Growth Networks*

Raja Kali    Josh McGee    Javier Reyes
Stuart Shirrell†
Department of Economics
Sam M. Walton College of Business
University of Arkansas
Fayetteville, AR 72701

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Abstract

Efficient networks in nature are frequently small-worlds, combining high clustering among nodes with short distance across nodes. We map the relationship between products in global trade (product space) and the products a country exports (product specialization) as a network to examine the hypothesis that countries whose product specialization resembles a small-world are more likely to experience high growth episodes. We devise network measures of spillovers within a country’s exports and distance between product specialization and the rest of product space. The interaction between spillovers and distance, representing trade-offs in the network, is key for the probability of growth acceleration. It is not enough to have only high spillovers between products, or only short paths to new products. An intermediate level of the interaction is associated with the highest probability of growth acceleration.

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†Department of Economics, Sam M. Walton College of Business, University of Arkansas – U.S.A.; e-mail: rkali@walton.uark.edu, jmcgee@uark.edu, jreyes@walton.uark.edu, sshirrell@uark.edu.
1 Introduction

Until quite recently, few relationships enjoyed as much consensus among economists as that between trade and growth. The view that integration into the global economy is a reliable way for countries to grow permeated advice from multilateral institutions such as the World Bank, the IMF, the OECD, as well as discussions by many distinguished economists (Krueger, 1998; Fischer, 2000, for example). This view was supported by an influential body of research, the best known of which are papers by Dollar (1992), Sachs and Warner (1995), Ben-David (1993), and Frankel and Romer (1999). However, the consensus has been thrown into disarray by criticism of this literature over problems in measuring openness, the statistical sensitivity of specifications, the collinearity of protectionist policies with other bad policies, and other econometric difficulties (Rodriguez and Rodrik, 2000; Harrison and Hanson, 1999). This has led to scepticism regarding the existence of a general, unambiguous relationship between openness and growth. A recent attempt to update the Sachs and Warner approach by Waczaig and Welch (2008) notes that while the evidence paints a favorable picture of outward-oriented policy reforms on average, it cautions against one-size-fits-all policy that disregards local circumstances. Focus has therefore shifted to a scrutiny of the channels through which trade openness may influence economic performance, and the way in which the relationship between trade and growth is contingent on country and external characteristics.

We contribute to this literature by identifying a novel mechanism which facilitates transition to a high growth path. We focus on the relationship between products in global trade and the characteristics of a country’s pattern of product specialization as revealed through its exports. The pattern of relatedness among products in global trade is referred to as “product space” following recent work by Hausman and Bailey (2007) and Hidalgo et. al. (2007). It seems natural to interpret “product space” in terms of a network. We therefore adopt a network interpretation of product space, which enables us to draw upon analytical methods from the recent literature on complex networks\(^1\). Explicitly mapping product space as a network and then superimposing a country’s pattern of product specialization on product space enables us to devise a measure of clustering between the products in a country’s export basket and a measure of how distant a country’s product specialization pattern is from the rest of product space. We use the clustering measure as a proxy for spillovers between the products in a country’s export basket. The distance measure gives us an indicator of how difficult it is likely to be for a given country to move from its current product specialization

\(^1\)Newman (2000) and Albert and Barabasi (2002) are good overviews of this literature. Jackson (2009) and Goyal (2008) are good introductions to the economics of networks.
to new products. We suggest that spillovers within the products constituting a country’s export basket and the distance to new products are of concurrent importance for a poor country’s ability to move to new products and higher growth rates.

One of the general results of the literature on complex networks is that high performance networks in many settings (biological, technological, social, economic) have the “small-world” property (Watts and Strogatz, 1998; Watts, 2004; Albert and Barabasi, 2002; Goyal et al., 2006). A small-world is a network whose topology combines high clustering among nodes with short average distance (path length) across nodes. Inherent in most networks is a trade-off between short distance across nodes and high clustering among nodes, since one comes at the expense of the other. By balancing this trade-off, the small-world is an “efficient” topology. In our context, nodes are products, and we associate high clustering in the network with strong spillovers (technological and informational) between products. Short average path length provides the potential for leaps across the network, to new products. Both features are advantageous in the context of economic development and growth. Could it be that the key to acceleration in the rate of growth is whether the pattern of product specialization of a country (as reflected in its export basket) develops a small-world topology before the take-off?

Why should a small-world network in product space facilitate rapid economic growth? The economic intuition is straightforward. Clustering of products enables economies of scale and scope and other agglomeration externalities. Short path length in the network allows “leaps” across product space to new products. The extent of scale and scope economies and knowledge externalities determine cost reductions, freeing up resources for investment. Investment capabilities in turn determine how far a country can leap. Distance in product space determines how far a country needs to leap to reach new products. The relationship between clustering and network distance in product space thus plays a role in determining the likelihood of a leap to a higher growth path. We present a simple formalization of this intuition in a model below. These arguments are closely related to the literature on successful industrial districts (such as Silicon Valley as studied by Saxenian, 1994 and Castilla et al., 2000) or city growth (Jacobs, 1984; Glaeser et al., 1992). However, prior perspectives have not explicitly adopted network methods, which enable quantification of these patterns.

We use these ideas to explain transitions in economic growth classified by Hausman, Pritchett and Rodrik (2005) as “growth accelerations”. Focusing on well defined growth acceleration episodes is advantageous because it circumvents common problems faced by

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2 Growth accelerations are defined as rapid growth episodes that satisfy the following conditions: (i) per-capita income growth increase ≥ 2% per year, (ii) the increase in growth has to be sustained for at least 8 years, (iii) the post-acceleration growth has to be at least 3.5% per year, and (iv) post-acceleration output has to exceed the pre-episode peak level of income, to rule out cases of pure recovery.
growth regressions which assume a single model for all countries when in reality different countries may be at different stages of development, as well as standard endogeneity concerns associated with growth regressions. Hausman et. al. find growth accelerations to be highly unpredictable. The vast majority of growth accelerations are unrelated to standard determinants such as political change and economic reform, and most instances of economic reform do not produce growth accelerations. This leaves us with a conundrum. Are growth accelerations idiosyncratic and a matter of luck? The implications of such a conclusion would be distressing, to say the least. But while the mechanics of these transitions continue to be a mystery, the good news is that Hausman et. al. find that growth accelerations are a fairly frequent occurrence. Of the 110 countries in their sample, 60 have had at least one acceleration in the 35-year period between 1957 and 1992 – a ratio of 55 percent.

A small-world configuration could come about because (global) product space and the (local) pattern of product specialization of a country, which are both evolving over time, intersect so as to create conditions approximating a small-world network. If true, then this implies that a country’s location in product space and its pattern of product specialization matter for its likelihood of experiencing a growth acceleration. If we can find evidence for this line of reasoning, then we will have made important progress in decoding the mystery of growth acceleration and its relationship to trade and comparative advantage. Examining this insight is the primary goal of this paper.

A summary of our methodology and findings is as follows.

1. First, we chart the topology of product space across time, from 1965 to 2000. This provides us with evidence that the product space network of relatedness among products based on the pattern of revealed comparative advantage in world trade has evolved considerably over this period.

2. Second, we map the product specialization pattern of individual countries in our dataset over the period 1965-2000. Then, for every year, we superimpose country-level product specialization on to the (global) product space network. Superimposing the country-level product specialization “sub”-network on to the larger product-space network enables us to identify network properties of country-level product specialization. From this we obtain network measures of clustering within a country’s export products and distance to potential products. We use these measures to suggest that countries which experienced episodes of growth acceleration had an overlap between their product specialization pattern and product space which provided a combination of high spillovers between current products and low network distance to potential new products prior to growth acceleration, while countries which failed to experience subsequent growth
acceleration did not. Following the literature on complex networks, we refer to the combination of high clustering and low network distance as the “small-world” configuration. Thus, countries that subsequently experienced growth acceleration had an intersection between their product specialization pattern and product space that created propitious, small-world-like, conditions. They were, we could say, ‘in the right space at the right time.’

3. Third, we run a multivariate probit regression to examine if there is large sample support for the hypothesis that if a country’s pattern of product specialization exhibits high clustering between current products and low average network distance to potential new products – resembles a small-world – then it is more likely to experience subsequent growth acceleration. We find that our network measures are statistically significant in predicting a heightened probability of experiencing subsequent growth acceleration. Consistent with our small-world hypothesis, we find that the interaction between our measure of spillovers (clustering) and distance plays a key role in enhancing the probability of country-level growth acceleration.

4. Fourth, we use the network-based spillover and distance measures computed from our data in conjunction with the estimated coefficients from the regression to build a grid of the probability function for different spillover-distance combinations. This exercise demonstrates that the interaction between these variables establishes a distinct region where the probability of growth acceleration is high. We find that the shape of the high probability region resembles an arc. The arc indicates that it is not enough to have only high spillovers between products, or only low average distance to new products, for a heightened probability of experiencing a growth acceleration. We also find that the probability of growth acceleration falls off quite sharply outside of the arc traced by this exercise. In other words, the interaction between spillovers and distance needs to be of a certain magnitude for the highest probability of growth acceleration. This is consistent with the trade-off between clustering and distance inherent in a small-world network.

By bringing a network approach to product space and then using these measures to explain growth acceleration, we bring disparate strands of research together, and, we hope, provide a distinct and valuable contribution to the literature on trade, comparative advantage, and economic growth. In the next section we explain our hypothesis and the network approach in more detail. In section 3 we present a simple theoretical framework to explain why spillovers within a country’s export basket and the distance of the export basket to
potential new products matter for growth acceleration. Section 4 outlines our empirical strategy. Section 5 presents results. Section 6 concludes.

2 Product Space, Country Specialization, and the Small World

Product Space

We follow Hidalgo et al. (2007) and Hausman and Bailey (2007) in computing the product space of relatedness among products based on the pattern of revealed comparative advantage in world trade. We provide a brief description here; the reader is referred to their papers for more detail. Like them, we use the NBER World Trade Database for the computation of product space (Feenstra et al., 2005).

The first step is the computation of “revealed comparative advantage” (RCA), which measures whether a country $c$ exports more of good $i$, as a share of its total exports, than the “average” country (i.e., $RCA > 1$ not $RCA < 1$).

$$RCA_{c,i} = \frac{\sum_i x(c,i)}{\sum_{c,j} x(c,i)}$$

(1)

RCA, thus computed, is then used to compute “proximity” between products, which formalizes the intuitive idea that the ability of a country to produce a product depends on its ability to produce other related products. If two goods are related because they require similar institutions, infrastructure, resources, technology, or some combination thereof, they will likely be produced in tandem, whereas dissimilar goods are less likely to be produced together. Formally, the proximity $\phi$ between products $i$ and $j$ is the minimum of the pairwise conditional probabilities of a country exporting a good given that it exports another:

$$\phi_{i,j} = \min\{P(RCAx_i|RCAx_j), P(RCAx_j|RCAx_i)\}$$

(2)

The matrix of these proximities characterizes product space. We compute the proximity matrix for every year between 1965 and 2000, using data for 187 countries. These matrices can be compared to understand how product space has evolved during this period. The proximity matrix can be considered a complex network, where each product represents a complex network that are large scale graphs that are composed of so many nodes and links that they cannot be meaningfully visualized and analyzed using standard graph theory. Recent advances in network research now enable us to analyze such graphs in terms of their statistical properties. Albert and Barabasi (2002) and Newman (2003) are good surveys of these methods.
node in the network while the edges between them and their intensities are denoted by the proximities between the products. Given the symmetry of the proximity matrix, the network resulting from it can be characterized as a weighted, undirected network. This perspective then allows us to analyze product space and its evolution in terms of the properties of the network.

**Country Level Product Specialization**

The set of products for which a country possesses RCA (>1) is referred to as country level product specialization. This is the comparative advantage of a country as revealed through its exports. We can examine how this set has changed over the time period of our data for countries which experienced growth acceleration and those that did not. Essentially, the set of products for which a country has RCA > 1 defines a sub-network in product space, which we study over time.

**The Small World Hypothesis**

We conjecture that if we were to superimpose country level product specialization on product space, we would find that the pattern of product specialization displays a small-world configuration for countries which experienced growth acceleration, prior to their take-off. Conversely, countries which did not experience growth acceleration did not see their country level product specialization pattern resemble a small world. This is our key hypothesis.

If product space is changing over time (due to changes in technology, preferences and other effects), then a country with a particular pattern of product specialization might find that the product space has moved to a configuration that creates advantageous conditions for product leaps and thus faster growth. It could also be that both product space and the country-level patterns of product specialization have changed over time. In other words, product space and country-level product specialization could have both evolved, and eventually intersected in such a way as to create a small-world and enable product leaps. According to this view, we could say that the key to growth acceleration is thus a matter of being ‘in the right space at the right time.’

3 A Model

We present a theoretical model to formalize the intuition for why a country should experience a greater likelihood of growth acceleration if its pattern of product specialization resembles a small world network in product space. The purpose is not to provide a general equilibrium economic growth model, but simply to highlight intuition that will help with the interpretation of our empirical results.

The countries that are the focus of our study are all lower income developing countries,
without dominant global market share in any product. Hence we consider them price-takers on the global market, similar to the familiar “small open economy” assumption in international macroeconomics. We also assume that access to financial markets to fund expansionary activities is not available to firms. This seems a reasonable assumption since the countries that are the focus of our inquiry are mostly low income with poorly developed financial markets.

At time $t = 1$ country $x$ has RCA (revealed comparative advantage) in a set of products, $R = \{y_1, y_2, \ldots y_{n1}\}$. Set $R$ can be referred to as the product specialization pattern for country $x$. Production takes place in firms, which produce one unit of a unique product in each period. Each product $i$ faces a world price of $p_{yi}$. The cost of production for a particular product is affected by positive spillovers from the other products in which the country has RCA. The magnitude of the spillover is increasing in the proximity of the other products to the product in question. The proximity measure between product $y_i$ and $y_j$ is $\phi_{ij}$, as defined in the previous section, and captures fixed investments, shared know-how, and other synergies between the two products. Thus we let the cost of production for $y_i$ be $c_{yi} = c(\sum_{j,j\neq i}^{n1} \phi_{ij})$. Assume $c' < 0, c'' < 0$, and $c(0) = \bar{c}$. That is, higher aggregate spillovers from products in the country’s export basket are associated with lower production costs.

The $\phi_{ij}$’s thus define a weighted network between the products that country $x$ has in its RCA set. Let the vector $g_i = (\phi_{i1}, \ldots \phi_{i,i-1}, \phi_{ii+1}, \ldots, \phi_{in1})$ represent the relatedness between product $i$ and all other products in $R$. The network of relatedness among all products in $R$ for country $x$ can then be represented by $G = (g_1, g_2, \ldots, g_{n1})$. Let $S_i = \sum_j g_i$ represent spillovers that benefit product $i$. Then $c_{yi} = c(S_i)$.

A firm can attempt to ‘leap’ to another product in product space that is not currently within set $R$ and develop RCA is this new product\(^4\). If the products are all indexed numerically, then we can say this implies a leap to a product in the set $\Delta = \{y_{n2}, y_{n3}, \ldots y_N\}$ where products $n_2, n_3, \ldots$ stand for products numerically indexed after $n_1$, which is the ‘last’ product in the RCA set $R$ of country $x$ as described above. $N$ is the total number of products in product space. However, moving to a product not currently in country $x$’s export basket is costly. Assume for simplicity that the cost of moving to new products for each unit distance in product space is $\theta$. In addition, in the period immediately after leaping to a new product, there are no spillovers from other products\(^5\). These spillovers develop by the following period, and depend upon the production cluster associated with the new

\(^4\)We do not consider moves by firms within $R$ since our focus is on changes in the pattern of product specialization.

\(^5\)The assumption of homogenous distance cost in product space is clearly a strong assumption. Allowing heterogeneity in distance costs would not affect the intuition of our key hypothesis, though it would yield interesting implications regarding the direction of product leaps. We leave this extension for future research.
product.

There are three periods. Production takes place in all three periods, but consumption/utility is realized only at the end of period three.

The firm’s profit at \( t = 1 \) is \( \pi^1 = p_{yi} - c(S_i) \).

In period 2 the firm can choose to make a leap to a nearby product. Let the distance in product space to the nearest product not in \( R \) be \( d \). If the firm uses its period 1 profits to make a leap, the furthest it can go is \( \frac{\pi^1}{\theta} = d \). If \( d \geq d \), then the leap is feasible. In other words, a necessary condition for a leap to a new product in period 2 is,

\[
\pi^1 = p_{yi} - c(S_i) \geq \theta d. \tag{3}
\]

The amount \( \theta d \) could be interpreted as the cost of fixed investments associated with moving into the new product. Call (3) the “Leap Feasibility” condition.

Now suppose the price for the nearest new product (\( k \)) is \( p_{yk} \).

If the firm leaps to product \( k \) then period 2 profits are \( \pi^2 = p_{yk} - \bar{c} \).

For a firm which has leaped to a new product in period 2, period 3 profits are \( \pi^3 = p_{yk} - c(S_k) \), where \( S_k = \sum_{j,j \neq k}^{n_k} \phi_{kj} \) represents the spillovers for product \( k \) associated with the new RCA set for country \( x \), call this \( R' \).

We can then outline three possible production scenarios. We refer to Scenario (I) as “growth acceleration,” Scenario (II) as “stagnation,” and (III) as “slow growth.” Parentheses indicate time periods.

Scenario (I), Growth Acceleration:

\( (t = 1) \) Original Product \( \Rightarrow (t = 2) \) New Product \( \Rightarrow (t = 3) \) New Product.

Payoff \( \Pi(I) = p_{yi} - c(S_i) + p_{yk} - \bar{c} + p_{yk} - c(S_k) \)

Scenario (II), Stagnation:

\( (t = 1) \) Original Product \( \Rightarrow (t = 2) \) Original Product \( \Rightarrow (t = 3) \) Original Product.

Payoff \( \Pi(II) = 3(p_{yi} - c(S_i)) \)

Scenario (III), Slow Growth:

\( (t = 1) \) Original Product \( \Rightarrow (t = 2) \) Original Product \( \Rightarrow (t = 3) \) New Product.

Payoff \( \Pi(III) = 2(p_{yi} - c(S_i)) + p_{yk} - \bar{c} \)

From this setup we can see that there are a couple of issues that will come into play in determining whether a firm will make a leap, and thus whether we will observe Scenario (I). There are both demand side (price) and supply side (cost) factors involved. If the move is to more “upscale” products, with higher prices, i.e., \( p_{yk} > p_{yi} \), then, other things being equal, the transition is more likely. If the production cluster associated with the new product is more densely connected, with consequently greater spillovers on the cost side, i.e., \( S_k > S_i \),
then, other things being equal, the transition is more likely.

To see the trade-offs more clearly, subtract Scenario (II) payoff from Scenario (I) payoff.

$$\Pi(I) - \Pi(II) = 2(p_{y_k} - p_{y_i}) - (\bar{c} - c(S_i)) - (c(S_k) - c(S_i)) \quad (4)$$

Call this the “leap-incentive” condition. The second term is the period 2 increase in cost due to the leap to new products and the third term is the period 3 decrease in cost after the leap. We can see from this that ceteris paribus, a high level of spillovers in period 1 (high $S_i$) can reduce the incentive to leap because of the period 2 increase in cost (which could be large) and the period 3 decrease in cost (which could be small). Condition (4) can also be written as,

$$\Pi(I) - \Pi(II) = 2(p_{y_k} - p_{y_i}) - \bar{c} + 2c(S_i) - c(S_k) \quad (5)$$

which is decreasing in current spillovers ($S_i$), increasing in potential spillovers ($S_k$), and increasing in the price premium of potential products over current products, $(p_{y_k} - p_{y_i})$.

At the same time however, high period 1 spillovers ($S_i$) makes it easier to satisfy (3), the leap-feasibility condition. Thus, while potential spillovers ($S_k$) increase the likelihood of growth acceleration, the impact of current spillovers ($S_i$) seems a priori ambiguous. Ultimately, whether current spillovers have a positive or negative influence on the likelihood of a growth acceleration depends respectively upon whether (3) or (4) is binding. (3) can be considered the “supply-side” and (4) the “demand-side” of the growth acceleration problem as framed here. In order to see how these two constraints interact consider the following.

Rewrite the leap-incentive condition (5) as an implicit function $I(S_i, S_k) \equiv 2(p_{y_k} - p_{y_i}) - \bar{c} + 2c(S_i) - c(S_k) = 0$. Then we can obtain $\frac{\partial S_k}{\partial S_i} = -\frac{I_{S_i}}{I_{S_k}} = \frac{2c(S_i)}{c(S_k)}>0$.

The boundary of the leap-feasibility condition (3) is $F \equiv \pi^1 = 0$. This implies $c(S_i) = p_{y_i} - \theta d$. Label this value of $S_i$ as $S_i^*$. Using this value of $S_i^*$ in $I(S_i, S_k) = 0$ yields $c(S_k) = 2(p_{y_k} - \theta d) - \bar{c}$. Label this value of $S_k$ as $S_k^*$.

We can represent conditions $F = 0$ and $I(S_i, S_k) = 0$ in the following figure. Both the feasibility and incentive constraint for growth acceleration are satisfied in the shaded region.

[Figure 1 here]

The intersection of the boundary conditions $F = 0$ and $I(S_i, S_k) = 0$ yield thresholds for current ($S_i^*$) and potential ($S_k^*$) spillovers that define the growth acceleration region. A country’s position in the figure will be determined by these spillovers at the level of the products its firms produce. We could say that if the country’s pattern of product
specialization is such that its firms are within the shaded area, then it will experience growth acceleration via its firms.

Empirically, the size of the shaded region in Figure 1 can be considered a measure of the probability of growth acceleration for a country. In order to understand the empirical implications of this framework it is helpful to consider some simple comparative statics. Figure 1 facilitates some simple comparative static exercises.

**Comparative Statics**

First consider each of the constraints in turn.

**Leap Feasibility, \( F = 0 \):**

If \( d \) increases, then from condition \( c(S_i^*) = p_{yi} - \theta d \), we can see that \( c(S_i^*) \) decreases. This implies the value of \( S_i^* \) increases. The \( F = 0 \) curve shifts to the right.

If \( p_{yi} \) increases, then from condition \( c(S_i^*) = p_{yi} - \theta d \), we can see that \( c(S_i^*) \) increases. This implies the value of \( S_i^* \) decreases. The \( F = 0 \) curve shifts to the left.

**Leap Incentive, \( I(S_i; S_k) = 0 \):**

If \( \theta d \) increases, then from condition \( c(S_k^*) = 2(p_{yk} - \theta d) - \bar{c} \) we can see that \( c(S_k^*) \) decreases. This implies the value of \( S_k^* \) increases. This implies the \( I(S_i; S_k) = 0 \) curve shifts to the left.

If \( \bar{c} \) increases, then from condition \( c(S_k^*) = 2(p_{yk} - \theta d) - \bar{c} \) we can see that \( c(S_k^*) \) decreases. This implies the value of \( S_k^* \) increases. This implies the \( I(S_i; S_k) = 0 \) curve shifts to the left.

Thus if \( \theta d \) increases, both curves shift. In other words, if the cost of making a leap to new products increases, then the \( F = 0 \) curve moves right and the \( I(S_i; S_k) = 0 \) moves left, reducing the shaded area where both constraints are favorable to growth acceleration.

**Spillover Levels \( S_i \) and \( S_k \)**

Now consider the implication of various levels of spillovers for the firms in a given country.

First consider the impact of higher levels of current spillovers \( S_i \), holding potential spillovers \( S_k \) constant. There are two cases to consider here, depending upon whether \( S_k \) is greater or less than \( S_k^* \). If \( S_k \leq S_k^* \) such as at point A on the figure, then higher levels of current spillovers \( S_i \) do not increase the probability of growth acceleration since there is no overlap with the shaded region as we move to the right of the diagram. The intuition is that higher levels of current spillovers do not make up for the lack of potential spillovers around new products. The leap incentive constraint becomes binding here. If \( S_k > S_k^* \) such as at point B, then higher levels of current spillovers \( S_i \) carry us into the shaded growth acceleration region. However, if \( S_i \) increases further, holding \( S_k \) constant, then we could overshoot into the non-shaded region, such as point C. The intuition for this is the “inertia effect” that takes hold if current spillovers are very high, decreasing the incentive to leap to new products. Note that this implies that starting from a low level of current spillovers, increasing current spillover levels can have a non-monotonic effect on the probability of growth acceleration.
acceleration.

Now consider the impact of higher levels of potential spillovers $S_k$, holding current spillovers $S_i$ constant. Here too there are two cases to consider, depending upon whether $S_i$ is greater or less than $S^*_i$. If $S_i \leq S^*_i$ such as at point A on the figure, then higher levels of potential spillovers $S_k$ do not increase the probability of growth acceleration since there is no overlap with the shaded region as we move up in the diagram. The leap feasibility constraint is binding here. If $S_i > S^*_i$ such as at point D, then higher levels of potential spillovers $S_k$ carry us into the growth acceleration region.

This analysis provides straightforward implications for the location of a country’s RCA set in product space, which we summarize below.

Result 1 is about shifts in the constraint lines of figure 1 while 2 and 3 are about points within the figure, holding the lines fixed.

1. High Distance: If the country RCA set is situated in a sparse part of the product space, then the fixed cost of leaping to a new product, $\theta_d$, will be high, resulting in a smaller shaded area. Empirically, this implies a low likelihood of growth acceleration. In other words, holding spillovers constant, a high distance to new products is a problem.

2. Low Spillovers: If the country RCA set is situated in a sparse part of the product space, then levels of both current and potential spillovers, $S_i$ and $S_k$ will be low, lying to the south-west of the shaded area. Empirically, this implies a low likelihood of growth acceleration. In other words, holding distance constant, low levels of spillovers are a problem.

3. Non-monotonicity: If potential spillover levels are above a threshold, then higher values of current spillovers have a non-monotonic effect on the probability of growth acceleration. Empirically, this implies that with higher current spillover levels the probability of growth acceleration first rises and then falls.

Note that in combination, these results leads us to expect a non-monotonic relationship for the interaction effect of spillovers and distance. If both spillovers and distance are low, the interaction between them will be low and the country will not lie within the shaded area. If one or both are sufficiently high, the interaction between them will be high, and the country will not lie in the shaded area either. If the interaction between spillovers and distance is intermediate valued, then it is most likely that the country’s RCA set will overlap with the shaded area.

To test these implications in our empirical work, we devise network measures of spillovers and distance. We describe these in section 4.3.
4 Empirical Strategy

There are several steps to our empirical strategy. A small-world configuration could come about because (global) product space and the (local) pattern of product specialization of a country, which are both evolving over time, intersect so as to create conditions approximating a small-world network. If true, then this implies that a country’s location in product space and its pattern of product specialization matter for its likelihood of experiencing a growth acceleration. Therefore, we first present evidence that the product space has changed considerably between 1962 and 1970. We then present examples to show that if we superimpose a country’s pattern of product specialization on to product space then there is evidence consistent with the idea that countries that subsequently experienced growth acceleration had an intersection between their product specialization pattern and product space that created propitious, small-world-like, conditions. They were, one could say, ‘in the right space at the right time.’

This provides the motivation for obtaining network measures of spillovers within a country’s export products and distance to potential products. We then use these measures in a multivariate probit regression to examine if there is large sample support for the hypothesis that if a country’s pattern of product specialization exhibits high clustering between current products and low average network distance to potential new products – resembles a small-world – then it is more likely to experience subsequent growth acceleration.

4.1 The Transformation of Product Space

The first step in our empirical methodology is to examine if product space has evolved over time. Are the tightly connected sectors in 2000 the same sectors that were tightly connected in 1965? If the topology of product space changed considerably, then can we identify which industries descended and ascended in terms of being well connected? To this end we first map the product space between 1962 and 2000. We consider product space to be a complex network, where each product represents a node in the network and the proximity between products is used to denote a weighted link between them. Given the symmetry of the proximity matrix, the resulting network can be characterized as an undirected network. With this representation, we study the evolution of product space via properties of the network.

To answer these questions we use methods developed recently in the physics literature.

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6 There are of course many properties of the network that are interesting in their own right, such as network density and distribution of links. For the purposes of our hypothesis we focus on the community structure of the network.
to detect community structure in networks, meaning the existence of some natural division of the network such that nodes within a group/sub-network are highly associated among themselves while having relatively fewer/weaker connections with the rest of the network. In our context, a community of nodes signifies products likely to be exported together, due to technological and knowledge spillovers and resulting complementarity between them.

The partitioning of a network into communities can be done in two different ways. One way is to use a community structure algorithm that decides by itself the most appropriate community structure without prior knowledge about the network and is able to distinguish between networks having clear community structures and networks with essentially random structures. This method is also referred to as hierarchical clustering. This approach organizes the data into communities based solely on the data. There are no assumptions made regarding the specific members of each cluster or the number of clusters to be identified. This approach addresses the first question above relating to the transformation of product space as a whole.

Another way to partition a network is to use knowledge about the number and allocation of nodes into communities that are relevant for the study. In our context we want to focus on the specific dynamics within and between industries in product space. We therefore use SITC codes to partition the network. This method is called graph partitioning. We use this approach to focus on the second question posed above, relating to the rise and decline of specific industries over time in terms of network connectedness.

The community structure (hierarchical clustering) algorithm for networks that we use here was proposed by Ruan and Zhang (2008) and is referred to as QCUT. This methodology is a refinement of the algorithm proposed by Newman (2007). We first use the QCUT algorithm to identify communities into which product space is partitioned in the year 2000, and then use the 2000 community structure to partition the data of the other years. This enables us to visually examine if the 2000 community structure matches up with other years. The top left-hand panel in Figure 2 presents the hierarchical clustering based community structure of product space for the year 2000, where the proximities between each product in the product space are presented in a color coded matrix (white = no interaction and black = high proximity). Figure 2 also shows the results for the product space of 1970, 1980, and 1990 when we use the community structure identified by the QCUT algorithm for the product space in 2000 to partition the data for these years. Visually, the community structure of 2000 does not appear to be a good representation of the state of connectedness of the product space for 1990, 1980, and 1970. For instance, in 2000, the interaction within community D and between this community and others in the product space is very low, as judged by the lack of gray-dark pixels in this area, while in 1970 the interaction of products
within community D and between this community and products in other communities looks relatively high, with many dark pixels.

[Figure 2 here]

In addition, to make this comparison clearer, as a quantitative metric of the extent of change in the product space we compute the Jaccard Index, also known as the Jaccard similarity coefficient (Jaccard, 1901; Tan, Steinbach and Kumar, 2005), a statistic used for comparing the similarity and diversity of sample sets. The Jaccard index measures similarity between sample sets, and is defined as the size of the intersection divided by the size of the union of the sample sets. For our context, consider a benchmark community structure $C_1$ and an alternative structure referred to as $C_2$, and let $S_1$ be the set of vertex pairs in the same community in $C_1$, and $S_2$ the set of vertex pairs in the same community in $C_2$. Then the Jaccard Index, which lies between 0 and 1, is defined as,

$$J(S_1, S_2) = \frac{|S_1 \cap S_2|}{|S_1 \cup S_2|}$$  \hspace{1cm} (6)

For the benchmark community we use that for the product space of 2000. We then compare the community structure of all the other years against this benchmark. The results, in Figure 3, suggest substantial changes in the product space through time. There also seems to be evidence for a structural break in the rate of change in product space around 1980. There is a big difference between 2000 and 1980, but not much difference between 1980 and 1962.

[Figure 3 here]

While the visual representation of the changes of the product space via community structure and the Jaccard Index suggest transformation in the product space over time, they do not identify where in product space the transformations are taking place. In order to study industry changes in connectedness we next compare specific product space network partitions, where the “communities” are pre-specified according to SITC one-digit industry codes. This partitions the product space into 10 SITC based clusters. The resulting 10X10 color coded graph partitioning product space matrices for 1970, 1980, 1990 and 2000 is presented in Figure 4. We see that the number of high intensity links (gray and dark pixels) increases over time and is substantially higher in 2000 as compared to 1970. The diagonal elements of this matrix denote the sum of the pair-wise, product by product, proximities within industries relative to the overall sum of proximities for the whole matrix, while the off-diagonal elements represent the sum of proximities that exist between industries relative to the overall sum.
The color-coded graph partitioning matrices for 1970, 1980, 1990 and 2000 in Figure 4 provide an overview of the evolution of the product space at the industry level. In 1970 we see that the within-industry interaction of the manufactured goods (classified by materials) industry (row 7 in the diagram, corresponding to SITC 6) dominated product space and there was some interaction between this industry and the machinery and transportation industry (SITC 7 which is row 8 in the matrix). The SITC 6 classification includes iron, steel, rubber, leather, paper and wood manufactures, while SITC 7 includes industrial machinery, data processing equipment, road vehicles, and telecommunications. Linkages within or between other industries were scarce in 1970. Over time a bigger cluster forms around the manufactured goods (classified by materials) industry (SITC 6), that besides the machinery and transportation industry (SITC 7) includes the industries of chemicals and related products (SITC 5, row 6) and the industry of miscellaneous manufactures (SITC 8, row 9). The SITC 5 industry classification includes goods like organic and inorganic chemicals, pharmaceutical products, fertilizers, and artificial resins, while SITC 8 includes more commercial manufactures like furniture, apparel, footwear, watches and photographic equipment.

To sum up, the results presented suggest that product space has not been static over the past 30 years. The number and the likelihood of pairs of products being exported together has increased. In terms of how the product space has changed, we see that in particular, the manufacturing industries (SITC 6 and SITC 8) and their overlaps with chemicals and related products as well as with machinery and transportation equipment industry have been the sectors that have experienced the clearest transformations in terms of becoming more tightly connected to surrounding industries.

4.2 Country-Level Specialization and the Small World

We now move from “global” product space to “local” country-level patterns of product specialization. Here we superimpose country-level patterns of product specialization on the product space to see if there is evidence consistent with our small-world hypothesis. If a country’s product specialization lies in industries that are in the tightly connected regions of product space then it is better positioned to take advantage of spillover effects within those industries and also across industries which overlap with the connected cluster. As described earlier, a small-world configuration in product space is of value to a country for two interlinked reasons. First, it enables spillovers, which reduce production costs and free

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7 Appendix 1 is a list of the products in each of the SITC classifications.
up resources for investment. Second, since the average distance to new products is low in a small-world, “leaps” to new products are not too costly, and are more likely to be feasible given the investment capabilities of the country.

The country-level product specialization pattern, defined as the set of products for which the country has RCA (>1), can be superimposed on the product space. In other words, once the set of products for which a country has RCA in a given year is identified, these products and the proximities between them as dictated by the product space for that year can be examined as an undirected complex network as was done for the product space. In addition, by using the graph partitioning method based on the one-digit SITC Industry codes described above, we can compare the evolution of product space and country-level product specialization in a given period. We perform this exercise for three countries, Ireland, South Korea and Greece. Ireland and South Korea experienced an episode of growth acceleration but Greece did not.

First consider Ireland. The left hand panels of Figure 5 present the community structure (hierarchical clustering) of product space (top left panel) and the graph partitioning of product space (bottom left panel) in 1980, with one-digit SITC Industry code labels added to both panels. The right hand panels present community structure (hierarchical clustering) in Ireland’s pattern of product specialization (top right panel), and graph partitioning of its product specialization (bottom right panel). Figure 6 presents the same information for Ireland in 1990. Ireland experienced a growth acceleration episode in 1985, and from these two figures we can examine Ireland’s country-level product specialization before and after the growth acceleration. It turns out that Ireland’s country-level product specialization pattern was highly correlated with the product space in 1980 as well as is in 1990. The pair-wise correlation between the specialization pattern for Ireland and the product space is above 0.80 in both years. There is a clear increase in the intensity of links within industries SITC 5, SITC 6, SITC 7, and SITC 8, and their overlap with the food and live animals industry (SITC 0) which includes products like vegetables, fruits, meat, dairy products and other edible products, and the crude materials industry (SITC 2) which contains products considered as inputs in production like crude rubber, wood, textile fibers, pulp and waste paper. For Ireland, we can say that the high density portion of its product specialization pattern in 1980 was right on top of the highly clustered area of the product space. According to our hypothesis this played a key role in enabling Ireland to leap into input-related products (SITC 0 and SITC 2) and expand its export product base.

[Figures 5 and 6 here]

Our second growth acceleration country is South Korea and we present similar analyses in
Figures 7 and 8. Korea experienced growth acceleration in 1984, so we replicate the analysis for 1980 and 1990. The graph partitioning diagram for 1980 shows that Korea’s country-level product specialization lay on top of the tightly connected region of the product space in 1980. In this case the pair wise correlation is close to 0.80, for both years, as it was for Ireland. But in contrast to Ireland’s experience, Korea did not increase the interaction of manufacture oriented industries with other products (like input products in Ireland’s case) in the period from 1980 to 1990. In Korea the density of links and proximities (strength of links) within the SITC 7 products increased dramatically, and the interaction of products of this industry level and those in the SITC 6 and SITC 8 classifications expanded. These spillovers allowed Korea to expand its export basket in products like data processing equipment, telecommunications, sound recording equipment, electric machinery, road vehicles, and transportation equipment, and this also benefited exports of products like apparel, footwear, and furniture (all SITC 8) and manufactured leather, rubber, non-metallic products (all SITC 6).

[Figures 7 and 8 here]

We now look at the country-level product specialization of Greece, a country that did not experience growth acceleration and therefore can be used as a counter example to Ireland and South Korea. We replicate the analysis presented above using the same years, 1980 and 1990. From Figures 9 and 10 we can see that although Greece’s country-level product specialization in 1980 has a relatively high level of interaction within the manufacturing industry (SITC 6) and there is no interaction between this industry and the other high density industries (SITC 5, SITC 7, and SITC8). In fact the manufacturing industry in Greece has its biggest overlap with the SITC 0 industry, similar to Ireland, but the overall pair-wise correlation of Greece’s country-level product specialization with the product space is 0.66, lower than that of Ireland or Korea. When we compare the results of 1980 with those of 1990, in Figures 9 and 10, we can see that Greece’s specialization pattern shows no major transformation, across the board or within and between industries, other than increasing the activity present within the SITC 8 industrial activities. Correlation with product space even falls slightly from 0.67 in 1980 to 0.58 in 1990. Spillover effects present in Ireland and Korea were very likely absent in Greece.

[Figures 9 and 10 here]

In summary, we see that the country-level product specialization of some countries has changed over time, such as for Ireland and Korea, but there are also cases where we observe no meaningful changes, such as for Greece. These examples, of both success and failure, are consistent with our hypothesis.
4.3 Network measures of spillovers and distance

In order to empirically test the small-world hypothesis we need to examine if a country’s pattern of product specialization prior to growth acceleration (GA) resembles a small-world in the product space network. To this end, we calculate network measures that are proxies for product spillovers and distance in product space. We describe our network measures below.

**Product Distance**

For our distance measure we desire a proxy for the distance between a country’s current pattern of product specialization and new potential products that a country does not currently produce. For this we compute the average minimum network distance in product space of a new potential product $y_j$ that a country does not currently export, to the country’s current export basket.

Extending notation from section 3, a firm can attempt to ‘leap’ to a new product in product space that is not currently within the RCA set $R_x = \{y_1, y_2, ..., y_{nx}\}$ of country $x$ and develop RCA is this new product. If the products are all indexed numerically, then we can say this implies a leap to a product in the set $\Delta_x = \{y_{nx+1}, y_{nx+2}, ..., y_N\}$ where products $n_x + 1, n_x + 2, ..., N$ stand for products numerically indexed after $n_x$, which is the ‘last’ product in the RCA set $R_x$ of country $x$. $N$ is the total number of products in product space.

For each potential product $y_j$ in set $\Delta_x$ we calculate the distance to each of the goods in country $x$’s current export basket $R_x$ and then select the minimum of these, $z_j = \min d(y_l, y_j)$, where $y_l \in R_x$ and $d(., .)$ is the distance metric. The distance metric is computed as the sum of the reciprocal of proximities of the nodes on the shortest network path between two products. Since lower proximity is associated with higher distance, the reciprocal of proximity provides appropriate weights for computing distance along the path. We then take the average of these over all potential products $y_j \in \Delta_x$ as our measure of distance $D_x$. Thus,

$$D_x = \frac{\sum_{y_j \in \Delta_x} z_j}{N - n_x}$$  \hspace{1cm} (7)

$D_x$ is a measure of how far away country $x$’s pattern of product specialization is to the rest of product space. In our econometric analysis we label this measure Distance.

**Product Spillovers**

In accordance with our theoretical framework, we compute two separate measures of country-level product spillovers: current spillovers – spillovers within its pattern of product specialization, and potential spillovers – spillovers to products outside its current pattern of product specialization.

(a) **Current Spillovers**: For this we desire a proxy for the spillovers that could arise
from within a country’s current pattern of product specialization. We therefore compute a measure that captures the weighted density of links to products within a country’s export basket. First, for each product \(i\) that is part of a country \(x\)’s current export basket \(R_x\), we compute the following:

\[
\omega_i^x = \frac{\sum_{l \in R_x, l \neq i} \phi_{il}}{\sum_{m \neq i} \phi_{im}}
\]

(8)

where \(l\) indexes all the products in country \(x\)’s export basket \((R_x)\). In the denominator, we consider the same product \((i)\) in a country’s export basket and compute the sum of proximities to \(i\) from every other product \(m\) that is in product space. In the numerator, we consider only the proximities to that particular product \((i)\) from the products that are part of the country’s export basket \((R_x)\). \(\omega_i^x\) can thus be interpreted as the weighted density of links to product \(i\) (that is part of a country’s export basket) that only come from within the set of export basket products. We then weight the “within” product density measure thus constructed for each of the products in a country’s export basket by its export share and then use the weighted sum to come up with one number for each country. Thus,

\[
Density_x = \sum_{i \in R_x} \left( \frac{e_i}{\sum_{l \in R_x} e_l} \omega_i^x \right)
\]

(9)

where \(e_i\) represents the export value of product \(i\) and \(l\) indexes all the products in country \(x\)’s export basket. This gives us a measure of clustering within the products that constitute a country’s export basket which we consider a proxy for spillovers. We call this measure \(Density\) in the econometric analysis.

(b) Potential Spillovers: For this we desire a proxy for the spillovers that a country could conceivably obtain if it were to shift to new potential products in the future. However, since we cannot predict where in product space a country will actually shift in terms of its pattern of product specialization, this notion is far from well defined, and any proposed measure will reflect this shortcoming. As a proxy for potential spillovers we therefore compute a straightforward measure of the network centrality of a country’s export basket. The idea here is that if a country’s pattern of product specialization is centrally located in product space then a move into new products is also likely to be centrally located implying ready spillovers associated with the new products. First, we compute the centrality for each product in a country’s export basket. Product \(i\)’s centrality is the average of its proximity
to every other product \( m \) that is in product space,

\[
centrality_i = \frac{\sum_{m \neq i} \phi_{im}}{N - 1}
\]  

(10)

where \( N \) is the total number of products in product space. A product that is more central in the product space will be connected to a greater proportion of the \( N - 1 \) other products and will therefore have a higher value for centrality. Then we create a weighted average of product centrality for a country \( x \) where the weight is the export share of each product,

\[
Centrality_x = \sum_{i \in R_x} \left( \frac{e_i}{\sum_{l \in R_x} e_l} \right) c_i
\]  

(11)

where \( e_i \) represents the export value of product \( i \) and \( l \) indexes all the products in country \( x \)’s export basket. Finally we scale country centrality by the number of products in a country’s export basket to yield \( n_x C_x \). Scaling by the number of products captures economies of scale and scope effects, albeit in a relatively crude way. This gives us a measure that captures the overall network position of a country’s export basket in product space, which we associate with potential spillovers from new products. We call this measure \( Centrality \) in the econometric analysis.

Table 1 contains summary statistics for these network measures.

[Table 1 here]

4.4 Growth Acceleration and Network effects: Regression Framework

The next step in our empirical strategy is to use the network-based measures of spillovers and distance described above as explanatory variables in a non-traditional growth regression. We follow Hausman, Pritchett and Rodrik (2005) (HPR) and focus on specific well-defined growth episodes rather than the determinants and dynamics of growth in general. HPR characterize specific episodes of growth, referred to as growth accelerations, that identify turning points in the growth dynamics of a country. A growth acceleration (GA) is classified as such when there is an increase of 2 percentage points or more in the growth rate of GDP per capita in a given year, followed by a growth rate of at least 3.5 percent sustained for at least eight years, and the post-acceleration level of output exceeds the pre-acceleration
peak so as to rule out recoveries from economic crises. By focusing on these episodes many of the problems faced by traditional growth regressions are avoided since the specific development stage of the country loses importance; the fact that growth accelerated is the relevant information for the analysis. The objective then becomes the identification of the conditions, policy changes, or structural characteristics that explain the occurrence of growth acceleration episodes observed across countries and through time.

Our goal is to explain the likelihood of observing growth acceleration, and our empirical specification uses a probit model where the dependent variable takes the value of one for the year before which, on which, and after which a growth acceleration occurred, and zero otherwise. Having a 3 year window to mark the growth acceleration accounts for possible noise in the data that could lead to a miscalculation of the specific year in which the acceleration took place. This probit methodology is the same as that followed by HPR, but in addition to their control variables, which account for the effect of economic reforms, terms of trade shocks and political regime changes, we include network-based measures of spillovers and distance for each country in order to evaluate our small world hypothesis.

We use the following general econometric specification of a probit model:

\[
p_t = P[Z_t \leq \beta \Gamma_t + \gamma \Lambda_t] = \Phi(\beta \Gamma_t + \gamma \Lambda_t)
\]  

(12)

where \(\Phi(z)\) denotes the probit function, and \(\Gamma\) and \(\Lambda\) represent two vectors of explanatory variables, the first of which contains the network measures (density, centrality and distance) that are the focus of our inquiry, and the second contains control variables for economic reforms, macroeconomic shocks, and political regime changes, as considered by HPR. The network variables are all computed using RCA/Product Space results from bilateral trade flows extracted from the NBER World Trade Database.

Our hypothesis is that if a country’s pattern of product specialization, as depicted by these network variables, resembles a small-world then it experiences a higher likelihood of growth acceleration. In other words, the growth rate observed at \(t\) is affected/determined by the export basket structure of a country in the recent past. In order to account for this lagged effect the network variables enter the regression with lagged values based on averages across time-windows. For example, the value of centrality in the dataset at time \(t\) is the average of centrality in periods \(t - 6, t - 5,\) and \(t - 4\). The reason to consider

\footnote{Hausman, Pritchett, and Rodrik (2005) present a detailed description of the identification of the growth acceleration episodes. They discuss the criteria used to select the period in which the growth acceleration started for the cases where the initial change of 2 percent in the growth rate happens in consecutive years. Here we do not focus on the intricacies of the identification of the growth acceleration periods, instead we use those periods identified in their paper. It should be noted that we use the growth acceleration episodes that were identified using the Penn World Tables.}
lagged window-averages is simply to better capture the state of RCA over a certain period of
time, instead of focusing just on specific points in time that could be volatile and therefore
introduce noise into the regression. The other network variables, distance and density, also
enter the regression in the same “lagged time-window averages” fashion.

Recall that the model implies that high density and low network distance are by them-
selves not sufficient to trigger a growth acceleration. A combination of high density and low
network distance is required, which we refer to as the small world configuration. The heart
of our test thus depends on the interaction effect between distance and density. Further, the
model suggests that the small world effect is non-monotonic. If the interaction effect is too
small the country will fall short of the high probability (of growth acceleration) region and
if the interaction effect is too large the country will overshoot the high probability region.
In other words, there is a “goldilocks” range of the interaction for which the probability of
growth acceleration is highest. In order to test this our econometric specification considers
a quadratic term for the interaction of density and distance.

The economic and political control variables included in \( \Lambda \) in (12) match those included
in the econometric specification proposed by HPR. Specifically, these measures are proxies
for external shocks, changes in political regime, and economic reforms. All these variables
enter the regression as dummy variables. HPR compute an indicator variable based on the
terms of trade which proxies for external shocks. This variable takes the value of one
whenever the change of the terms of trade variable is in the upper ten percent from the
start of the growth acceleration in period \( t \), to \( t - 4 \), four periods before the start of the
growth acceleration. Political regime changes have been linked to changes in the underlying
fundamentals of the economic structure of countries the have experienced them. These
dramatic changes may shift the economy to a different trajectory of economic growth that
in many cases corresponds to higher rates of growth. These political regime changes are
identified in the HPR dataset by using the Polity IV data provided by Marshall and Jaggers
(2002). The corresponding dummy variable in the econometric specification takes the value
of one in the five periods following a regime change, which is defined as a change of at least
three units in the polity score, or by a regime interruption. Finally, the economic reform
variables control for trade and financial liberalization episodes. Opening an economy to
trade and financial flows provides access to markets, competition, and a better allocation
of resources that leads to an improved economic environment that, in theory, results in
higher rates of growth. Pin-pointing the exact periods on which a country is opened up
for free trade and financial flows is not an easy task. Wacziarg and Welch (2003) have
updated and expanded the index proposed by Sachs and Warner (1995) which incorporates
several dimensions of the structural fundamentals of a country’s economic system. The
index controls for foreign currency black market premiums, levels of tariffs, and other trade barriers. HPR use it as an indicator of transition towards trade openness. The dummy variable included in our regression that uses the information derived from this index takes the value of one during the five years after a transition towards openness has occurred.9

5 Regression Results and Analysis

Our probit regression starts by replicating the HPR specification as a baseline for our analysis. Columns 1 and 2 in Table 2 present the results for the core specification presented in HPR. Column 1 reports the results using the exact same sample (countries and years) included in their analysis, while column 2 presents results from the reduced sample (countries and years) used in this study. The changes in the sample come from data constraints arising from the computation of RCA and corresponding network variables for as many countries and years as possible. We see that the statistical significance and the magnitude of the coefficients from our sub-sample are very close to those of the original sample, suggesting that the loss of observations due to limited data on the RCA based variables does not affect the fundamentals of the analysis, and validates comparison of our results with those of HPR. The marginal effect10 of external shocks (measured through the terms of trade) and regime change on the probability of experiencing a growth acceleration, computed from the estimated coefficients in column 1, are 4.4 and 5.3 percentage points respectively, essentially replicating HPR’s results for the same specification.

[Table 2 here]

Columns 3 to 5 in Table 2 present results for the econometric specifications that test the implications of our hypothesis. Columns 3 and 5 in Table 2 present the probit regression coefficients obtained when no interaction terms are included. We consider two specifications here, one that includes both centrality and distance in the same econometric specification and one in which only density is included, since these two variables are strongly correlated. When the network variables are included in the regression without any considerations for the small world effect via interactions, we see that the results point to the statistical significance of density and distance for both specifications considered (i.e., excluding/including centrality), but the estimated coefficient for density is negative, which is not in line with the theory. The coefficient for network distance is negative as expected. For centrality, the


10Evaluated as in HPR.
estimated coefficient is negative but not statistically significant. We should also note that the coefficients of the HPR variables remain virtually unchanged across all of the regression specifications, implying that our measures represent new information for the regression exercise.

As suggested by the model, what is missing is the interaction between density and network distance. According to the model, the small-world effect operates as a catalyst for growth only when the interaction between density and network distance lies within an intermediate range. This is why it is not surprising to see that when interaction effects are not accounted for, the results are not fully in line with intuition. In addition, the interaction effect is expected to be non-monotonic, which is why we include a quadratic term.

Specifications 4 and 6 in Table 2 present regression results that include linear and quadratic interaction variables between density and network distance in the specification. Once again, we run the regressions including and excluding centrality. The sign for density is now positive and statistically significant at the one percent confidence level. The independent effects of distance are now positive but only significant for the case where centrality is excluded. Centrality itself still is not statistically significant. The small-world variables - the linear and quadratic interaction effects - are significant in both specification 4 and 6.

In terms of our measures, recall that density and distance, are respectively, our country-level measures of current spillovers and cost of moving to new products. Conceptually at least, these measures are well defined. Centrality, on the other hand, is our measure of potential spillovers. Since it is hard to predict to which products a country will leap, it is much harder to come up with a well-defined measure of potential spillovers. Hence, here we focus on the results for density and distance and discuss those for centrality later.

A clean interpretation for the results of the small world effect can be obtained by evaluating the estimated probit function for all the possible levels of the interaction terms, while keeping the other control variables at their means. In other words, we can build a grid of all the possible combinations for density and distance and evaluate the probability function at each point. This exercise enables us to see if the interaction effects between these variables establish a distinct region where the probability of growth acceleration is high, and if this region conforms with the intuition of our small-world hypothesis.

Figure 11 presents the results for the grid of density and distance, using the relevant ranges in our dataset to evaluate the econometric specification presented in column 4 of Table 2. The left-hand panel of the figure presents a 3-D view of the probability function while the right-hand panel presents a birds-eye view. From the right-hand panel we see that the shape of the high probability region (indicated by the black zone) resembles an arc, and that it is not enough to have only high spillovers between products or only low average
distance to new products for a heightened probability of experiencing a growth acceleration. We also see that the probability of growth acceleration falls off quite sharply outside of the arc traced by this exercise. We see that if network distance exceeds 75 the intensity of the dark area (the high probability area) fades quickly. In order to get a sense of the magnitude of changes in the probability levels brought about by changes in distance it is helpful to pick a value for density (keeping the other control variables at their means) and increase distance. For example, holding density at 0.35, the highest probability (39.8%) of growth acceleration is achieved when distance is around 71.6. If distance increases by one standard deviation (6.269) the probability drops by almost 10 percentage points, and if distance increases by two standard deviations the probability decreases by almost 25 percentage points. This is in accordance with the trade-offs inherent in the small-world hypothesis.

[Figure 11 here]

We should also note that the results presented here are robust and do not vary significantly when other control variables are considered. For example, when controls for financial liberalization are included in the regression analysis as in HPR, the statistical significance of the small-world effect and the arc shape of the high probability region persist, with $R^2$ increasing to 0.095.

In summary, our regression results provide statistical support for the small-world effect that emerges from the interaction of density and distance. The results are consistent with the intuition from our theoretical framework.

**An Alternative Small-World Variable**

As mentioned earlier, centrality is our proxy for potential spillovers, but the variable is not particularly well-defined since it is hard to predict to which products a country will move. Nonetheless, we also build an alternative small-world interaction term using centrality and distance. Call this interaction variable small-world-B. When we run the same regression specifications as reported above with this alternative small-world variable, the results are similar to those using our preferred small-world variable that is built using density and distance. The statistical significance and signs of the small-world variables prevails, and the probability function resembles an arc supporting the small-world hypothesis. However, the function becomes more susceptible to changes in distance. In this case, holding centrality at 0.04, the maximum probability of experiencing a growth acceleration (39.9%) is achieved when distance is around 71.3. According to the estimates from this probability plot, if distance increases by one and two standard deviations, the probability drops by about 15 and 34 percentage points, respectively.
6 Conclusion

While consensus on the trade-growth nexus is in disarray, recent research continues to paint a favorable picture of outward-oriented policy reforms on average while cautioning against a one-size-fits-all policy that disregards local circumstances. Focus has therefore shifted to a scrutiny of the channels through which trade openness may influence economic performance, and the way in which the relationship between trade and growth is contingent on country and external characteristics. Our paper contributes to this literature by identifying a new mechanism which facilitates transition to a high growth path.

We focus on the relationship between products in global trade (product space) and the characteristics of a country’s pattern of product specialization as revealed through its exports. Explicitly mapping product space as a network and then superimposing a country’s pattern of product specialization on product space enables us to devise a measure of the spillovers between the products in a country’s export basket and a measure of how distant a country’s product specialization pattern is from the rest of product space. The latter measure gives us an indicator of how difficult it is likely to be for a given country to move from its current products to new products. Our hypothesis is that the spillovers within a country’s export basket and the distance to new products are of concurrent importance for a poor country to move to higher income products and thus higher growth rates. The economic intuition is straightforward. Clustering of products enables economies of scale and scope and other agglomeration externalities, providing the ability to move to new products. Short distance in the network makes “leaps” to higher-income products feasible. The combination of high network spillovers and short distance is what we refer to as the “small-world” configuration.

We provide evidence in support of this hypothesis. Our network measures are significant in predicting a heightened probability of experiencing subsequent growth acceleration. Consistent with our small-world conjecture, we find that for enhancing the probability of a country-level growth acceleration, the interaction between spillovers and distance is key. We use the combinations of network spillovers and distance from our data in conjunction with the estimated coefficients from the probit regression to build a grid of the probability function at each point. This exercise demonstrates that the interaction between these variables establishes a distinct region where the probability of growth acceleration is high. We find that the shape of the high probability region resembles an arc, and indicates that it is not enough to have only high spillovers between products, or only low average distance to new products, for a heightened probability of experiencing a growth acceleration. We also find that the probability of growth acceleration falls off quite sharply outside of the arc traced by this exercise.
Our findings have useful implications for industrial and development policy. For example, the approach used here can suggest ways in which a country could target or prioritize sectors of the economy given its current pattern of product specialization so as to be well-primed for a high-growth trajectory. The network-based methodology unravels characteristics of the growth acceleration process that are difficult to both see and understand using conventional approaches. In this sense, the methodology itself can expand the scope of the questions that we will be able to ask. For example, the literature on complex networks proposes many ways in which the small world configuration may arise (short-cuts, hubs, modularity). This in turn suggests that a number of different policies or historical accidents could lead to this configuration and therefore to conditions that are propitious for growth acceleration. This seems a promising extension for future research.
References


Figure 1. Growth Acceleration

\[ F = 0 \]

Figure 2. Hierarchical Clustering for the Product Space
Figure 3. Jaccard Index (Relative to the 2000 Cluster)
(0 = Completely different community structures, 1 = Exactly equal community structures)

Figure 4. Graph Partitioning of Product Space
Figure 5. Hierarchical Clustering and Graph Partitioning for the Global Product Space and Ireland’s Product Specialization (1980)

Figure 6. Hierarchical Clustering and Graph Partitioning for the Global Product Space and Ireland’s Product Specialization (1990)
Figure 7. Hierarchical Clustering and Graph Partitioning for the Global Product Space and South Korea’s Product Specialization (1980)

Correlation between Product Space and Country-level Product Specialization (product pairs) = 0.27685
Correlation between Product Space and Country-level Product Specialization (industry interactions) = 0.81063

Figure 8. Hierarchical Clustering and Graph Partitioning for the Global Product Space and South Korea’s Product Specialization (1990)

Correlation between Product Space and Country-level Product Specialization (product pairs) = 0.23663
Correlation between Product Space and Country-level Product Specialization (industry interactions) = 0.78028

Correlation between Product Space and Country-level Product Specialization (product pairs) = 0.27685
Correlation between Product Space and Country-level Product Specialization (industry interactions) = 0.81063

Correlation between Product Space and Country-level Product Specialization (product pairs) = 0.23663
Correlation between Product Space and Country-level Product Specialization (industry interactions) = 0.78028
Figure 9. Hierarchical Clustering and Graph Partitioning for the Global Product Space and Greece’s Product Specialization (1980)

Figure 10. Hierarchical Clustering and Graph Partitioning for the Global Product Space and Greece’s Product Specialization (1990)
Figure 11. Probit Function Evaluated for all Possible Combinations of Density and Distance (at the mean of the other control variables)

Table 1. Summary Statistics for Network Measures

<table>
<thead>
<tr>
<th>GA Episode</th>
<th>Density</th>
<th>Distance</th>
<th>Centrality</th>
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<tr>
<td>Median</td>
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<td>Maximum</td>
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<tr>
<td>Minimum</td>
<td>0</td>
<td>0.0198</td>
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<td>Std. Dev.</td>
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Table 2. Regression Results

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<th>IV</th>
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<th>VI</th>
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<td>Small World (Density x Distance)</td>
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<td>-2.08</td>
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<td>Small World sq. (Density x Distance)^2</td>
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<td>-0.0065***</td>
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<td>0.36***</td>
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<td>1.13</td>
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<td>Regime Change</td>
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<td>0.29***</td>
<td>0.29***</td>
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<td>3.03</td>
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<td>0.0426</td>
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Notes: *, **, and *** denote statistical significance at the 10, 5 and 1 percent confidence levels

z-statistics for the coefficients appear in italics
### Appendix 1. SITC Industry Classification

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<tr>
<th>Code</th>
<th>SITC 2 Digit Description</th>
<th>Code</th>
<th>SITC 2 Digit Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Live animals chiefly for food</td>
<td>61</td>
<td>Leather, leather manufactures, nes, and dressed furskins</td>
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<tr>
<td>01</td>
<td>Meat and preparations</td>
<td>62</td>
<td>Rubber manufactures, nes</td>
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<tr>
<td>02</td>
<td>Dairy products and birds eggs</td>
<td>63</td>
<td>Cork and wood, cork manufactures</td>
</tr>
<tr>
<td>03</td>
<td>Fish, crustacean and molluscs, and preparations thereof</td>
<td>64</td>
<td>Paper, paperboard, and articles of pulp, of paper or paperboard</td>
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<tr>
<td>04</td>
<td>Cereals and cereal preparations</td>
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<td>Textile yarn, fabrics, made-up articles, nes, and related products</td>
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<tr>
<td>05</td>
<td>Vegetables and fruit</td>
<td>66</td>
<td>Non-metallic mineral manufactures, nes</td>
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<tr>
<td>06</td>
<td>Sugar, sugar preparations and honey</td>
<td>67</td>
<td>Iron and steel</td>
</tr>
<tr>
<td>07</td>
<td>Coffee, tea, cocoa, spices, and manufactures thereof</td>
<td>68</td>
<td>Non-ferrous metals</td>
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<tr>
<td>08</td>
<td>Feeding stuff for animals (not including unmilled cereals)</td>
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<td>Manufactures of metals, nes</td>
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<tr>
<td>09</td>
<td>Miscellaneous edible products and preparations</td>
<td>70</td>
<td>Power generating machinery and equipment</td>
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<td>11</td>
<td>Beverages</td>
<td>71</td>
<td>Machinery specialized for particular industries</td>
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<tr>
<td>12</td>
<td>Tobacco and tobacco manufactures</td>
<td>72</td>
<td>Metallurgical machinery</td>
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<tr>
<td>21</td>
<td>Hides, skins and furskins, raw</td>
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<td>General industrial machinery and equipment, nes, and parts of, nes</td>
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<tr>
<td>22</td>
<td>Oil seeds and oleaginous fruit</td>
<td>74</td>
<td>Office machines and automatic data processing equipment</td>
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<td>23</td>
<td>Crude rubber (including synthetic and reclaimed)</td>
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<td>Telecommunications, sound recording and reproducing equipment</td>
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<tr>
<td>24</td>
<td>Cork and wood</td>
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<td>Electric machinery, apparatus and appliances, nes, and parts, nes</td>
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<td>25</td>
<td>Pulp and waste paper</td>
<td>77</td>
<td>Road vehicles</td>
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<td>26</td>
<td>Textile fibres (not wool tops) and their wastes (not in yarn)</td>
<td>78</td>
<td>Other transport equipment</td>
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<td>27</td>
<td>Crude fertilizer and crude minerals</td>
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<td>Sanitary, plumbing, heating, lighting fixtures and fittings, nes</td>
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<tr>
<td>28</td>
<td>Metalliferous ores and metal scrap</td>
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<td>Furniture and parts of, nes</td>
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<td>Crude animal and vegetable materials, nes</td>
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<td>Coal, coke and briquettes</td>
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<td>32</td>
<td>Coal, coke and briquettes</td>
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<td>Articles of apparel and clothing accessories</td>
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<td>33</td>
<td>Petroleum, petroleum products and related materials</td>
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<td>Footwear</td>
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<td>Gas, natural and manufactured</td>
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<td>Professional, scientific, controlling instruments, apparatus, nes</td>
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<td>Photographic equipment and supplies, optical goods, watches, etc</td>
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<td>Animal oils and fats</td>
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<td>Miscellaneous manufactured articles, nes</td>
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<td>Fixed vegetable oils and fats</td>
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<td>Miscellaneous manufactured articles, nes</td>
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<td>43</td>
<td>Animal and vegetable oils and fats, processed, and waxes</td>
<td>88</td>
<td>Special transactions, commodity not classified according to class</td>
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<td>51</td>
<td>Organic chemicals</td>
<td>89</td>
<td>Animals, live, nes (including zoo animals, pets, insects, etc)</td>
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<tr>
<td>52</td>
<td>Inorganic chemicals</td>
<td>90</td>
<td>Armoured fighting vehicles, war firearms, ammunition, parts, nes</td>
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<tr>
<td>53</td>
<td>Dyeing, finishing and colouring materials</td>
<td>91</td>
<td>Coin (other than gold coins), not being legal tender</td>
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<td>54</td>
<td>Medicinal and pharmaceutical products</td>
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<td>Gold, non-monetary (excluding gold coins and concentrates)</td>
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<td>Fertilizers, manufactured</td>
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<td>57</td>
<td>Explosives and pyrotechnical products</td>
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<td>58</td>
<td>Artificial resins and plastic materials, and cellulose esters</td>
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<td>59</td>
<td>Chemical materials and products, nes</td>
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<th>Code</th>
<th>SITC 1 Digit Description</th>
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<td>0</td>
<td>Food and live animals chiefly for food</td>
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<tr>
<td>1</td>
<td>Beverages and tobacco</td>
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<tr>
<td>2</td>
<td>Crude materials, inedible, except fuels</td>
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<tr>
<td>3</td>
<td>Mineral fuels, lubricants and related materials</td>
</tr>
<tr>
<td>4</td>
<td>Animal and vegetable oils, fats and waxes</td>
</tr>
<tr>
<td>5</td>
<td>Chemicals and related products, nes</td>
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<td>6</td>
<td>Manufactured goods classified chiefly by materials</td>
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<td>7</td>
<td>Machinery and transport equipment</td>
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<td>9</td>
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