Knowledge Linkages, Specialization and Growth*

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Abstract

Technologies differ in their scopes of applications. The types of technology used in a country's production and export have important effects on its growth. We construct measures quantifying the *applicability* of knowledge at the sector level using cross-sector patent citations. We find that a country grows faster when it initially specializes in sectors with more applicable knowledge, which enable it to readily adapt existing technologies to develop new advanced products in other sectors. Countries' geographic characteristics are found to play an important role in determining specialization patterns, and hence are used as instrumental variables to obtain estimates of the effect of specialization on income. Trade costs block the knowledge circulation in the economy and hinder the technological progress of sectors with general knowledge disproportionately more. Hence, countries tend to produce and export less general purpose knowledge to geographically distant destinations. Countries that are generally far from others specialize in producing less applicable products and grow slower.

Keywords: Cross-sector knowledge spillovers; product space; trade cost; endogenous growth

JEL Classification: O33, O14, O41, F10, O19

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1 Introduction

Recent research in growth literature emphasizes that the type of products that a country export matters greatly for its economic performance including growth, volatility and trade patterns (e.g. Hausmann, Hwang and Rodrik, 2007; Hidalgo et al, 2007; Koren and Tenreyro, 2007; Nunn 2007; Kali et al, 2009). Specializing in some sectors brings higher growth and lower volatilities than specializing in others. In this paper, we explore the growth effects of a specific characteristic of products – the *applicability* of the knowledge or idea embodied in different sectors. Some products incorporate general purpose knowledge, which can be easily adapted to produce other products, highly connected with other products and hence have dramatic impacts on growth; other products contain sector specific knowledge and are isolated from the rest of product space. *[WE NEED MORE LITERATURE REVIEW ON SPECIALIZATION AND GROWTH]*

Economic historians have long recognized the spillover benefits generated by key technologies in the process of growth (e.g. David 1990; Rosenberg, 1982; Landes, 1969). "Computer and dynamo form the nodal elements of physically distributed (transmission) networks. Both occupy key positions in a web of strongly complementary technical relationship that give rise to 'network externality effects' of various kinds, ... " (David, 1990). Lacking quantitative measures of the knowledge applicability, however, growth and development economists have been unable to incorporate this characteristic of products into empirical analysis and formal models.

Recently developed patent citation data provide a natural paper trail of knowledge flow across sectors and generate a network of connectivity between products, or product space. Using this network, we construct a measure, called "authority weight", to quantify sectoral knowledge generality by applying Kleinberg's (1998) algorithm. Formally, authority weight captures the contribution of the specific knowledge embodied in a product to the rest of the product space.[1] Products with high authority weight are located in a densely connected center whereas products with low generality form the less connected periphery.

Using this measure, we empirically investigate the effects of trade specialization on income. As a first look, rich countries tend to export in more sectors and export product mix with higher authority weight (see Figure 1). But when a country starts exporting in a specific sector, poor countries expand into mature sectors with high authority weight; while rich countries' new export products tend to be less connected but newer. In general, countries with a product mix of higher authority weight enjoy more rapid growth rates after controlling for the normal factors like initial income, institutions, factor endowments, human capital etc (see Figure 2).

However, because the authority weight of a country's export mix are highly persistent over time for most countries. This relationship may not reflect an effect of specialization on growth, since specialization may be endogenous. In this paper, we find that geography play a significant role in driving the patterns of specialization across countries. More specifically, using a regression of bilateral trade specialization that resembles the standard gravity model (Frankel and Romer,

[1] A dual measure of authority weight is "hub weight", which indicates the ability of the specific product in utilizing knowledge from the other products.

1999; Helpman et al, 2008), we find that at the country pair level, countries export more knowledge with higher applicability to destinations that are closer to them and significantly less applicable knowledge to geographic distant destinations. Interestingly, geography is not only a powerful determinant of bilateral trade volume, but also provides considerable information about the composition of trade between countries.

We then estimate a geographic determinant of countries' export knowledge generality, and use it as an instrumental variables to estimate the effects of specialization on income. Consider the criticism of Rodriguez and Rodrik (2000), we also control for omitted variables such as distance to the equator or institutions in our second stage. Overall, it is evident that specializing at producing more applicable knowledge significantly contribute to higher income level.

We also provide a theoretical interpretation of these facts by developing a multi-sector model of innovation and growth. The key insight about idea is that not only its nonrival and has scale effect, it is also a capital that depreciates little and one idea can generate another. Therefore, the linkages between ideas are important factors in innovation and knowledge spillovers.

Traditionally, products are characterized by factor intensity or technological intensity (e.g. R&D-sales ratio). There are several recent attempts to quantify the other attributes of products such as the dependence on financial institutions and contract environment.[2] Most closely related to ours are Hausmann et al (2007) and Hidalgo et al (2007). The former constructs an outcome-based index of implied productivity of specific goods by a weighted average of the per-capita GDPs of the countries that exporting these products. The latter purposes a measure of "proximity" between a pair of sectors basing on the pairwise conditional probabilities of both being exported by the same group of countries.

However, this index is essentially a mixture of many elements that influence production specialization, including infrastructure and transport costs, trade intervention and government subsidies, distribution and marketing techniques, and the degree of fragmentability of production tasks under vertical specialization,etc. Our measure reveals and concentrates on the cross-sector relatedness in terms of intrinsic knowledge utilization.

This paper contributes to two strands of growing literature. One is about firms' innovation and endogenous product entry using plant or firm level data and another is on the relationship between a country's product space and endogenous growth. The first literature emphasizes the fact that many innovations appear in the form of new products and firms grow by making innovations in products new to them (see Klette and Kortum (2004), Aghion and Howitt (1992)). Bernard, Redding and Schott (2009a, 2009b) emphasizes that most firms switch their product frequently and they incorporate endogenous product selection within firms into existing theories of industry dynamics. The critical difference between their paper and ours is that we allow heterogenous sectors to be inherently connected by their knowledge content. Hence, the entry selection also depends on the attributes of existing products.

[2]For example, in Nunn (2007), products are characterized by its "contract intensity" (products with higher contract intensity are more differentiated or complicated); Krishna and Levchenko (2009) use the total number of intermediates in production as a proxy for product complexity measure.

In the area of product space and endogenous growth, Hidalgo and Hausmann (2009) argue that countries are related to the products they export and show that it is possible to quantify the complexity of a country's economy by characterizing the structure of the product network. "the measures of complexity are correlated with a country's level of income and that deviations from this relationship are predictive of future growth. Similarly, we find that the applicability of knowledge contained in a country's export mix also predicts its future growth. However, we observe that our applicability measure is not highly correlated with the sophistication measure in Hidalgo and Hausmann (2009). Among the less-connected sectors, most of them produce simplistic products (e.g. food and kindred products, primary ferrous products). Some sectors actually produce complicated products (e.g. transportation equipment, aircraft, guided missiles and space vehicles), but the knowledge could be too specific to be useful for other sectors.

Koren and Tenreyro (2007) document that poor country tend to concentrate on industries that experience high volatility. Nunn (2007) suggests that rich countries export more highly differentiated products while poor countries tend to concentrate on simple goods production. French (2009) further documents that poorer countries not only export a narrower set of products, but also the same types of product.

Kali et al (2009) uses Hausmann et al (2007)'s measure of relatedness among sectors to construct the network density among a country's export products and the distance between a country's local product space to the rest of the global product space. They find that local product space density has positive effect on subsequent economic growth, while distance to the rest of global product space imposes negative effect. Their product space relatedness measures ignore the importance of related sectors. Using an outcome-based measure, Hidalgo, Klinger, Barabasi and Hausmann (2007) find that countries that specialize in "rich-country products" are likely to grow faster than countries that specialize in others.

Other thoughts 1. Another strand of the related literature highlights the extensive margin in exports and growth. Hummels and Klenow (2004), Romer (1990).

2. Should talk about China's rising sophistication as in Shangjin Wei and Zhi Wang's paper ... in the policy implication part.

3. Maybe controlling for self selection in growth regressions. (endogeneity issues; what should be proper IV instrument?)

4. More to write about trade cost

5. Strike the fact that in our model, countries can be exactly symmetric except for the entry cost, yet, one can generate comparative advantage ... (note that comparative advantage comes from the sectoral differences in productivity or endowment and usually saying countries cannot be asymmetric on that)

6. Interestingly, we should relate ours to the "big push" literature on industrialization.

The rest of the paper is organized as follows. Section 2 describes the construction of our measure of authority weight and the empirical findings using cross country sectoral trade data. Section 3 introduces the model and Section 4 discusses characteristics of the general equilibrium. Section

5 calibrates the world economy. Section 6 discusses welfare and policy implications. Section 7 concludes.

2 Knowledge Linkages Measure

3 Empirical Evidence

3.1 Data Sources

Recently developed patent citation data provide a natural paper trail of knowledge flow across sectors and generate a network of complementary technical relationship between sectors. We use the 2006 edition NBER Patent Citation Data (see Hall, Jaffe and Trajtenberg (2001) for details) to trace the direction and intensity of knowledge flows and to construct indices of knowledge linkages among sectors. The data provides detailed information of every patent granted by the United States Patent and Trade Office (USPTO) from 1976 to 2006. Each patent contains highly detailed information on innovation itself, the application year, the applying firm id and the submission location up to the city level, etc. Each patent corresponds to one of the 3-digit United States Patent Classification System (USPCS) technological class and also one of the 7-digit International Patent Classification (IPC) class.

To translate the data based on technological categories into industrial sector classifications at which cross-country industrial statistics and trade data are available, we use the following mappings.[3] To link the data to export and import values, we use the 2005 edition of concordance table provided by USPTO to match USPCS into SIC72 (Standard Industrial Classification) codes, which constructs 42 fields. We then map the trade flows data (1962 -2000) at the 4-digit SITC Rev. 2 industry level from the World Trade Database (Feenstra, et al 2005) into the 4-digit SIC72 level using Zhu's concordance.[4] The trade flow values at the SIC72 level are then aggregated into the 42 fields using the concordance provided by USPTO. The world trade data is thereby linked to the patent citation data at the 42-sector level. Because the patent technological classes do not perfectly match into the industry sectoral level, some export may not be mapped into one of the 42 sectors. We delete countries if more than 50 percent of its export cannot be mapped into the 42 fields.[5]

[3] The patents are classified according to either the intrinsic nature of the invention, or its function the invention is used or applied. It is inherently difficult to allocate the technological category into economically relevant industries in a finer differentiation even with detailed firm level information. Because, first, most of the patents are issued by multi-product firms that are present in multiple SIC-4 industries; Second, in the best scenario, one only has industry information of the origin of the patents but not the industry where the patent is actually applied to.

[4] Thanks to Susan Zhu, who provides a converter derived from Feenstra (1997) mapping the 4-digit SITC codes into 4-digit US SIC (1972 basis). Her converter also carefully deals with the roll-up problems which are detailed in Feenstra et al. (1997) and Feenstra (2000).

[5] We have also studied the relationship between technology and industrial performance. United Nations Industrial Development Organization (UNIDO)'s industry statistics database provides industrial value added, output and employment information at the 4-digit ISIC_rev3 level. It is then mapped into 44 fields using the concordance by Schmoch et al (2003), which provides a sophisticated mapping of IPC codes to the same 44 fields.However, the large number of missing observations in the UNIDO data at the 4-digit ISIC level significantly impedes the accuracy of our empirical analysis. Therefore, the following sections, we focus on the results from trade flow data and confirm

Details on the construction of all country specific variables are provided in Appendix I.

3.2 Sectoral Knowledge Applicability

We connect all sectors in the economy with citation flows among them and generate an intersectoral knowledge diffusion network. Some sector contains general purpose knowledge that provides the most prominent sources of content that are also applicable in other sectors. This kind of sector acts as the knowledge *authority* in the network. Other product relies knowledge from many other sectors and serves as an important knowledge *hub*. This type of sectors resemble focused hubs that direct users to recommended authorities in the network.

We apply an algorithm (Kleinberg, 1998) which extracts information from hyperlinked environments to the constructed patent citation network and to construct two sectoral indices $-$*authority weight* and *hub weight*. Sector i's authority weight is proportional to the sum of the hub weights of the sectors that utilize knowledge from sector i. Sector i's hub weight is proportional to the sum of the authority weights of the sectors that provide knowledge to sector i. Formally, let aw^i denote the authority weight and hw^i denote the hub weight of product i. They are calculated according to

$$\begin{aligned} aw^i &= \lambda^{-1} \sum_j W^{ij} hw^j \\ hw^i &= \mu^{-1} \sum_j W^{ji} aw^j \end{aligned}$$

where λ and μ are the norms of vectors $\boldsymbol{aw}$ and $\boldsymbol{hw}$, respectively. W^{ij} is the weight of the link, corresponding to the strength of citations made by sector j (second subscript) from sector i (the first subscript). Generally speaking, a sector with high authority weight gives large knowledge flow to other sectors with highly ranked hub weights; a sector with high hub weight utilizes large knowledge flow from other sectors with highly ranked authority weights.[6]

We set $W^{ij} = OC^{ij}/OC^i$ which is the percentage of citations made by j to i. In the data, the first pair of the applicability measure is positively correlated with the size of patent stocks in that sector (0.65), reflecting the fact that a citation link is more likely to exist between two sectors with larger patent stock. Sectoral authority weight and hub weight are highly correlated with a correlation around 0.98 and the distribution of authority weight (or hub weight) follows the log-normal distribution[7]. We list the 42 sectors used for our cross-country analysis sorted by authority weight in Table 1. As one would expect, in general, more complicated product classes have higher authority weight and hub weight, such as "Electronics ", "Professional and scientific instruments", implying that they are more likely to be located at the core of the product network.

the general consistency with the industrial production data.

[6]These measures are more suitable for our purpose than the simple citation count. For example, comparing two sectors that received the same number of citations, it is desirable to elevate one sector's ranking, if this sector receives citations from more important sectors than the other sector.

[7]The log-normal distribution still holds, when we use different industry classifications at different digit levels.

In contrast, more primary products tend to be in the periphery. There are a few exceptions, for example, "transportation equipment"and "aircraft and parts "both have low authority/hub weight. This is not surprising given that the technology incorporated in the innovation of these sectors is likely to be specialized.

Figure 4 presents the time trend of the authority weight for several sectors. The ranking of the weight for most sectors do not change much over time. However, starting from mid-90s, following the IT revolution, the sectors related to electronics and information and communication became increasingly important. In contrast, product classes like "Petroleum and natural gas extractor" and "Food and kindred products" are moving towards the periphery of the product network.

Another characteristics of the calculated hub and authority weights is that they seem to be highly correlated with the size of the sector (total number of products). This relationship in fact is quite robust. No matter using the number of citations as the weight W^{ij} or simply fixing $W^{ij} = 1$ for every connected sector pairs, the correlation is always above 0.6.

3.3 Knowledge Applicability of a Country's Export

We now study the growth implications of a country's product space. First, we define the applicability of knowledge associated with country c's export basket, KA_c, as a weighted average of the authority weight of products exported by that country using the product share in the country's total exports value, $EX_c^i / \sum_i EX_c^i$ as weights. That is,

$$KA_c = \sum_i aw^i \left(\frac{EX_c^i}{\sum_i EX_c^i}\right)$$

The first question we ask is that how does the export knowledge applicability change over time in different countries? Figure 5 presents the time trend for export knowledge applicability for eight countries – USA, China, Korea, Mexico, Chile, Ecuador and Nigeria, as an example sample of high income, middle income Asian and Latin American countries and low income countries. The export of Korea has the highest knowledge applicability among all the countries. Although Mexico started high, this measure was drifting downward until early 90s. Perhaps as a result of the Information Technology revolution, the export knowledge applicability of Korea, USA, Mexico, China and India has increased sharply in the mid 90s. The most striking observation is that China's export knowledge applicability has been growing steadily and rapidly, converging with USA and Korea and exceeding Mexico over the past decades.[8]At the other end, exports of Chile, Ecuador and Nigeria have low knowledge applicability, reflecting the fact that their exports are primarily simple products or primary products and natural resources.

To further illustrate the evolution of a country's production structure, we fix the ranking of all the products according to their 1980 applicability level and compare the distribution of export shares in 1980 to that in 2000 for a selected sample of countries. The pattern of specialization is shown

[8]As pointed out in Koopman, Wang and Wei (2008), however, a significant share of China's exports is based on processing trade, where it imports sophisticated product parts to produce the sophisticated final product.

in Figure 6. As expected, the U.S. specializes in producing products with the highest applicability in 2000. China has significantly shifted its industrial structure preferentially from specializing in producing low or middle knowledge applicable products towards more highly applicable products. The same pattern holds true for Malaysia. In contrast, India in 2000 still largely concentrates on producing products close to their existing goods in 1980. This evidence illustrates a large difference between two rapidly growing economies - China and India. China has gone through spectacular structural transformation while India has been static on that front. Lastly, Colombia and Nigeria seem to be stuck with exporting low applicability products.

Relating this pattern to the different in cross-country growth rates, one may speculate that countries may not experience large economic growth simply because the knowledge learned and accumulated in the current production is not so useful in innovating and upgrading the industrial structure by themselves. Unless adopting and learning newer technology, these countries would have difficulties undergoing structural transformation, that often stimulates the long-run economic performance.

Using country data, we investigate which characteristics of a country matter for the knowledge applicability of its export. Table 2 suggests that besides the country size (real GDP per capita) that positively affects the knowledge applicability of export, financial and institutional factors such as financial development and entry barriers play significant roles in determining the export knowledge applicability.[9] Better financial development and lower entry cost improve the country's export structure, increasing the export share of sectors with highly applicable knowledge. Surprisingly, human capital and institutional quality proxied by the Rule of Law index do not seem to be associated with the export knowledge applicability.

3.4 Export Composition and Growth

We study the impact of the knowledge applicability of a country's export bundle on economic growth. The literature has suggested several important factors in growth determination, including human capital, factor endowments and institutions (Hall and Jones,1999; Acemoglu et al. 2001, 2002; Dollar and Kraay, 2003; Easterly and Levine, 2003; Rodrik et al. 2004).

To examine the quantitative importance of differences in the knowledge content of industrial production as determinants of income differences across countries, we consider a growth regression specification of the following type.

$$(\log y_{c,t+\tau} - \log y_{c,t})/\tau = \beta_0 + \beta_1 \log(y_{c,t}) + \beta_2 \log(KA_{c,t}) + \boldsymbol{\delta Z}_{c,t} + \varepsilon_i \tag{1}$$

The left-hand-side measures the growth rate of per capital GDP(y) for country c from year t to $t+\tau$. $KA_{c,t}$ denotes the applicability of knowledge associated with country c's export bundle. $\boldsymbol{Z}_{c,t}$ is a vector of other control variables. We are particularly interested in the coefficient β_2, which

[9] Financial development is measured using the amount of credit by banks and other financial intermediaries to the private sector as a share of GDP (private credit) from Beck et al. (2000). The measure of entry costs is taken from World Bank- doing business dataset (2010) that was originally constructed by Djankov et al. (2002).

measures the impact of knowledge applicability on growth.

3.4.1 Constructing the Instrument: Bilateral Trade Composition

There are two potential problem with the previous regression. Trade specialization may be endogenous and there is selection bias in the trade data. That is we only observe trade data when the country pair is trading in that sector. In this section, we attempt to deal with these two issues.

Define the knowledge applicability of country c's export to country k as $KA_{ck} = \sum_i aw^i(\frac{EXP^i_{ck}}{\sum_i EXP^i_{ck}})$. It is easy to show that $KA_c \equiv \sum_i aw^i(\frac{EX^i_c}{\sum_i EX^i_c}) = \sum_k(\frac{EX_{ck}}{\sum_k EX_{ck}})KA_{ck}$. First, we regress the authority weight of bilateral trade on a series of exogenous geographic variables following the specification as below

$$\log(KA_{ck}) = \alpha_0 + \alpha_1 \log(Dist_{ck}) + \alpha_2 \log(N_c) + \alpha_3 \log(A_c) + \alpha_4 \log(N_k) + \alpha_5 \log(A_k) + \boldsymbol{\beta X}_{ck} + u_{ck}, \tag{2}$$

where c and k denotes exporters and importers, respectively. D_{ck} is the distance between them. A_c and A_k are measures of their area and N_c and N_k are numbers of workers. $\boldsymbol{X}_{ck}$ is a set of country pair geographic, institutional and culture characteristics.

The first column in Table **??** provides a basic estimate of the above equation for all bilateral trade flows reported in 1986 from a set of 133 countries, including only exogenous georgraphic variables in the right-hand-side. The second column presents the estimate when bilateral institutional, cultural and social factors are also included. The results show that country c exports more products incorporating applicable knowledge to country k when the two countries are closer to each other, they share a common language, both belong to the same regional free trade agreement (FTA), they are not landlocked, they are both islands or one country colonized the other. This measure of trade knowledge applicability also increases with the number of workers in both exporting and importing countries, but decreases with the geographic size of the exporting countries.

This specification, however, disregard country pairs that do not trade with each other in specific sectors and produces biased estimates (Helpman, Melitz and Rubinstein, 2008). We then use Helpman (1979) selection bias correction method to correct for the no trade observations. Define T_{ck} to be one when country c is exports to country k and zero when it does not. Let ρ_{ck} be the probability that country c exports to k, conditional on a set of observables. Similar to Helpman et al (2008), we use the country specific regulation costs of firm entry (Djankov et al. 2002) as variables for the selection equation. These regulation costs are measured by their effects on the number of days, the duration of procedures and monetary costs to legally start a business, and are used as proxies for the fixed export market entry cost. We include the sum of the costs above the median for both countries. As the first stage, we estimate the Probit equation specified as

$$\begin{aligned} \rho_{ck} &= \Pr(T_{ck} = 1 | \text{ obs variables}) \\ &= \phi(\gamma_0 + \gamma_1 \log(Dist_{ck}) + \gamma_2 \log(N_c) + \gamma_3 \log(A_c) + \gamma_4 \log(N_k) + \gamma_5 \log(A_k) + \tilde{\boldsymbol{\gamma}} \boldsymbol{X}_{ck} + Cost_{ck} + \eta_{ck}) \end{aligned}$$

We use this Probit equation to derive consistent estimates of $\log(KA_{ck})$. Table **??** shows that in most specification, the knowledge applicability of a country's production explains income differences, even when including other endogenous variables characterizing the institutions in the country. Standard errors in the second stage are adjusted following Frankel and Romer's (1990) method. The results are shown in Column (2) and (3) of Table **??**

Next, we construct the predicted country level knowledge applicability measure

$$\widehat{KA}_c = \sum_k \frac{EX_{ck}}{\sum_k EX_{ck}} \exp[\widehat{\log(KA_{ck})}]$$

where the fitted value, $\widehat{\log(KA_{ck})}$, is predicted from regression (2). This predicted value is then used as instrumental variable in the growth regression.

3.4.2 Results

Table 3 reports the regressions. Column (1)-(4) show OLS regression results from a series of cross-country growth regressions. The average annual growth rate from 1986 to 2009 are regressed on initial values of existing export knowledge applicability, initial income level and other controls suggested by the previous empirical studies. Following Hall and Jones (1999), we include distance from the equator and language as proxy for institutional differences. The coefficients on $\log KA_c$ are always positive and highly significant, indicating a very strong correlation between growth and export pattern in this large sample of countries. However, $\log KA_c$ is endogenous countries specialize in sectors with high knowledge spillovers because they are rick. Column (5)-(8) address this concern and report the results from instrumental variables estimation of the efect of a change in export knowledge applicability on growth. We find a highly significant positive effect of the geographically determined component of trade pattern on growth, with a even larger coefficient than in the OLS regression. The evidence again suggests that specializing in sectors with large knowledge spillovers brings growth in the future,

3.5 Alternative Approach [to be done]

Using panel time series technique, which is robust to endogeneity and has the superconsistency property.

4 Policy Implications

Our study has important police implications for economic. First, it suggests that industry policies that shift industry structure towards high relatedness products boost economic growth.[Second, institution reforms that lower the entry cost reinforce the effect of the industry policy, because it can be challenging to shift to more advanced industry given the fixed cost of learning and adapting technology in new sectors. **There is no entry cost in this paper. I suggest we rewrite the**

policy implications] Using China, the economy with an average growth rate of 9 percent, as an example, over the past two decades, it has significantly shifted its industrial structure from exports of low or medium connectivities (30 percent of export in "Textile mill products" and 24 percent in "Food and kindred products") to highly connected products (20 percent of export in "Electronic components and accessories and communications equipment", 14 percent in "Office computing and accounting machines"). Chinese government has adopted a sequence of policies promoting structural transformation. Concurrently, institutional economic reforms, such as privatizing state owned firms and free entry into many previously monopolistic sectors, facilitate the structure transformation policy.

As the ranking of sectoral authority weight changes overtime, a country has to constantly shift its product space towards the updated authority sectors in order to stay on the accelerated growth path. Therefore, a successful growth policy includes not only identifying and moving towards current authority sectors, but also predicting future authority sectors and preparing related knowledge to enter these sectors. So far, we find that conditional on current authority weight, the relation between a sector's authority weight 10 year later and the age of the sector are reverse U shaped.[10] The peak of the curve arrives at around age 20. In summary, a promising future sector is a young and low related sector.

5 Conclusion

[TO BE COMPLETED]

[10]We measure the beginning of the sector by the first year that a patent in that patent classification was granted. The age of the sector is the current year minus the beginning year.

6 Appendix

6.1 Data Appendix

1. GDP per capita, growth rate, number of workers
   Source: Penn World Table ver. 6.3
   Year: 1970-2000
   Series: GRGDPCH (growth rate of GDP), CGDP (GDP per capita), $worker = \frac{\text{RGDPCH*POP}}{\text{RGDPWOK}}$

2. Financial development
   Source: Beck, Demirguc-Kunt, and Eric Levine(2010), "A New Database on Financial Development and Structure (updated April 2010)", World Bank Economic Review 14, p.597-605
   Year: 1960-2008
   Series: Private credit by deposit money banks and other financial institutions/GDP ($pcrdbofgdp$)

3. Human capital
   Source: Barro and Lee. "A New Dataset of Educational Attainment in the World, 1950-2010", NBER Working Paper 15902.
   Year: 1950-2000 (every 5 years)
   Series: yr_sch (average years of schooling attained) in "Educational Attainment for Population Aged 25 and Over"
   Note: Human capital was constructed following Caselli's (2005) method.

4. Physical capital to labor ratio
   *Physical capital was computed following the perpetual inventory method, as explained in Caselli (2005). Year: 1970-2000

5. Entry cost
   Source: World Bank Doing Business
   Year: 2004-2010
   Series: Cost (% of income per capita)

6. Natural resource endowment
   Source: Expanding the Measure of Wealth
   Year: ?
   Series: Natural Capital in Appendix table 1, p. 34

7. Rule of law
   Source: World Bank, Governance Matters 2009: Worldwide Governance Indicators
   Year: 1996-2008 (missing 1997, 1999, 2001)
   Series: Rule of Law (column "Est")

8. Hall and Jones data
   Source: Hall and Jones (1999), " Why Do Some Countries Produce So Much More Output per Worker than Others?". *Quarterly Journal of Economics*, 114, 83-116.
   Dataset available on Jones' website
   Series: Latitude, fraction of English speakers, fraction of European language speakers

9. Frankel and Romer data
   Source: Frankel and Romer (1999), "Does Trade Cause Growth?". *American Economic Review*, 89, 379-399.
   Dataset available on Romer's website
   Series: Distance between importer and exporter, area, border dummy, landlock dummy

10. Dollar and Kraay data
    Source: Dollar and Kraay (2003), "Institutions, trade, and growth". *Journal of Monetary Economics*, 50, 133-162.
    Dataset available on Kraay's website
    Series:

    - Contract intensive money (CIM): 1 minus the ratio of currency in circulation to M2. This measures the extent to which property rights are sufficiently secure that individuals are willing to hold liquid assets via financial intermediaries.
    - *revolution*: average number of revolutions per decade since the 1960s
    - *freedom house rating*: the Freedom House measure of political freedom (higher values indicate less freedom)
    - *ICRG*: a measure of rule of law reported in the International Country Risk Guide
    - *war deaths*: fraction of the population killed in wars

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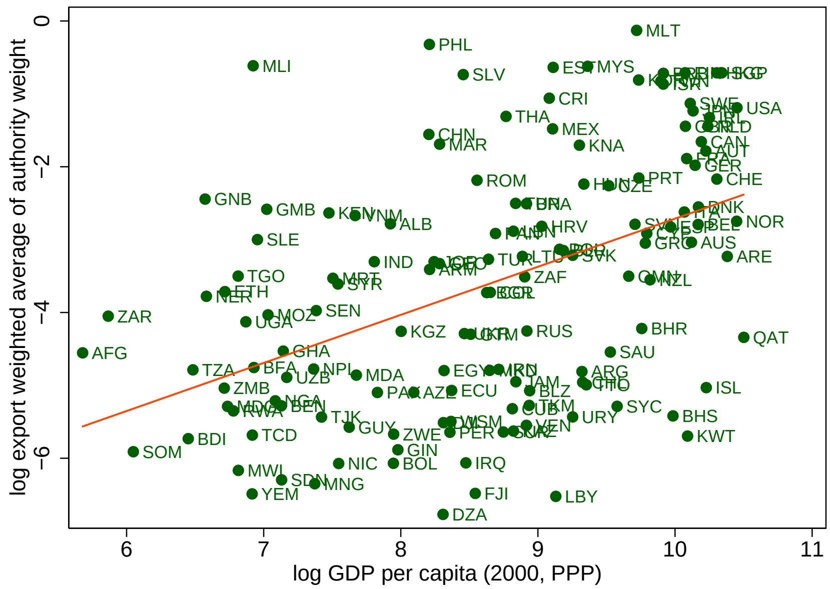
Figure 1: Richer countries on average export products with higher connectivity



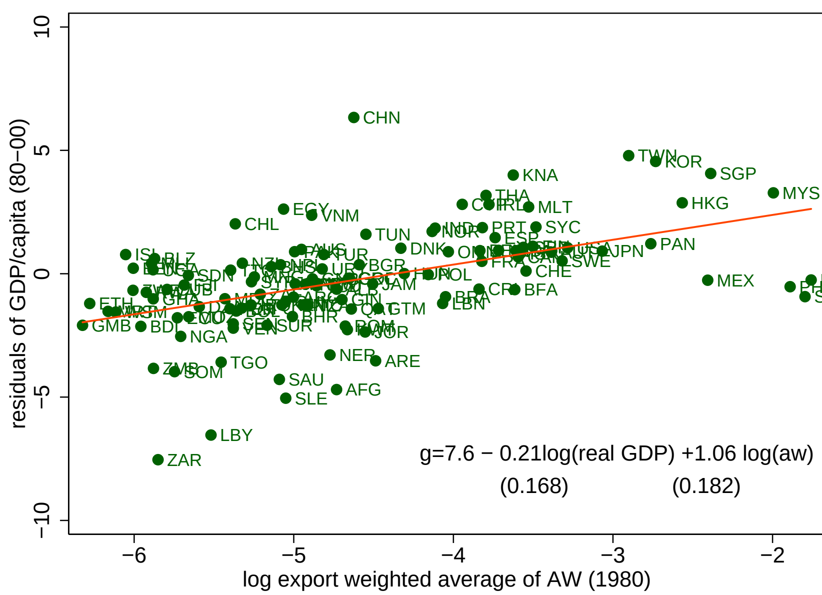
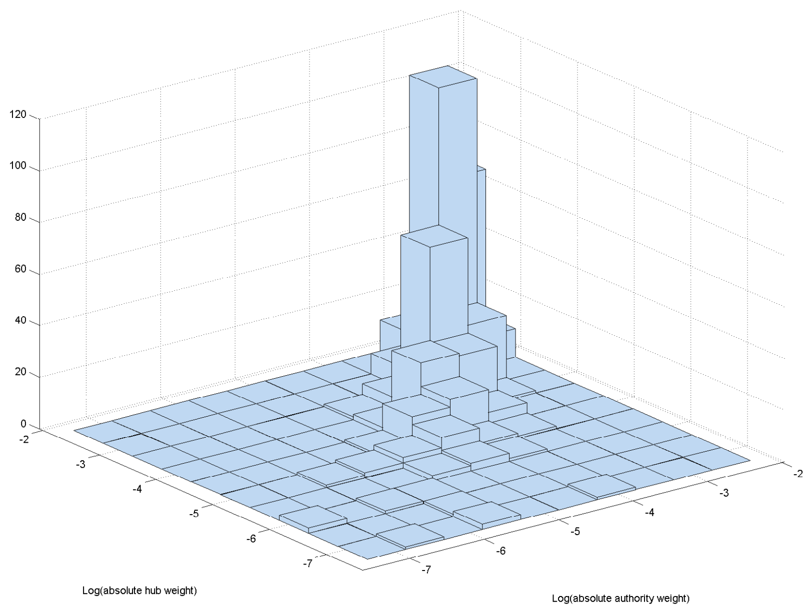


Figure 2: Countries specializing in producing highly connected products grow faster

Figure 3: Histogram of authority weight and hub weight across 42 industry fields



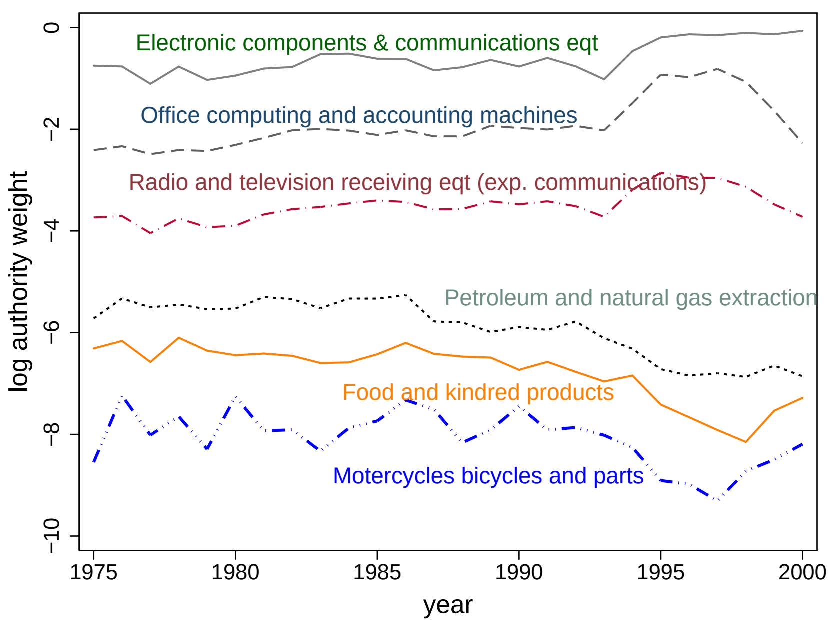
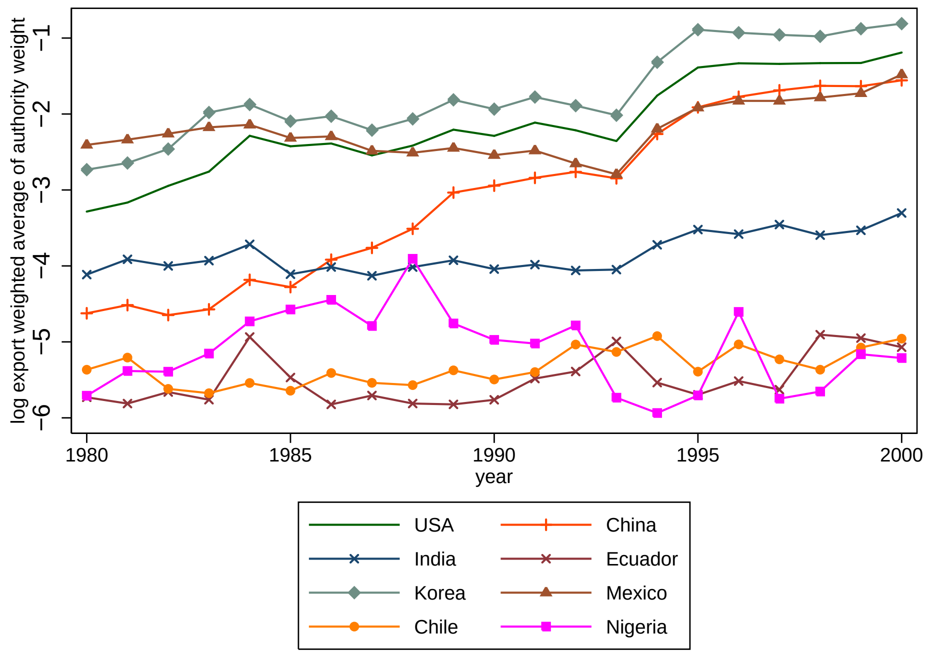
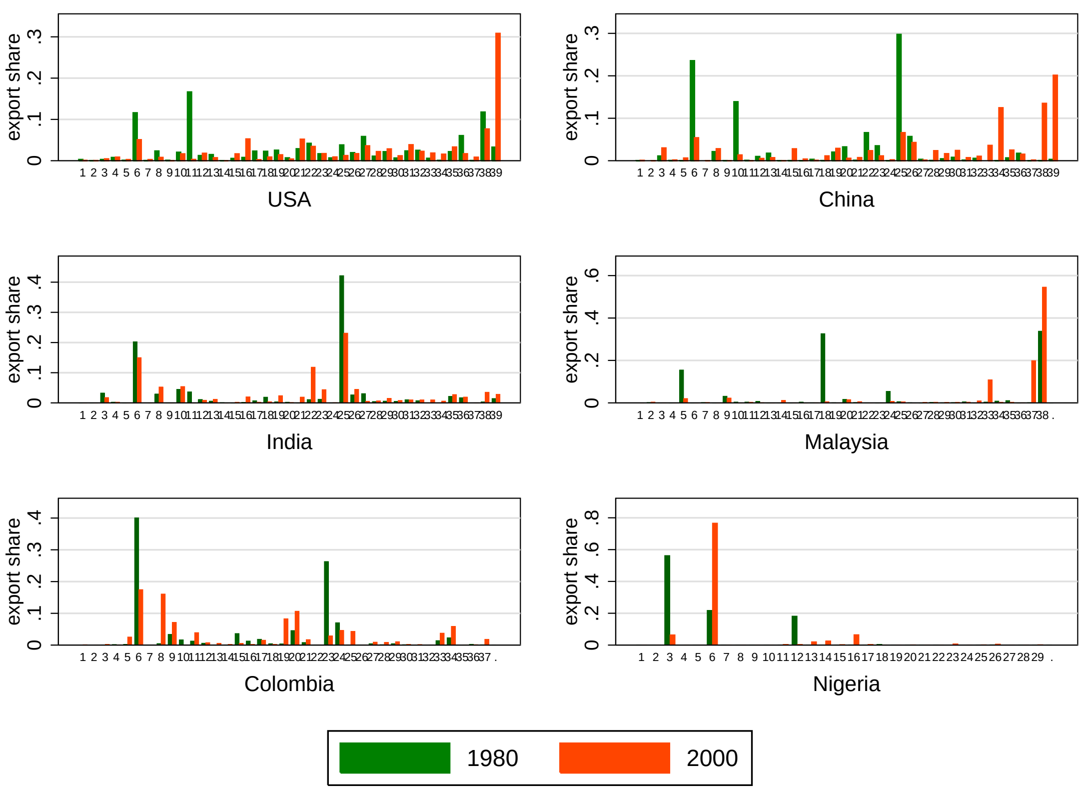


Figure 4: Authority weight over time for selected sectors

Figure 5: Export Knowledge Applicability Over Time for Selected Countries



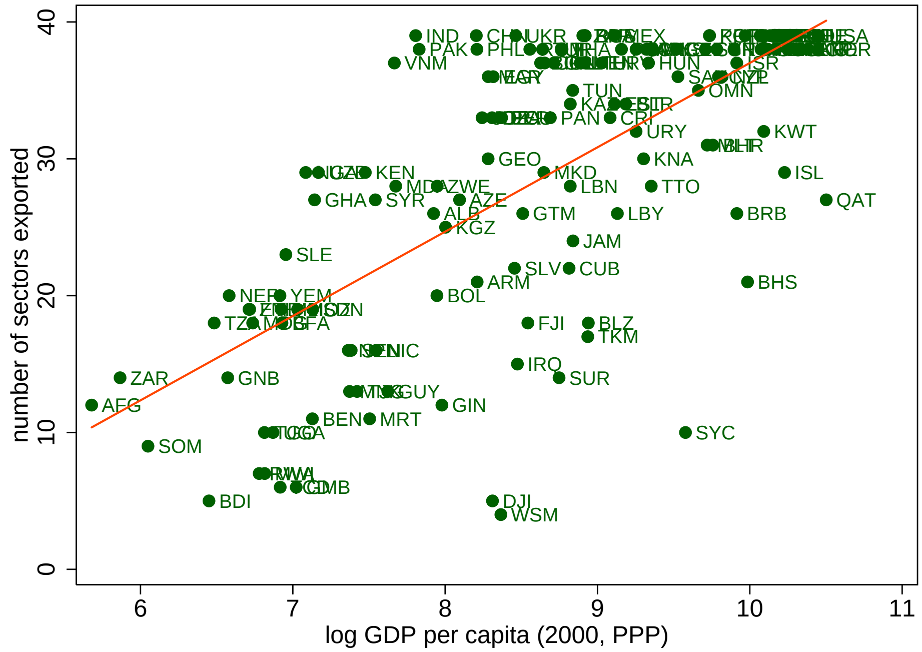


sectors

ranked by the 1980 authority weight

Figure 6: Distribution of Sectoral Export Shares in 1980 vs. 2000

Figure 7: Rich countries export in more knowledge appicable sectors



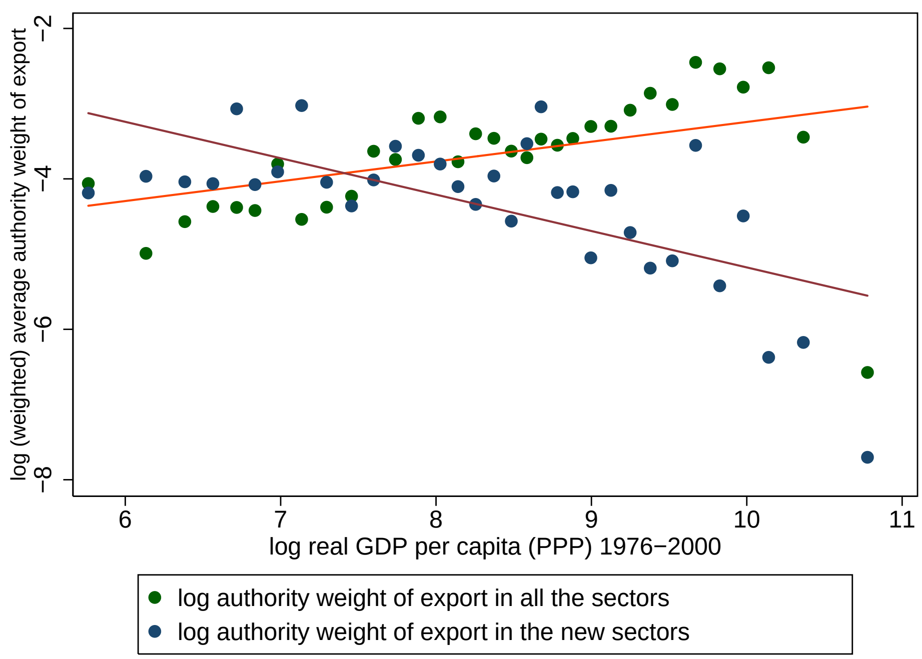


Figure 8: New export sectors of richer countries are less connected

Figure 9: Distribution of Sectoral Innovations in Canada, Japan and Mexico Compared to US

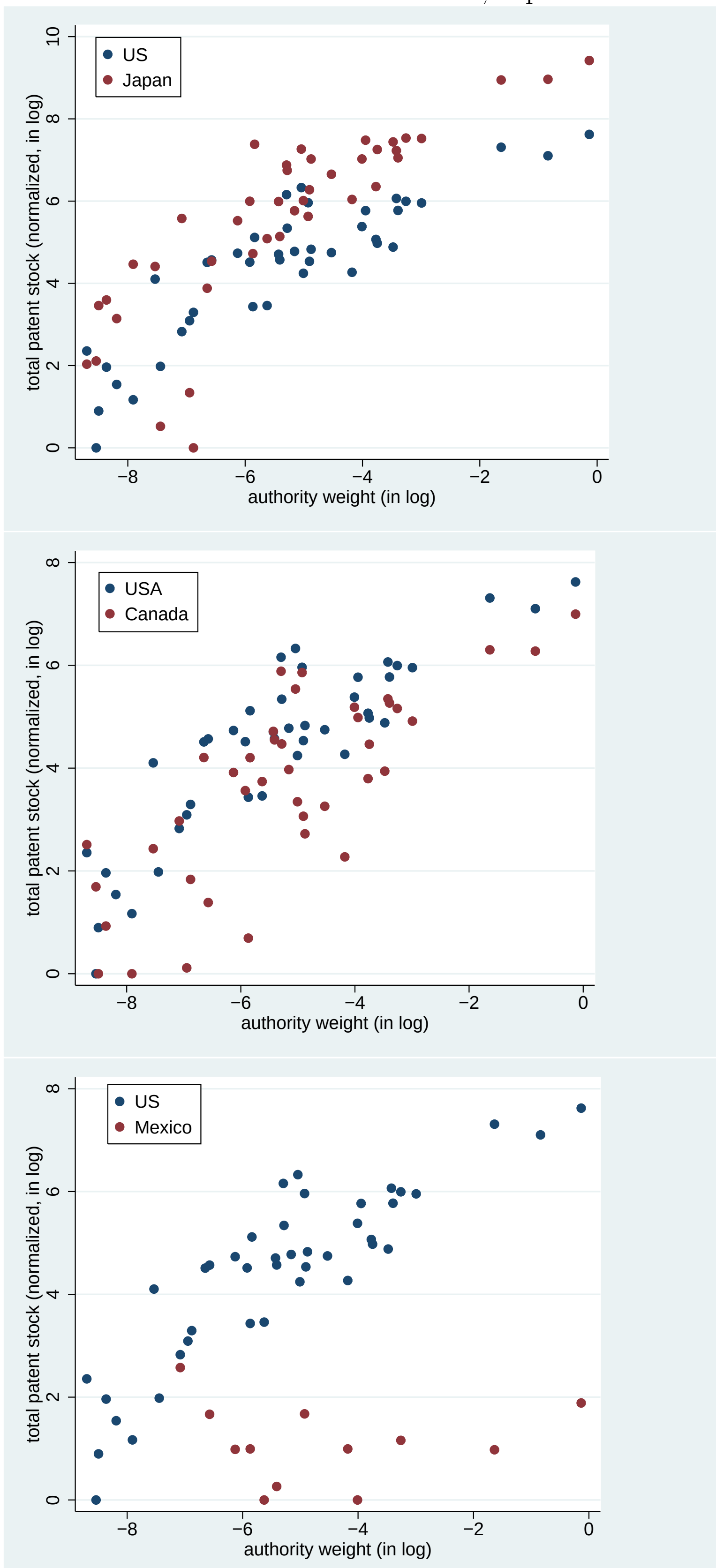


Table 1: List of 42 Sectors Ranked According to the Authority Weight

Field	Sector Name	Authority Weight	Hub Weight
36	Railroad equipment	0.00017	0.00021
38	Miscellaneous transportation equipment	0.00022	0.00027
37	Motorcycles, bicycles, and parts	0.00024	0.00022
35	Ship and boat building and repairing	0.00033	0.00029
28	Household appliances	0.00041	0.00070
25	Miscellaneous machinery, except electrical	0.00045	0.00033
14	Primary ferrous products	0.00059	0.00090
34	Guided missiles and space vehicles and parts	0.00069	0.00040
1	Food and kindred products	0.00093	0.00078
40	Aircraft and parts	0.00125	0.00108
39	Ordinance except missiles	0.00133	0.00102
7	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	0.00189	0.00158
11	Petroleum and natural gas extraction	0.00190	0.00170
3	Industrial inorganic chemistry	0.00232	0.00291
17	Engines and turbines	0.00268	0.00303
8	Paints, varnishes, lacquers, enamels, and allied products	0.00273	0.00346
24	Refrigeration and service industry machinery	0.00284	0.00304
15	Primary and secondary non-ferrous metals	0.00329	0.00358
9	Miscellaneous chemical products	0.00429	0.00428
5	Plastics materials and synthetic resins	0.00466	0.00657
18	Farm and garden machinery and equipment	0.00528	0.00593
19	Construction, mining and material handling machinery and equipment	0.00575	0.00614
13	Stone, clay, glass and concrete products	0.00670	0.00740
33	Motor vehicles and other motor vehicle equipment	0.00712	0.00693
2	Textile mill products	0.00776	0.00829
4	Industrial organic chemistry	0.00834	0.00898
6	Agricultural chemicals	0.00865	0.00651
20	Metal working machinery and equipment	0.00942	0.01143
10	Drugs and medicines	0.00982	0.00737
29	Electrical lighting and wiring equipment	0.01623	0.01278
30	Miscellaneous electrical machinery, equipment and supplies	0.01861	0.02048
22	Special industry machinery, except metal working	0.02046	0.02034
27	Electrical industrial apparatus	0.02110	0.02267
23	General industrial machinery and equipment	0.02431	0.02592
16	Fabricated metal products	0.02988	0.03529
31	Radio and television receiving equipment except communication types	0.03663	0.04815
42	All Other Sectors	0.03800	0.03936
12	Rubber and miscellaneous plastics products	0.04078	0.04329
26	Electrical transmission and distribution equipment	0.04212	0.05120
21	Office computing and accounting machines	0.32458	0.29495
41	Professional and scientific instruments	0.56854	0.56551
32	Electronic components and accessories and communications equipment	0.74939	0.76206

Table 2: Correlates of log knowledge applicability of export mix

	Dependent variable: log export knowledge applicability in 1995					
	(a)	(b)	(c)	(d)	(e)	(f)
Log GDP per Capita	0.973	1.003	0.652	0.835	0.914	0.642
	(8.13)***	(4.38)***	(3.63)***	(3.76)***	(6.58)***	(2.11)**
Log Human Capital		-0.281				-0.272
		(-0.19)				(-0.18)
Financial Development			1.675			1.433
			(2.91)***			(2.10)**
Rule of Law				0.199		
				(0.77)		
Entry Cost					0.0003	
					(0.34)***	
Log Population						0.239
						(1.91)*
Log Natural Resources						-0.149
						(-0.62)
Constant	-12.224	-12.208	-10.148	-11.083	-10.774	-10.774
	(-11.94)***	(-8.18)***	(-7.47)***	(-6.00)***	(-4.23)***	(-4.23)***
Observations	104	80	91	80	64	64
R2	0.40	0.35	0.47	0.35	0.47	0.47

*** significance at 1% level; ** significance at 5% level; * significance at 10% level t-statistics in parenthese

Table 3: Cross-Country Growth Regressions

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV	(6) IV	(7) IV	(8) IV
log initial GDP/cap	-0.35	-0.57**	-0.98***	-1.85*	-0.55*	-0.67**	-1.07***	-1.92**
	(0.204)	(0.211)	(0.251)	(0.790)	(0.256)	(0.238)	(0.251)	(0.744)
log initial KA	1.06***	0.98***	0.88***	0.72**	1.58***	1.21***	1.23***	1.58***
	(0.231)	(0.206)	(0.216)	(0.268)	(0.370)	(0.316)	(0.318)	(0.437)
dist. to equator		3.91***	3.25**	5.27***		3.93***	3.49**	5.16***
		(1.040)	(1.064)	(1.369)		(1.014)	(1.066)	(1.549)
log human capital			1.99**	3.23*			1.57*	2.25
			(0.677)	(1.258)			(0.739)	(1.399)
log natural resources				0.10				0.39
				(0.257)				(0.313)
log K/L				0.20				0.02
				(0.389)				(0.388)
Constant	8.73***	9.07***	10.92***	12.03**	12.78***	10.87***	13.43***	17.18***
	(2.496)	(2.209)	(2.298)	(3.728)	(3.591)	(3.015)	(2.895)	(4.649)
Observations	114	109	95	70	113	108	95	70
r2	0.27	0.36	0.41	0.47	0.21	0.35	0.38	0.31
ch2					0.04	0.32	0.13	0.02

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

*** significance at 1% level; ** significance at 5% level; * significance at 10% level t-statistics in parenthese

Table 4: Panel Growth Regressions, 1975-2005

	5-year Panel (1975-2005) Growth rate of GDP per capita			
	OLS (pooled)	OLS(pooled)	FE	FE
log initial Product connectivity	0.648	0.587	0.688	0.629
	(5.75)***	(5.65)***	(2.97)***	(3.01)***
log initial GDP per cap	-0.827	-0.663	-1.924	-0.891
	(-4.06)***	(-2.53)**	(-4.90)***	(-2.36)**
log human capital	4.758	4.438	6.143	3.397
	(4.19)***	(3.98)***	(3.01)***	(1.85)*
log capital-labor ratio		-0.054		-1.529
		(-0.33)		(-4.55)***
constant	8.763	8.214	17.314	32.857
	(5.42)***	(4.47)***	(4.71)***	(6.36)***
Observations	507	438	507	438
R2	0.10	0.11	0.04	0.06

*** significance at 1% level; ** significance at 5% level; * significance at 10% level t-statistics in parenthese

Table 5: Knowledge Applicability of Bilateral Trade (OLS, Probit and IV regressions)

	OLS	IV	
Dependent Variable	$\log(aw_{ij})$	T_{ij}	$\log(aw_{ij})$
Log distance	-0.262***	-0.112***	-0.078**
	(0.034)	(0.010)	(0.035)
Log workers (exporter)	0.553***	0.156***	0.291***
	(0.022)	(0.005)	(0.029)
Log area (exporter)	-0.352***	-0.035***	-0.296***
	(0.017)	(0.004)	(0.018)
Log workers (importer)	0.112***	0.092***	-0.041*
	(0.022)	(0.005)	(0.024)
Log area (importer)	-0.011	-0.028***	0.031*
	(0.018)	(0.004)	(0.018)
Landlocked	-0.117*	-0.155***	0.184***
	(0.060)	(0.013)	(0.064)
Border	1.415	-0.040	1.550
	(1.485)	(0.466)	(1.517)
Border*Log(distance)	0.264	0.189 ***	-0.041
	(0.285)	(0.073)	(0.291)
Border*Log(workers$_i$)	-0.092	-0.081**	0.056
	(0.074)	(0.033)	(0.076)
Border*Log(area$_i$)	-0.032	0.040	-0.092
	(0.091)	(0.032)	(0.093)
Border*Log(workers$_j$)	-0.124	-0.032	-0.034
	(0.084)	(0.030)	(0.086)
Border*Log(area$_j$)	-0.067	-0.062*	-0.022
	(0.110)	(0.036)	(0.119)
Border*$(L_i + L_j)$	0.048	-0.102	0.187
	(0.196)	(0.076)	(0.197)
Regulation cost	-1.064***	-0.429***	
	(0.072)	(0.012)	
Procedures and days	-0.633 ***	-0.115***	
	(0.090)	(0.022)	
Bias correction			-1.351***
			(0.093)
Constant	-3.702***		-2.111***
	(0.376)		(0.391)
Observations	5874	12210	5874
R^2	0.153	0.274	0.144

Table 6: Knowledge Applicability, Trade Specialization and Income (second stage)

	(1)	(2)	(3)	(4)	(5)	(6)
Log country authority weight	0.668***	0.378***	0.268*	0.216**	0.337***	0.203*
(predicted from the 2nd stage)	(0.178)	(0.115)	(0.113)	(0.098)	(0.113)	(0.068)
Log human capital		2.884***	2.234***	1.743***	2.557***	0.324
		(0.254)	(0.276)	(0.278)	(0.281)	(0.189)
Financial development			0.854***			
			(0.209)			
Rule of Law				0.537***		0.162***
				(0.086)		(0.045)
Entry cost					-0.003**	
					(0.001)	
Log natural resources						0.122*
						(0.047)
Log capital-labor ratio						0.528***
						(0.037)
Constant	11.285***	7.948***	7.603***	8.049***	8.140***	0.208
	(0.759)	(0.567)	(0.541)	(0.467)	(0.554)	(0.527)
Observations	97	88	79	88	88	70
R^2	0.143	0.668	0.748	0.774	0.689	0.963

Table 7: Alternative Approach: Exogenous Determinants of Country Knowledge Applicability

Dependent variable: Log country authority weight (exported-weighted sum across trade partners)

Distance from the equator	2.627***
	(0.760)
Log predicted country authority weight	1.225***
	(0.188)
Fraction of population speaking English	1.000
	(0.620)
Fraction of population speaking a European language	0.390
	(0.410)
Constant	0.420
	(0.920)
Observations	112
R^2	0.413

Table 8: Alternative Approach: Knowledge Applicability and Income (second stage)

Dependent variable: Log GDP per capita in 1995						
	(1)	(2)	(3)	(4)	(5)	(6)
Log country authority weight	0.568***	0.290***	0.284**	0.168**	0.278***	0.136
(predicted from the 1st stage)	(0.083)	(0.086)	(0.139)	(0.078)	(0.098)	(0.091)
Log human capital		2.286***	2.119***	1.682***	2.099***	0.338
		(0.304)	(0.254)	(0.252)	(0.291)	(0.299)
Financial development			0.298			
			(0.363)			
Rule of Law				0.410***		0.119
				(0.105)		(0.078)
Entry cost					-0.002	
					(0.001)	
Log natural resources						0.062
						(0.049)
Log capital-labor ratio						0.497***
						(0.080)
Constant	10.811***	7.985***	7.936***	7.900***	8.176***	0.834
	(0.331)	(0.542)	(0.803)	(0.406)	(0.542)	(1.197)
Observations	112	98	88	98	96	71
R^2	0.309	0.672	0.710	0.769	0.687	0.943