient to economic growth. Since products can be aggregated by measuring their monetary value, nations did not need to worry about *what* they made, but rather on *how much* they got out of it.

For several years now the view of the world in which products do not matter appeared to be inconsistent with empirical observations. For instance, countries rich in natural resources that generated large revenues from a few mineral products did not outgrow resource-poor countries [REF]. Indeed, countries that have been able to export their way into prosperity, such as Korea and Taiwan, have done it by exporting products that are different from the products exported by countries that have not emerged from high rates of poverty, despite generous revenues from mineral fuels and natural resource exports, such as Venezuela and Nigeria. These facts are incompatible with a view of economic growth in which products do not matter.

Recently, an alternative view of the development process has been provided by research that combines the statistical physics of networks with development economics. At the heart of this new view is the creation of new analytical tools that can be used to quantify the economic relevance of the historically disregarded productive structure [REF]. One important observation of this research is that ***what*** a country produces matters more than ***how much*** value it extracts from its products [1, 2]. This is because not all products are equally sophisticated and therefore, in the long run, the income of countries is determined by the variety and sophistication of the products they make, rather than by the traded value of their exports. Countries become ***what*** they make.

Some of the mechanisms by which the sophistication of products can affect the development of countries have been explained using a simple theory. The theory proposes that the productive structure of countries is determined by the local availability of highly specific inputs, or *capabilities*, which can be thought of as specific building blocks of production [3]. Capabilities could be tangible inputs, such as bridges, ports and highways, or intangibles, such as norms, institutions, skills or the existence of particular social networks. In this theory, at any given point in time, countries are endowed with a set of capabilities, whereas products require specific capabilities. The sophistication of a product is related to the number of capabilities that the product requires; whereas the complexity of a country's economy is related to the set of capabilities it has locally available.

If countries can only produce the products for which they have all the required capabilities, and if capabilities are hard to accumulate, then the current mix of capabilities available in a country will not only determine the products that the country can make today, but also the products that it will be able to make in the future. This is because countries will bias their future production towards products that use many of the capabilities that are already available. Countries that can produce products requiring a relatively large number of capabilities, therefore, should have economies that are more adaptable than countries producing less complex products. Given their large capability endowment, these countries will have more potential uses for any new capability that comes along. Ultimately, this will make development easier for countries with more complex productive structures, explaining why ***what*** you export matters [1, 3], as equal revenues from products of different levels of complexity do not translate into equal future possibilities.

This theory has been described formally and tested empirically by using the structure of the network connecting countries to the products they export to infer the complexity of products and of the countries that produce them [3]. These measures showed that the complexity of a country's economy is strongly correlated with income and that deviations from this relationship predict future growth, suggesting that countries reach a level of income that is dictated by the complexity of their economies [3].

Another important method that has been used to understand the development of this high dimensional theory of development is the *Product Space* [4]. The Product Space is a network that connects products based on the probability that countries export them in tandem, by assuming that similarities in the capability requirements of products are expressed through co-exports. The Product Space can be seen as an industrial map of where economic development occurs. This is because, according to the theory explained above, an important aspect of economic development process is the process by which countries upgrade their productive structures. The Product Space shows explicitly which products require similar capabilities to the ones a country already makes, helping to inform industrial policy. The fact that countries tend to diversify towards products that are close by in the product space was recently demonstrated empirically, providing further validation to the theory presented above [4] and adding to the contribution that network science is making to economic development research.

These examples and theory show the avenue of economic development research that has been opened by collaborations between physicists and development economists. The Physics community has produced other work, however, that has also used networks to help understand macroeconomic patterns. One example is the World Trade Network (WTN) or World Trade Web (WTW) [5-9], which is a web in which countries are connected if they happen to have traded any type of product. The WTN has been used to show that fast growing nations, over time, have become more central in the WTN than poor performers [8], yet details on the productive structure of countries and the complexity of their economies are absent from this view. Links between countries do not consider the specific products that flow through them, limiting the potential policy advice that might stem from this approach.

Another area of application of the tools of statistical physics in the economic sciences is the analysis of the time series' described by economic indicators, such as stocks and commodity prices [10-17]. Indeed, the term "econophysics" is commonly used to describe the use of tools of statistical physics in finance [18]. This literature has been recently expanded by the introduction of networks as a tool that can be used to study the space of correlations that is defined by sets of financial time series [19-23]. This methods have been used, for instance, to show that the optimal Markowitz portfolio [24] is composed mainly of stocks that lie in the periphery of such networks [22].

In this paper, however, we concentrate on expanding the literature of economic complexity and development by studying changes in the complexity of countries' productive structures over a period of 42 years. We will begin by commenting on the relationship between the measures of economic complexity that we use in this paper and other measures of sophistication that were recently introduced. We will then move on to explore how countries' economies have evolved between 1963 and 2005 and on to the study of changes in the relative complexity of products and in the structure of The Product Space during this period. In the discussion we will explain how these results add to the economic development narrative.

Results and Methods

Data

International trade data between 1963 and 2000 is taken from Feenstra, Lipsey, Deng, Ma, & Mo's "World Trade Flows: 1962-2000" dataset [25]. This dataset consists of imports and exports both by country of origin and by destination, with products disaggregated to the SITC revision 4, four-digit level. The authors build this dataset using the United Nations COMTRADE database. The authors cleaned the dataset by calculating exports using the records of the importing country, when available, assuming that data on imports is more accurate than data from exporters. This is likely, as imports are more tightly controlled in order to enforce safety standards and collect customs fees. In addition, the authors correct the UN data for flows to and from the United States, Hong Kong, and China. We focus only on export data, and do not disaggregate by country of destination. More information on this dataset can be found in NBER Working Paper #11040, and the dataset itself is available at http://cid.econ.ucdavis.edu/data/undata/undata.html and at http://www.chidalgo.com/productspace/data.html . The dataset was expanded using net export data for the 2001-2005 period using the UN COMTRADE. We used data only from countries with a population larger than 3.5 million.

Product Sophistication, with and without income

Hausmann, Hwang and Rodrik [1] recently created a measure of the sophistication of a product by averaging the income per capita of the countries that exported that product, weighted by the Revealed Comparative Advantage (RCA) that each country had on that product. In principle, such measure could be interpreted as the expected wage of a worker producing such product. Yet, as we will demonstrate shortly, this interpretation may not be the most appropriate.

The Revealed Comparative Advantage (RCA) that a country has on a product is defined as the ratio between: (i) the share of the market of a country that a product has and (ii) the share of the world market that a product represents [26]. For instance, in the year 2000, copper represented 26% of Chile's exports, but accounted for 0.2% of total world trade. Hence, Chile had an RCA on copper for the year 2000 of R=26/0.2=130, indicating that Chile is an extremely competitive copper exporter. In general, it is customary to say that country c has RCA in product p if $R_{cp}\geq 1$. By definition if a country does not export a product it will have no revealed comparative advantage in it (R=0). RCA is a measure of the importance of a product in a country's export basket that controls for both~~,~~ the size of the country's economy and the size of the products market.

Mathematically, if we define X_{cp} as a matrix whose entries are equal to the exports of country c in product p, then R_{cp} is defined as:

$$R_{cp} = \frac{X_{cp}}{\sum_p X_{cp}} \Big/ \frac{\sum_c X_{cp}}{\sum_{c,p} X_{cp}}. \tag{1}$$

Using this definition of RCA, Hausmann, Hwang and Rodrik defined product sophistication, or $PRODY$ [1], as

$$PRODY_p = \frac{1}{\sum_c R_{cp}} \sum_c R_{cp} Y_c, \tag{2}$$

where Y_c is the average income per capita of country c adjusted by purchasing power parity (ppp).

$PRODY$ was then used to estimate the sophistication of country's productive structures as the average $PRODY$ of the products a country exports. This variable is called *EXPY* and is defined as:

$$EXPY_c = \frac{1}{\sum_p R_{cp}} \sum_p R_{cp} PRODY_p. \tag{3}$$

By using (2) $EXPY$ can be written as a function of R and Y as

$$EXPY_c = \frac{1}{\sum_p R_{cp}} \sum_p \frac{R_{cp}}{\sum_c R_{cp}} \sum_c R_{cp} Y_c. \tag{4}$$

Now, if we interpret R_{cp} as a network connecting countries to the products they export, then $EXPY$ and $PRODY$ are measures of sophistication that mix information on income (Y) with information on the structure of the R_{cp} network.

The use of income information in the creation of $PRODY$ and $EXPY$ has been criticized. This is because income information makes the observation that "rich countries export rich country goods"

[REF] seem somehow circular. This criticism, however, can be answered properly by separating the information on income (Y) from the information on network structure (R_{cp}) in $PRODY$ and $EXPY$.

We can remove the contribution of income (Y) from $PRODY$ and $EXPY$ explicitly from their definitions in two steps. First, we set $R_{cp} = 1$ if R_{cp} is larger than a certain $R*$ threshold. This is a simple way to transform R_{cp} into a simple graph, making the network structure explicit. Going forward, we avoid confusing the weighted and unweighted versions of the network by referring to the unweighted version as M_{cp}, while we continue to use R_{cp} for the weighted version. Finally, we make Y_c equal to the number of connections, or degree (k_c), that that country has in this network. k_c is a measure that comes only from the structure of the network. Mathematically these transformations are:

$$M_{cp} = 1 \; if \; R_{cp} \geq R^*, \tag{5}$$

$$Y_c = k_c \; \forall \; c. \tag{6}$$

where k_c is given by

$$k_c = \sum_p M_{cp}, \tag{7}$$

and represents the *diversification* of country c (the number of products that that country makes).

Additionally, we define the degree, or *ubiquity*, of a product in this network as

$$k_p = \sum_c M_{cp}. \tag{8}$$

We refer to k_p as the ubiquity of a product, as it is the number of countries that export that product.

If we apply these transformations to the definition of $PRODY$ presented in (2), we find that after removing the contribution of income, $PRODY$ reduces simply to the average nearest neighbor degree [27, 28] of a product in the network, which we denote as $k_{p,1}$, where the 1 subscript is used to indicate that this is the average degree of the nodes that are at distance 1 from product p.

$$PRODY_p \rightarrow k_{p,1} = \frac{1}{k_p} \sum_c M_{cp} k_c. \tag{9}$$

Similarly, these transformations take EXPY into a weighted average of the degree of nodes at distance two in the network of country c. Here the weights are given by the probability that a random walker that started at country c would end up in country c' after two steps. These weights are the sum of the reciprocal of the degrees of all nodes that lie between country c and c', including that of country c. Formally this is:

$$EXPY_c \rightarrow k_{c,2} = \frac{1}{k_c}\sum_p M_{cp}k_{p,1}$$

$$k_{c,2} = \frac{1}{k_c}\sum_p \frac{M_{cp}}{k_p}\sum_{c'} M_{cp}k_{c'}. \qquad (10)$$

Figure 1 compares PRODY and EXPY with their network counterparts: $k_{p,1}$ and $k_{c,2}$.The strong correspondence between PRODY and EXPY with their network counterparts suggests that most of the information contained in PRODY and EXPY comes from the structure of the network connecting countries to the products they export, rather than from income.

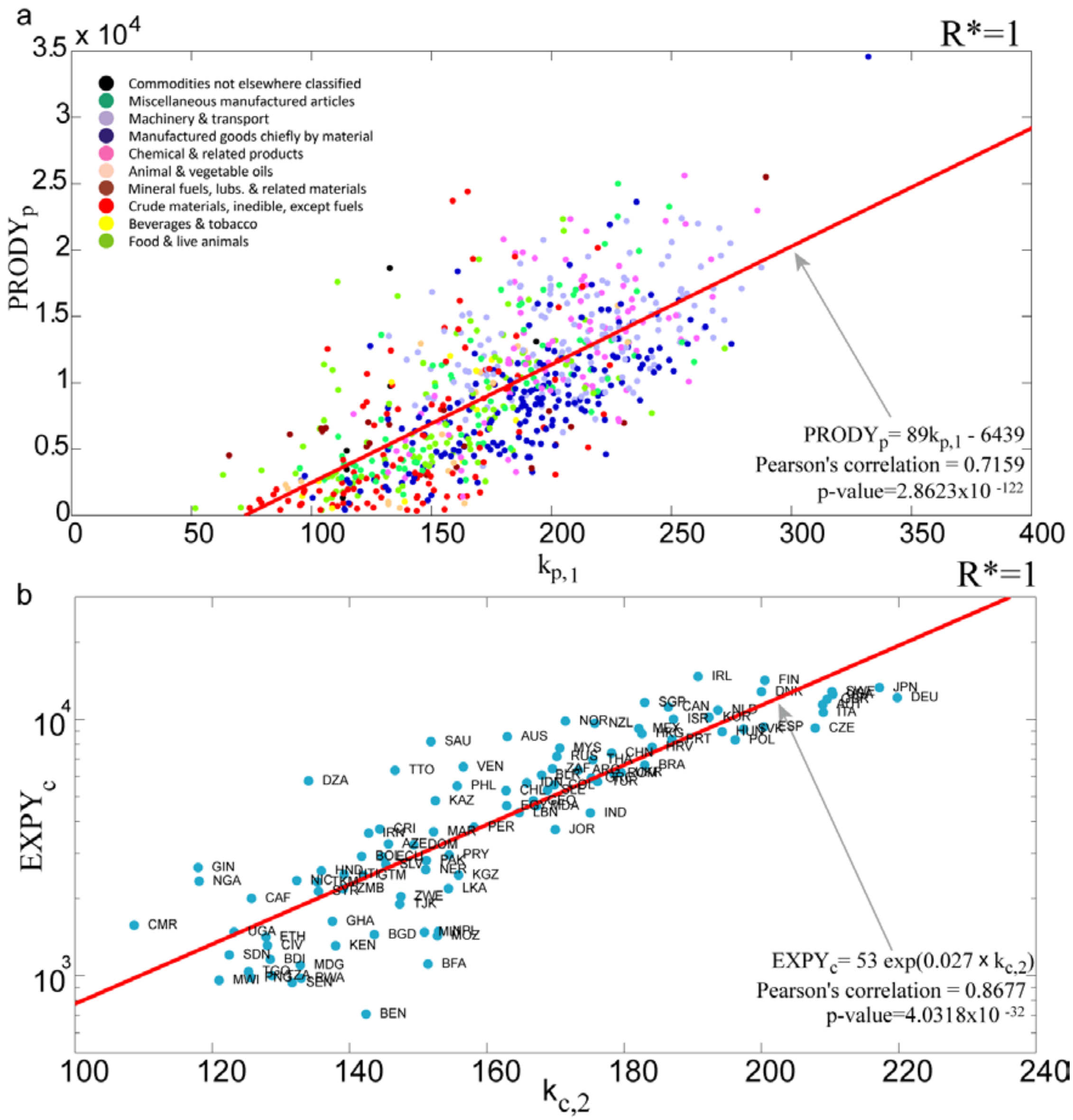

Figure 1 PRODY, EXPY and their pure network counterparts. **a.** PRODY v/s $k_{p,1}$ calculated for the year 2000 using R*=1. **b.** EXPY v/s $k_{c,2}$ calculated for the year 2000 using R*=1.

The fact that most of the variance in PRODY and EXPY comes from the structure of the network connecting countries to the products they export, rather than from the income of countries, suggests that the explanatory power that these measures of sophistication have demonstrated [1, 2] comes from the information on the diversification of countries and on the ubiquity of products. A simple explanation for why these network properties are good estimates of the level of sophistication of countries and products comes from the "Capabilities Theory" summarized in the introduction, in which a country needs a specific combination of inputs, or capabilities, to produce a product. This is because we expect countries with many capabilities to produce a wider variety of products – in other words, to be more diversified -- than countries with fewer capabilities. This is because countries with more capabilities will be more likely to have the combinations of capabilities required by more products than countries with fewer capabilities. This suggests that the level of diversification of a country will be related to the number of capabilities it has available and that k_c, $k_{p,1}$ and $k_{c,2}$ should be related to the number of capabilities available in a country.

Diversification is related to the number of capabilities available in a country, albeit imperfectly. This is because countries producing the same number of products could be making goods that require a different numbers of capabilities. In such cases, the diversification of countries would not be the most accurate estimator of the number of capabilities available in those countries, and we would need a measure of the number of capabilities required by a product to correct for this.

Using the symmetry of the bipartite network we can estimate the number of capabilities required by a product by looking at that product's ubiquity. This is because products that require few capabilities will be more likely to be produced in many countries, as countries with both many and few capabilities will probably have the necessary mix of capabilities required by products that only need a few capabilities to be produced. Therefore, we can improve our estimate of the number of capabilities available in a country, or of the complexity of its economy, by looking at the average ubiquity of the products that a country exports.

Yet the ubiquity of a product is also an imperfect measure of the number of capabilities it requires and it needs to be corrected by a measure of the number of capabilities available in the countries producing that product. From the above we know that we can approximate the number of capabilities in a country by that country's level of diversification. Hence, diversification and ubiquity are both measures of the number of capabilities available in a country, or required by a product, that have complementary biases and can be used to create estimates of the relative number of capabilities available in a country and required by products by iteratively correcting for one another. This is the idea behind the *Method of Reflections* [3] which results in a family of variables that can be used to estimate the complexity of countries' productive structures and the sophistication of products. The variables are given by:

$$k_{c,n} = \frac{1}{k_{c,0}} \sum_{p=1}^{N_p} \boldsymbol{M}_{cp} k_{p,n-1}, \tag{11}$$

$$k_{p,n} = \frac{1}{k_p} \sum_{c=1}^{N_c} \boldsymbol{M}_{cp} k_{c,n-1}, \qquad (12)$$

where $k_{p,0}$=k_p and $k_{c,0}$=k_c. The variables produced by the method of reflections can be seen as estimators of the number of capabilities available in a country and required by products and will be used in the rest of the paper as indicators of the complexity of country's productive structure and product sophistication. As we increase n, the values taken by these variables converge to the mean, so we need to worry only about the relative values obtained after enough iterations that the ranking of these variables remains unchanged. Here we use $k_{c,18}$ as our measure of a country's economic complexity and $k_{p,19}$ as our measure of product sophistication.

Results

We use the variables of the method of reflections (eqns. (11) and (12)) to study the dynamics of the level of sophistication of countries and of products. We interpret the dynamics of $k_{c,n}$(t) as a measure of changes in countries' productive structures. Figure 2 a shows the evolution of the relative ranking of economic complexity of countries, estimated by $k_{c,18}$, between 1963 and 2005. Each line follows the ranking of each country in the dataset during this period. Countries in the top rows have high values of $k_{c,18}$, indicating complex productive structures with many capabilities, whereas countries in the bottom rows have relatively low $k_{c,18}$ values, indicating that they have only a few capabilities available. In 1963, the country at the top of this list was Sweden (SWE), followed by Japan (JPN), Austria (AUT), Norway (NOR) and Great Britain (GBR), and by 2005 the countries on the top of the ranking had changed to Japan (JPN), Korea (KOR), Finland (FIN), Sweden (SWE) and Singapore (SGP). The colors of the lines that represent each country were assigned following a gradient that corresponds to the positions in the ranking occupied by countries in 1963. This coloring allows us to see that, in broad terms, the position of countries in the complexity ranking is relatively stable, albeit with some notable exceptions.

Figure 2 b highlights the countries that moved up the ranking substantially during this period. The "great transformers" of this period were Indonesia (IDN), Brazil (BRA), Turkey (TUR), Thailand (THA), Malaysia (MYS), China (CHN), Korea (KOR) and Singapore (SGP). Figure 2b, however, shows some differences in their stories. For instance, Indonesia, Brazil and Turkey started this 42 year period with primitive productive structures, which occupied spots in the bottom third of the ranking, whereas China, Korea and Singapore's progress took place within the top positions of the ranking. Our indicators suggest that even in the 1960's the productive structure of China, Korea and Singapore were quite complex and that we should have expected the income of these countries to catch up, eventually, with the complexity of their economies. Korea and Singapore grew significantly during this entire period, supporting this theory. China's growth, however, came after a series of reforms started by Xiaoping Deng in the late 1970's. Our analysis allows us to add to the story of China's miracle by suggesting that what these reforms did was to unleash an economic power that was already latent in China. Figure 2 suggests that the productive structure of China had been relatively sophisticated all along and that the economic hardships that China suffered between the 50's and 70's resulted more from a poor incentive structure than from a lack of capabilities. This also explains why we would not expect these reforms to have the same effects in other countries with productive structures that are not as sophisticated as that of China. Indeed, countries with faulty incentive structures that are at the bottom of the ranking do not have any economic complexity to unleash. Economic growth is much harder to achieve in these cases, and the use of similar policies is not necessarily advisable. Innovation to help develop new capabilities in these countries may be as important, if not more, than policies that concentrate on incentives and improving governance.

The other side of the coin is presented by Figure 2 c. Here we highlight countries whose productive structures fell behind during this 42 year period. This does not necessarily imply that these countries have not made any progress, only that any changes that occurred, whether positive or negative, have not allowed these countries to maintain the positions they held at beginning of this period. The countries that fell behind the most during this period were Jordan (JOR), Pakistan (PAK), Egypt (EGY) and Jamaica (JAM).

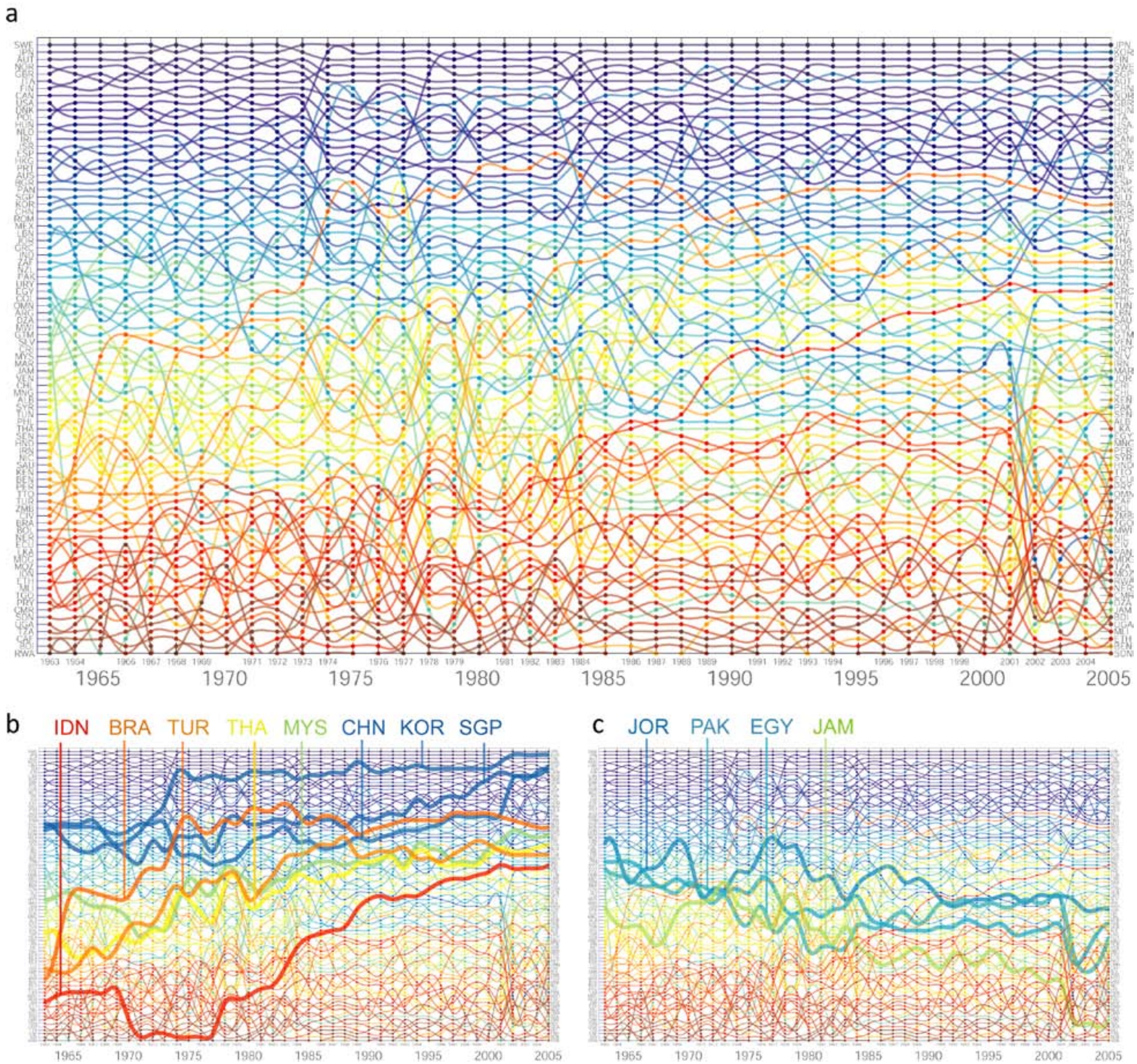

Figure 2. The dynamics of economic complexity during a 42 year period. **a.** Yearly ranking of countries by $k_{c,18}$. **b.** same as **a**, but where the countries that have increased in the ranking the most where highlighted. **c.** Same as **a**, but where the countries who have lost more positions in the ranking are emphasized.

These measures of economic complexity can also be used to track relative changes in the sophistication of products. Figure 3 compares standardized values of $k_{p,19}$ between 1985 and 2005. Products that are above the identity line are products whose relative sophistication increased during this period¸ according to this method. These products include photographic cameras, laboratory equipment, children's toys and reaction engines. Products below the line, on the other hand, are products whose relative sophistication was observed to decrease during this twenty year period, such as fuel oil, corded cotton and motorcycles.

There are several ways to interpret these changes. For some products, such as photographic cameras and laboratory equipment, we can think that the number of capabilities demanded by them changed significantly between 1985 and 2005. Photographic cameras and laboratory equipment definitely increased in sophistication during this twenty year period. The method of reflections will pick up a change in the number of capabilities required by a product as either an increase in the diversity of the countries producing such products or a reduction in that product's ubiquity. A reduction in the relative ubiquity of a product could come from either countries exiting the market of that product when they are not able to keep up with increases in its sophistication, or from a relatively small increase in ubiquity during that same period. For instance, an increase in the number of capabilities demanded by a product is likely to reduce the chances that new countries, with less sophisticated productive structures, enter that market. This would reduce that product's relative, but not absolute, ubiquity.

The relative reduction in the sophistication observed for some products, however, could be due to either a reduction in the number of capabilities required in the production of that product, a widening in the spectrum of that product's sophistication, or adverse affects associated with the specialization of a country in a product. Globalization is likely to reduce the number of capabilities required by many products, as it allows countries to trade tasks and product parts. This will help break down the complexity required to produce a product by allowing countries to specialize in specific parts of the value chain that require a reduced number of capabilities. Other products, on the other hand, could have an increase in their range of sophistication that is biased toward less sophisticated varieties. Motorcycles, for instance, while they are still a relatively sophisticated product, have increased their variety towards less sophisticated types, such as very simple scooters. This reduction in sophistication is somehow spurious, but would disappear with more disaggregated data that could differentiate, for instance, between high performance racing motorcycles and basic scooters. Finally, natural resource products are known to affect the productive structure of countries by limiting their ability to diversify, through mechanisms such as Dutch Disease (a disproportionate appreciation of the exchange range due to large natural resource exports) and because of the peripheral location of natural resources in the product space, which forces those countries to specialize in capabilities that do not have many alternative applications [4].

Despite this variation, Figure 3 shows that most products remain close to the line, indicating that the level of sophistication of products remains relatively stable during this 20 year period. Indeed, the correlation between these two series is $\rho=0.8047$ ($p<10^{-176}$), confirming that while there were many links formed and destroyed in the network (the number of links in 1985 with $R^*\geq1$ was 10884 while in 2005 it was 16458) the observed relative complexity of products did not change considerably. This suggest that countries diversify their productive structures by moving towards products with a complexity that is similar to that of countries' current productive structure [3], leaving some macro structures of the network unchanged as the network becomes more dense.

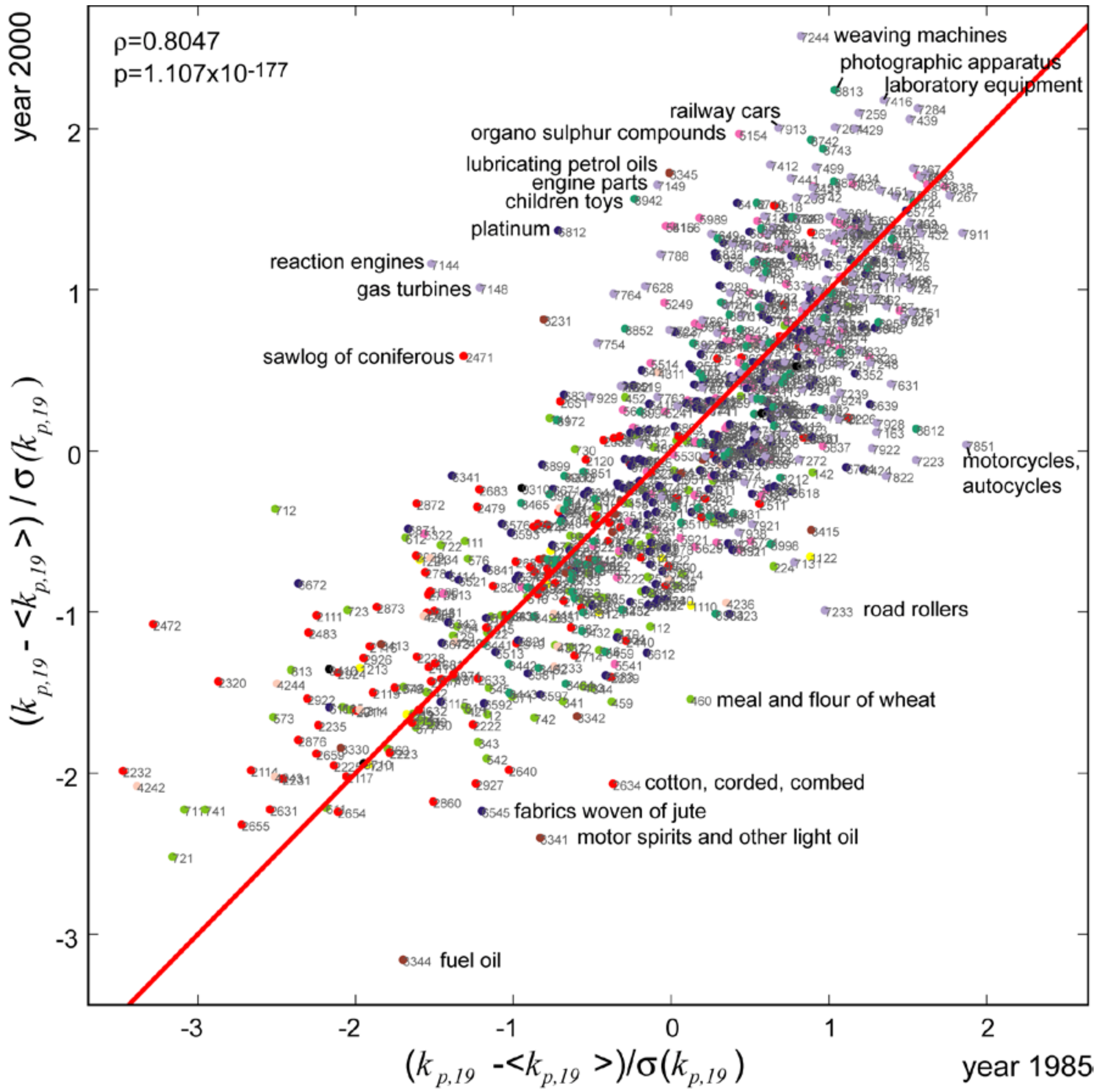

Figure 3 Comparison between the sophistication of products in the years 1985 and 2000 through the use of the normalized values of $k_{p,19}$.

We can quantify the degree to which these macro properties of the network connecting countries to the products they export changed during this period by calculating the average correlation between the economic complexity indicators, $k_{c,n}(t)$ and $k_{p,n}(t)$, at different time intervals. We define

$$\rho(k_{x,n}, T) =< corr\left(k_{x,n}(t), k_{x,n}(t+T)\right) >, \tag{13}$$

where x can be either c or p, and the "<" and ">" braces stands for the average, which in this case is taken over all pairs of $k_{x,n}$ that are separated by a time difference of T. Figure 4 a shows the dependence on T of $\rho_{x,n}$ for countries and products, demonstrating that the rankings of productive structure complexity, and of product sophistication, change slowly over time. This means that the macro network structure captured by $k_{x,n}$ is fairly stable during this 42 year period.

Finally, we turn our attention to the Product Space [4], the projection of M_{cp} in which products are connected according to the probability that countries export them in tandem. We measure the distance between products in the Product Space by using *proximity*, which is defined as the minimum of the pairwise conditional probability of co-exporting a pair of products, given that you export either one of them [4]. Formally, the proximity between products p_1 and p_2 is defined as:

$$\phi_{p_1p_2}(M_{cp}) = \min\left(\frac{\sum_c M_{cp_1}M_{cp_2}}{\sum_c M_{cp_1}}, \frac{\sum_c M_{cp_1}M_{cp_2}}{\sum_c M_{cp_2}}\right). \tag{14}$$

We can study changes in the connectivity of products across time by introducing

$$Q_p = \sum_{p'} \phi_{pp'} \tag{15}$$

as the weighted average degree, or connectivity, of product p, and by studying the dependence on T of $\rho(Q_p, T)$. Additionally, we study $\rho(Q_c, T)$, where Q_c is the equivalent for countries of Q_p, obtained by using (14) and (15) and changing countries by products.

Figure 4b shows that the connectivity of products in the Product Space does not change substantially during this 42 year period, yet the connectivity of countries in the "Country Space" does. This suggests that while the structure of the Product Space remains quite stable during this period, due to the relatively slow changes in technology that alter the sophistication of products, the relationships between the productive structures of countries did not. Changes in the structure of M_{cp} , therefore, are mostly driven by the structural transformation of some countries in a world where products evolve slowly.

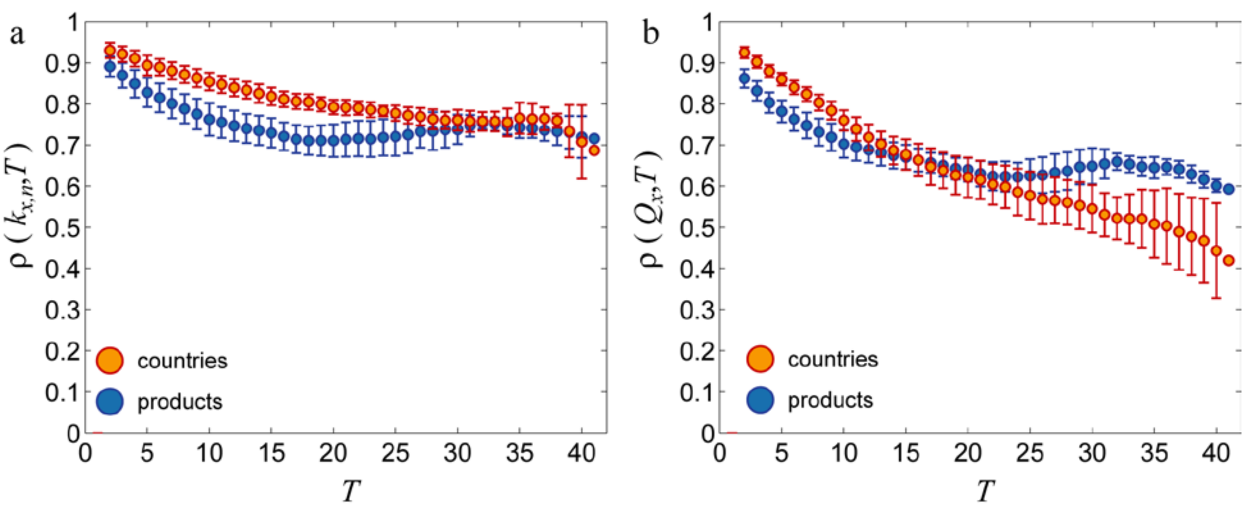

Figure 4 Changes in M_{cp} and in the Product Space. **a.** Average correlation between measures of economic complexity and product sophistication taken with a separation of T years (n=19). **b.** Average correlation between the connectivity of countries and products in their respective projections of M_{cp} (the Country Space and the Product Space) measured T years apart.

Finally, we visualize the structure of the Product Space during this period by creating network visualizations of the Product Space following the same procedure that was used to visualize the Product Space when it was first published. Figure 5 shows five panels in which we present network visualizations of the Product Space for the years 64-66, 74-76, 84-86, 94-96 and 03-05. These visualizations allow us to see the evolution of some important qualitative properties of the Product Space.

Figure 5 shows that during the entire study period products such as vehicles and machinery (in light blue) populated the more densely connected part of the network. Oil and some of its derivate products (in crimson), in contrast, are always located in a weakly connected "twig" on the periphery of the network, demonstrating that oil remained a peripheral product that required specific capabilities that did not foster development, despite the large revenues that oil generated. Agricultural products (in light green) and raw materials (in red) are also consistently located in the periphery of the space during the entire study period.

An interesting story that emerges from Figure 5 is that of the evolution of the electronics sector (light blue). The figure suggests that electronics started as a small cluster of peripheral nodes in the mid-80's that evolved into a large group of densely connected nodes in the mid-90's. The cluster then became part of the core of the network during the first decade of the 21st century. This shift suggests that the capabilities required to produce electronics in the 80's were very industry specific, but could have coevolved with other capabilities to find a wide set of applications during the last couple of decades. While motivated by this analysis, this hypothesis would need further research to be confirmed.

Finally, we look at the dynamics of the garment sector, which appears to oscillate in and out of the central cluster during this period. This pattern is likely due to the fact that several of East Asia's fast structural transformers produced garments at some point during this period. It would suggest, as many have argued [29, 30], that garments can be an important first step towards industrialization.

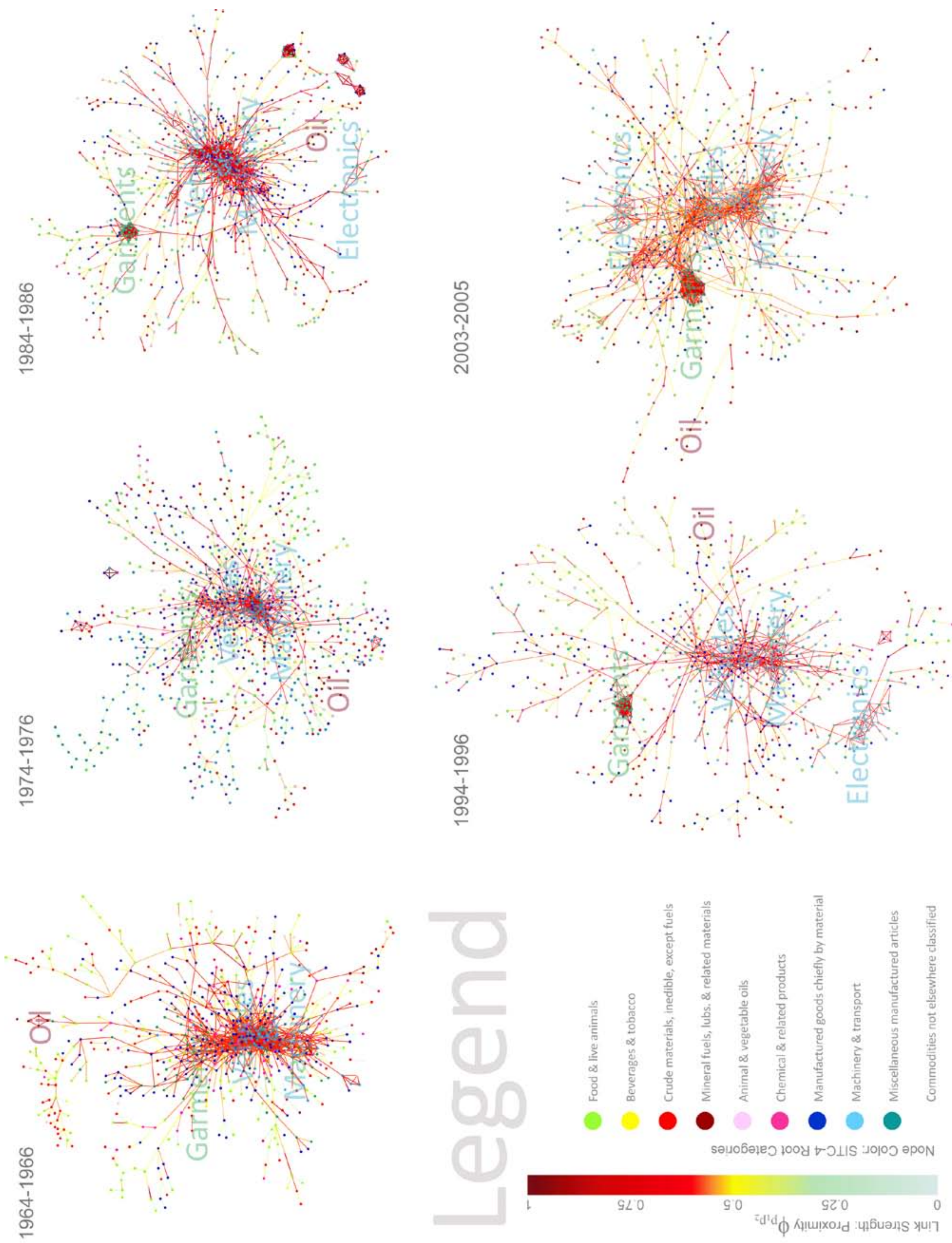

Figure 5 Visualization of the Product Space at five different time periods

Discussion

Understanding economic complexity-- and creating quantitative measures that capture it -- can help to illuminate the path of economic development. Measures of economic complexity and product sophistication provide us with objective metrics for a country's level of industrial development and can inform strategic decision making, as the sophistication of the products that a country currently exports, together with their location in the Product Space, are relevant for the future development of that country's economy.

In this paper we studied the dynamics of the network connecting countries to the products they export, and some important observables that are derived from that network, such as the measures of economic complexity that are defined by the method of reflections, and the two projections of the M_{cp} network, The Product Space and The Country Space.

Through this analysis we learned that the productive structure of countries evolves slowly in a space of products that has relatively stable qualitative and quantitative features. We identified some of the best structural transformers of this period and found differences in their stories. Countries such as Brazil, Indonesia and Turkey, transformed their productive structures dramatically, primarily between 1963 and 1990. These countries now compete with a relatively complex productive structure that is still less sophisticated than that of China, Korea and Singapore, who advanced significantly in the complexity ranking during this period, albeit having started from a relatively high position.

These observations are relevant because the development advice that usually emerges from economic research deals primarily with questions of incentives and institutions. The data presented here, however, highlights another important aspect of development that is rarely considered, which is *capability-building*. Traditional economic theory assumes that the production of goods and services is trivial, and that therefore their availability depends only on the demand for them and the costs of the few abstract factors that are required to produce them. This counterintuitive idea comes from the way in which products have been traditionally abstracted away in the development of economic theories, which is as different combinations of a fixed set of factors. According to traditional economic theory, a banana and a satellite are different combinations of a few factors of production such as labor, land and capital. The fact that some countries produce bananas and others produce satellites emerges, therefore, from differences in the local cost of these factors, as the theory assumes that these factors are available to some degree anywhere. In a world in which bananas and satellites are different combinations of the same things, countries such as Liberia and Honduras "choose" not to build satellites because the cost of production is too large, not because they do not have what it takes to make them.

The Capabilities Theory, which provides the logical underpinning of the empirical analysis presented in the body of the paper, abstracts products differently by describing them as large collections of specific inputs that must be locally available for a product to be produced. In this worldview, a banana and a satellite can in principle use many of the same capabilities, but can also use a completely different set of them. The latter case is critical to improving development policy, as it implies that development is not necessarily about lowering the relative cost of a few abstract factors of production, but rather about the accumulation of new capabilities. Moreover, as products are combinations of capabilities, their complementarities introduce coordination challenges. As capabilities generate returns only in the presence of other capabilities, their accumulation can be extremely difficult to manage.

The theory and empirical analysis that we presented in this paper help differentiate cases such as Singapore, Korea and China, from other countries. The narrative the analysis proposes is that these growth miracles did not sonly occur because of appropriate incentive structures, but also because of a complex economic structure that had been dormant for decades, even if it was present only in a small fraction of the urban population. China was ~80% rural during the 20th century, but the 20% that was urban, which in absolute numbers was quite large, was enough to sustain a large network of complex economic interactions that seeded the productive structure of China today. The measures presented here, while they make claims about past economic complexity historically after the fact, they do so using data from the period.

One question that emerges then is how much of the miracle of small, fast- growing states such as Singapore and Hong Kong is due to the European institutions that were exported into these countries by colonial powers, or was due to the latent potential in the collective evolutionary process that already existed in these societies? The fact that other European colonies failed to transform the way East Asian miracles did would suggest that the evolution of economic complexity could play an important role in development. This hypothesis has yet to be tested, and should be explored more rigorously.

Finally, these findings motivate a discussion of the role of the government in a country’s economy. Much of the debate over the economic role of the public sector has focused on whether the government should be an active economic agent or stay completely out of businesses that are not related to the provision of public goods. Economies are complex evolutionary systems, however, and like all evolutionary systems, are characterized by important path dependencies. The current state of the system matters, and our results show that there is substantial variation in the level of complexity from which most countries begin the development process. In cases in which this complexity is present, good governance and institutions might be all that is needed to stimulate capability-building and economic growth. In complex economies the private sector has enough feet on different rungs of the development ladder that it can use this strong footing to push the economy into the next rungs. In cases where economic complexity is not present, however, it may be beneficial to have an active government to help coordinate the accumulation of capabilities. In our experience, however, this type of investment should not translate into, the creation of government enterprises, but rather into the design of a new set of institutions and agencies that would more strategically cater to the needs of the private sector, considering both, existing businesses and emerging players that do not yet have the political capital to influence public inputs. Like chaperones in cell biology, these agencies would help catalyze the private sector’s own self-discovery process [31] by helping to identify and develop capabilities that are necessary to move businesses into increasingly more sophisticated products -- and move countries into increasing levels of prosperity.

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