Does complexity explain the structure of trade?

Asier Minondo*

Francisco Requena**

January 2012

Abstract

This paper analyzes whether complexity, measured by the number of skilled tasks that are performed simultaneously in production, explains countries' commodity trade structure. We modify Romalis (2004) model to incorporate differences in complexity across commodities together with differences in average skills across countries and monopolistic competition. Our model predicts that the share of developed countries in world trade increases with products' complexity. The empirical tests confirm this prediction. Moreover, in most cases, complexity seems to provide a better explanation of countries' commodity trade structure than the one offered only by skill intensity.

Key words: complexity, skill-intensity, factor proportions, trade structure, specialization.

JEL classification: F11, F12, F14

Corresponding author: Francisco Requena, University of Valencia, Faculty of Economics, Avda Tarongers s/n, Valencia (46022), Spain. E-mail: francisco.requena@uv.es

* Deusto Business School

** University of Valencia

Acknowledgements: We thank participants in the research seminar at the Universidad Complutense and in Inteco's VIII Jornadas de Integración Económica for their valuable suggestions. We acknowledge financial support from Spanish Ministry of Science and Innovation (ECO2010-21643/ECON; project ECO 2011-27619/ECON) and Generalitat Valenciana (project Prometeo/2009/098).

1. Introduction

One of the features of the globalization process is the increasing number of firms located in developing countries engaged in international markets, and the emergence of the so-called emerging markets champions. Moreover, some of these firms are able to compete in skill-intensive activities with firms located in developed countries. For example, among services, some skill-intensive activities, such as medical diagnoses or software development, are outsourced to developing countries. Among manufactures, we also observe some developing countries' firms capturing substantial market shares in skill-intensive products, such as aircrafts, special garments, petrochemicals or high-quality furniture.

The increasing number of firms located in developing countries competing in skill-intensive activities does not fit well into the factor proportions theory of trade. According to this theory, developing countries should specialize in goods and services that make intensive use of the factor of production in which they are relatively well endowed: unskilled labor. In this paper we offer a novel explanation for the pattern of trade between developed and developing countries, an explanation that accommodates the growing presence of southern firms in some skill-intensive activities. We contend that complexity, defined as the number of skilled tasks that are performed simultaneously in production, offers a complementary description of the pattern of trade between developed and developing countries.

Goods and services differ in their level of complexity. For example, among goods, the number of different skilled tasks needed to produce an aircraft is much larger than the number of skilled tasks needed to produce a bicycle. Among services there are also large differences in complexity. For example, the number of different skilled tasks needed to provide the services of a business school is much larger than the number of different tasks needed to run a barbershop. Usually, there is a correlation between the skill-intensity of a product or service, measured by the share of skilled workers in total employees, and its complexity level. However, there are cases in which a large skill-intensity does not imply a high level of complexity. For example, some of the goods and services where we observe an increasing presence of developing countries' firms (special garments, medical diagnoses or software writing) are characterized by a high degree of skill-intensity, but by a low degree of complexity.

Building on this concept, we contend that developed countries have comparative advantage in complex goods, whereas developing countries have comparative advantage in less complex goods. The advantage of developed countries in complex goods stems from the fact that small differences in workers' skills are magnified when a large number of skilled workers performing different tasks are combined in production. As average skills are higher in developed than in developing countries, productivity differences between the former and the latter will increase with the complexity of goods. In contrast, when products or services do not require complex production processes, differences in productivity are not magnified, and developing countries might compete in them. Hence, it is not only the intensity, but also the diversity of skilled tasks what determines developed countries' comparative advantage.

Complexity can also explain developed countries specialization in high-quality goods (Schott, 2004). Customers perceive a product as of higher quality, if it incorporates attributes than are not present in other products.[1] Attributes can be very diverse. For example, they can refer to emotional attributes, such as the feeling of success or elegance linked to a trade mark. They can also refer to physical attributes such as the softness or the lightness of the product. Or, they might refer to the additional set of services that are provided with the product. Usually, in order to build these additional attributes, firms have to incorporate additional skilled tasks

[1] Or more generally when the number of all attributes (characteristics) are larger than in other products (Lancaster, 1979).

into their production process. These additional skilled tasks can be related to new managerial competences, scientific research or key inputs provided by professionals. For example, in the cosmetics industry, if a firm wants to upgrade a low-quality cologne into an exclusive fragrance, it will have to incorporate new skilled tasks in the production process, such as container designers, artists or models with which to associate the fragrance, and media-experts to position the product in a more exclusive market. In the aircraft industry, engine manufacturers can provide a higher-quality service if they provide an on-line data-system which quickly detects when an engine needs reparation, and prepare in advance a fixing team in the airport where the aircraft is going to land, minimizing aircrafts' idle-time (The Economist, 9th January 2009). In this case, in addition to the different managerial and mechanical engineering tasks that are required for manufacturing the engine, the firm needs to incorporate new engineering tasks related to communication and data-analysis.[2] Hence, in our framework, developed countries comparative advantage in high-quality products or services is explained by the more complex production processes required by superior varieties.

The contribution of this paper is to formalize these ideas, developing a model that incorporates differences in average skills across countries, differences in complexity across commodities and monopolistic competition. The model predicts that developed countries share in trade will increase with the complexity of goods. This prediction receives ample support in the empirical analysis. Moreover, we show that complexity provides a better explanation of countries' trade structure than the one offered only by skill intensity. Both the model and the empirical analysis take into account the possibility for vertical fragmentation of the production process and the tradability of tasks.

[2] Sometimes, the larger number of tasks involved in high-quality products is obtained combining the tasks performed in different firms. For example, the mobile phone industry combines a large number of highly-skilled manufacturing and software design process tasks that are performed in different firms (The Economist, 20th August 2011).

This paper is related to several strands of the literature. First, it is linked to the literature that has worked on the concept of complexity and its influence on productive specialization. In particular, we draw the concept of complexity from Kremer (1993) and place it in a general equilibrium two-country model. Kremer defines complexity as the number of activities that might go wrong during the production process and influence the value of the product as a whole. In his model there are differences in skills across workers, where skills are defined as the probability a worker will successfully complete a task. One prediction of the model is that countries with a larger number of skilled workers will produce more complex goods. However, Kremer does not test his model empirically. Our definition of complexity is also close to Hidalgo and Hausmann (2009), who define it as the number of capabilities required to manufacture a good. These authors argue that the set of capabilities, or intangible skills, that are available in developed countries is much larger than in developing countries. If complex products require the combination of a large number of capabilities, it will be more probable to find the whole set of the required capabilities in developed than in developing countries. However, developing countries may still have comparative advantage in those activities that require a small range of skill-intensive capabilities. They estimate complexity by a method that iterates the number of products that a country exports (diversity) and the number of countries that export a product (ubiquity). Hidalgo and Hausmann (2009) observe that complexity predicts well country's income level and growth; however, they do not study whether complexity explains countries' trade structure. Costinot (2009) also defines complexity as the number of tasks that are required to produce a good. In his model, the tasks required to manufacture a good can be performed by one worker or by different workers. If a good involves a larger number of tasks, the worker should devote more time to training. Hence, in his empirical analysis, complexity is proxied by the average training that workers need to participate in production. His model also predicts that developed countries should specialize in more complex goods. Due to training costs, there are gains if workers specialize in a simple task. However, a large range of simple tasks leads to a higher number of workers participating in production process, which demands, in turn, a larger effort to monitor them and ensure contract enforcement. As developed countries have higher-quality institutions than developing countries, contract enforcement costs will be lower, yielding them comparative advantage in complex goods. In our paper, in contrast to Costinot (2009), the link between complexity and comparative advantage does not stem from specialization but from differences in workers' average productivity. In addition to that, we use a different proxy for complexity, estimate a model with a much larger sample of countries, and compare the relative contributions of complexity and skill-intensity to countries' commodity trade structure. Finally, complexity is also linked with the concept of "*new industry*" developed in the innovation literature (Baró and Villafraña, 2009), which captures the fact that the competitive success of manufacturing firms in developed countries depends increasingly on the service activities that they develop or incorporate.

This paper is also related to recent studies that examine the pattern of international trade between developed and developing countries, and particularly, to Romalis (2004). This author develops a model to analyze how differences in factor proportions influence the commodity structure of trade. His model predicts that countries relatively well endowed with skilled labor will have a larger share in the world production and trade of skill-intensive goods. As predicted by the model, he shows that the share of developed countries in US imports is increasing in the skill-intensity of goods. Our paper complements Romalis' analysis showing that complexity also plays a substantial role in determining the pattern of trade between developed and developing countries. As mentioned above, other studies, such as Schott (2004), have analyzed the predictions of the factor proportions theory for vertical specialization, finding that developed countries specialize in high-quality products whereas developing countries specialize in low-quality products. Our paper is also related with recent studies, such as Morrow (2010) and Chor (2010), that analyze the role of factor proportions theory and other forces, such as productivity and institutional differences, in explaining the commodity trade pattern in samples that combine develop and developing countries.

Finally, this paper is also related to recent literature where trade is described as an exchange of tasks, rather than as an exchange of goods. Grossman and Rossi-Hansberg (2008) develop a model to explain which tasks are offshored by firms and which tasks are performed in-house. They also analyze the consequences on reducing the costs of offshoring on domestic factor rewards. Other authors have analyzed which tasks are more likely to remain in developed countries, and which tasks have a higher risk of being offshored to developing countries (Autor et al., 2003; Blinder, 2009; Autor, 2010). These authors show that routine and impersonal tasks are easier to offshore to developing countries. In the paper, we analyze how the tradability of tasks might influence the predictions of the model, and the empirical analyses control for the possibility of offshoring less complex tasks to developing countries.

The rest of the paper is organized as follows. The next section develops the model. Section 3 presents the empirical tests and comments the results. Section 4 concludes.

2. The Model

We modify the model developed in Romalis (2004) to get a prediction on the relationship between a country's average skills and its share in the world production of complex goods. Romalis develops a model based on the factor proportions theory, where countries differ in their relative endowments of skilled and unskilled workers, and products differ in their skill-intensity. The model predicts that countries relatively well endowed in skilled workers should capture a larger share in the world production and trade of skill-intensive goods. In contrast, in our model differences across countries do not stem from differences in factor endowments but from workers' productivity. In particular, we assume that northern countries' workers are more productive than southern countries' workers. This higher productivity is explained by the higher level of human capital in the North than in the South. On the other hand, in our model products are not differentiated by skill-intensity but by their complexity level, defined as the number of workers performing different tasks that participate simultaneously in the production process. Following Kremer (1993), workers' higher productivity is reflected in a higher probability of performing their task correctly. The North will be more efficient than the South in the production of all products. However, northern countries advantage increases with the complexity of goods. Hence, northern countries develop comparative advantage in complex products and southern countries develop comparative advantage in less complex products. Substituting the factor proportion source of comparative advantage by a technological source of comparative advantage, and following the analytical steps taken in Romalis, we can derive a prediction on the relationship between a country's average skills and its share in the world production and trade of complex goods.

To reach this prediction, we assume that there are M countries in the North and M countries in the South. As explained above, there is only one factor of production, labor. The differences between northern and southern countries stem from workers' average skills, which are larger in the former than in the latter. We also assume that average skills are the same for each worker within a country. There is a continuum of industries z in the interval $[1, n]$. The index z ranks industries by their complexity level, defined as the number of workers performing different tasks that participate simultaneously in production. Industries with a higher z are more complex.

Preferences are identical for all consumers in all countries. At the industry level, consumers have Cobb-Douglas preferences, so a fixed amount of income (bY) is spent in each industry *z*. Within each industry, firms are able to differentiate their products without any cost, and consumers enhance their utility consuming a larger set of varieties. Based on these assumptions, the demand for variety *i* of industry *z* depends on the price of variety *i* relative to a price index, and the expenditure in industry *z*:

$$q^D(z,i) = \frac{\hat{p}(z,i)^{-\sigma}}{\int_{i' \in I(z)} \hat{p}(z,i)^{1-\sigma}\, di'} bY \qquad (1)$$

where *I(z)* denotes the set of varieties in industry *z* and σ the elasticity of substitution between varieties, which is greater than one. $\hat{p}(z,i)$ denotes the price of variety *i* paid by consumers. For varieties produced in other countries this price includes transport costs, which have the iceberg form, where τ units should be shipped for 1 unit to arrive ($\tau \geq 1$).

It is convenient to define the ideal price index *G(z)*:

$$G(Z) = \left[\int_{i \in I(z)} \hat{p}(z,i)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}} \quad (2)$$

The varieties of industry *z* consumed in a northern country can be produced domestically, in other northern countries or in southern countries. If we mark southern varieties with an asterisk and drop the industry notation, the ideal price index *G* can be expressed as:

$$G = [np^{1-\sigma} + (M-1)n(p\tau)^{1-\sigma} + Mn^*(p^*\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}} \ (3)$$

where *p* is the factory gate price set by a northern firm and *n* the number of varieties. The revenue of a typical northern firm be expressed as:

$$pq^s = bY\left(\frac{p}{G}\right)^{1-\sigma} + (M-1)bY\left(\frac{p\tau}{G}\right)^{1-\sigma} + MbY\left(\frac{p^*\tau}{G}\right)^{1-\sigma} \quad (4)$$

The supply side of the model is inspired in the Kremer (1993) O-ring production function. Each variety requires the combination of different tasks. We assume that each worker performs only one task and each task only requires one worker. Varieties belonging to different industries differ in the number of tasks required to manufacture them: varieties belonging to more complex industries require more tasks than varieties belonging to less complex industries. Each worker performs a task with a probability γ to perform it correctly. For example, $\gamma = 1$ means that the worker always performs the task correctly. As all tasks are needed to produce the good, if $\gamma = 0$ the production process stops and output equals zero. As northern workers have more human capital than southern workers their γ is larger. For simplicity, we assume that all tasks are subject to failure.

If firms are risk-neutral, production of variety *i* in industry *z* can be expressed as,

$$q^s(z,i) = \frac{L_{zi}}{z}\gamma^z, where\ L_{zi} \geq z\ \ and\ \ L_{zi}\ is\ a\ multiple\ of\ z \quad (5)$$

where L_{zi} represents the number of workers that participate in the production of variety *i* in industry *z*. As all tasks should be performed for the product to have full value, the product of γ represents the percentage of occasions where all workers involved in production perform their task correctly. The index *z*, which measures the level of complexity, also denotes the number of workers that participate simultaneously in the production process.

If production involves a fixed cost α, total costs can be expressed as

$$TC(q^s(z,i)) = \alpha + \left(\frac{q^s(z,i)z}{\gamma^z}\right)w \quad (6)$$

where w denotes the wage of workers in northern countries. As there is monopolistic competition, firms maximize their profits establishing a constant mark-up over marginal costs.

$$p(z) = \frac{\sigma}{\sigma - 1} \frac{zw}{\gamma^z} \qquad (7)$$

Based on equation (7), we can express the relative price of industry's z variety i in the North as:

$$\tilde{p}(z) = \frac{p(z)}{p^*(z)} = \frac{w}{w^*} \frac{\gamma^{*z}}{\gamma^z} \qquad (8)$$

Note that as $\gamma^{*z} < \gamma^z$ the relative price in the North is decreasing in z ($\tilde{p}' < 0$): the higher the complexity of the good the lower the relative price of northern varieties.

As explained in Romalis (2004), using equations (3) and (4), and their analogues for the South, it is possible to solve for partial equilibrium in industry z. As long as there is no complete specialization, these solutions lead to an equation that establishes a link between the share of northern firms in z-industry's world revenues (v) and the relative price of northern goods:

$$v = \frac{Y}{W} \left[\frac{-p^{-\sigma}\tau^{1-\sigma}MF\left(\frac{Y^*}{Y} + 1\right) + \tau^{2-2\sigma}M^2\frac{Y^*}{Y} + F^2}{-(p^{-\sigma} + \tilde{p}^{-\sigma})\tau^{1-\sigma}MF + \tau^{2-2\sigma}M^2 + F^2} \right] \qquad (9)$$

where W is total world income ($W=M(Y+Y^*)$) and F is the quantity a northern firm sells in all northern markets divided by its domestic sales ($F=1+(M-1)\tau^{1-\sigma}$).

Equation (9) closes the relationship between a higher skill-level and a larger share in the production and trade of complex goods. Northern workers have higher skills than southern workers. As higher skills raise the probability of completing a task correctly, northern countries are more productive than southern countries in all products. However, because tasks should be performed simultaneously, the advantage of northern countries will be higher in those products that require a large number of tasks. Hence, given a relative wage, the price of varieties in North relative to the South will decrease with the complexity of goods. As countries have the same preferences and there is full employment, northern countries will specialize in more complex products and, hence, will capture a larger share of the world revenue and trade of these products.

In the model, we have assumed that the probability of committing mistakes is the same in all tasks. In this scenario, northern firms do not have any incentive to fragment the production process between northern and southern countries, even if it was technologically feasible to do so. If northern firms decided to move production to a southern country due to lower costs, all production stages would be transferred. Northern firms would have incentives to transfer some stages of the production process to a southern country if the probability of committing mistakes were different across tasks. In particular, northern firms would outsource to southern countries the tasks where the probability of committing mistakes was lower. Note that specialization of southern countries in risk-free tasks would reduce the relative price of northern varieties in all industries.

Does the possibility of offshoring affect the prediction of the model? The answer is affirmative if there are goods that incorporate highly complex components, and whose assembly is performed in southern countries. An example can illustrate this point. A mobile phone is a good which incorporates highly complex components that are manufactured in northern countries, but whose assembly is performed in southern countries (Xing, 2011). A mobile phone can be considered as a complex good, because a large number of different tasks are involved in the manufacturing of the electronic components, and in assembly.[3] Our model predicts that the higher the complexity of the good the larger the share of northern countries in world production and trade. However, due to the offshoring of the assembly stage, southern countries will command a large share in the production and trade of mobile phones, a complex product, contradicting the predictions of the model.

Offshoring would be less damaging for the prediction of the model if country's share in imports were not measured in gross value terms, but in value-added terms. As the value added in assembly is much lower than the value added in other production stages, even when assembly was offshored, southern countries would still command a low share in complex products production and trade. Even when gross value was used, offshoring would also be less damaging for the prediction of the model if it happened in a low-complexity component, which is then incorporated in a complex good, whose assembly was performed in a northern country. On its hand, offshoring does not affect the prediction of the model when both components and final goods have a low-complexity level. In the empirical analyses, we control for goods that incorporate complex components, but whose final assembly is performed in southern countries.

3. Testing the model

As Romalis (2004) points out, the predictions of the theoretical framework explained above are particularly sharp with respect to trade. As explained above, as consumers in all countries have the same preferences, and complex goods are relatively cheaper in northern countries, the share of northern countries in another country's imports should increase with the

[3] Dedrick et al. (2010) and Linden et al. (2009) provide other examples of products that incorporate highly complex components whose assembly is performed in southern countries.

complexity of goods. To present this idea formally, we calculate the share of a northern country's firms in another northern country's total imports of commodity *z*:

$$x = \frac{nbY\left(\frac{p\tau}{G}\right)^{1-\sigma}}{(M-1)nbY\left(\frac{p\tau}{G}\right)^{1-\sigma} + Mn^*bY\left(\frac{p^*\tau}{G}\right)^{1-\sigma}} \qquad (10)$$

Rearranging,

$$x = \frac{1}{(M-1) + M\frac{n^*}{n}\tilde{p}^{\sigma-1}} \qquad (11)$$

Equation (11) establishes an inverse relationship between the share in imports and the relative price. By equation (8) the relative price of northern firms decreases with the level of complexity. Hence, we expect a positive relationship between a northern country's share in imports and commodity's complexity.

The regression equation to test this prediction can be expressed as

$$x_{ijz} = \beta_0 + \beta_1 z + u_{ijz} \qquad (12)$$

where x_{ijz} is the share of northern country *i* in northern country's *j* total imports of commodity *z*. The term z also denotes the complexity level, defined as the number of different tasks that are performed in production; u_{ijz} is the error term.

Estimation of equation (12) demands detailed industry-level bilateral imports data. At present, data meeting these characteristics is only available for merchandises and, hence, we have to exclude services from the analysis. This represents a limitation for our study. As explained in the introductory section, services provide examples of developing countries specializing in the supply of skill-intensive, but low-complexity activities. Hence, it would have been interesting to test whether these examples are isolated facts, or they constitute a pattern for the services sector.

The indicator of the complexity of goods comes from the Occupational Employment Statistics (OES) survey of the U.S. Bureau of Labor Statistics (www.bls.gov/oes). The OES uses a sample of 1.2 million establishments that operate in manufacturing and services to estimate how workers are distributed across occupations. The OES follows the Standard Occupational Classification (SOC), which distinguishes 801 different occupations. We consider that each occupation corresponds to a different task. In our theoretical model the complexity of a good is defined as the number of tasks subject to mistakes involved in the production process. To identify the tasks subject to mistakes we look to the skill-level required to produce the task, and assume that only skilled tasks are subject to failure. Hence, we measure complexity by the number of skilled tasks required to produce a good. We consider as skilled occupations those included between SOC category 11 and SOC category 29: management and other occupations that involve an intensive use of scientific and technical knowledge. At the end of this section, we use an alternative complexity measure to test the robustness of the empirical results. The OES database classifies good following the NAICS 4-digit classification. To be as close as possible to the features of the model, we restrict the sample to the 66 narrow manufacturing industries included in the OES database, removing those industries where natural resources may also play a role in determining comparative advantage.[4]

To calculate goods' complexity level we use data collected in a northern country: USA. As explained before, to perform a valid estimation of the model, we should control for goods that incorporate complex components, but whose final assembly is performed in southern countries. This control is especially important when the highly complex components and the

[4] In addition to agricultural and mineral raw materials, we also exclude from the sample food and beverages, wood products and non-metallic minerals.

final good belong to the same 4-digit NAICS industry. To identify these industries we draw on recent work by Koopman et al. (2012) on the domestic content of Chinese exports, the most important assembler among southern countries.[5] These authors find that the lowest share of domestic value-added in Chinese exports happen in electronic and optical equipment. This sector includes the manufacture of office, accounting and computing machinery; electrical machinery and apparatus; radio, television and communication equipment; medical, precision and optical instruments, watches and clocks. Moreover, this sector presents a large share of process exports, where Chinese firms import components from abroad, and after being assembled are exported as final products. In addition to that, a large percentage of firms manufacturing processed exports in this sector are owned by foreign firms. Hence, electronic and optical equipment constitutes a sector where southern countries have a large presence in the final stage of production, and where southern countries use a large share of components produced in foreign countries. Products belonging to this industry also rank at the top position in studies that use alternative indexes to measure the degree of offshoring (OECD, 2007).

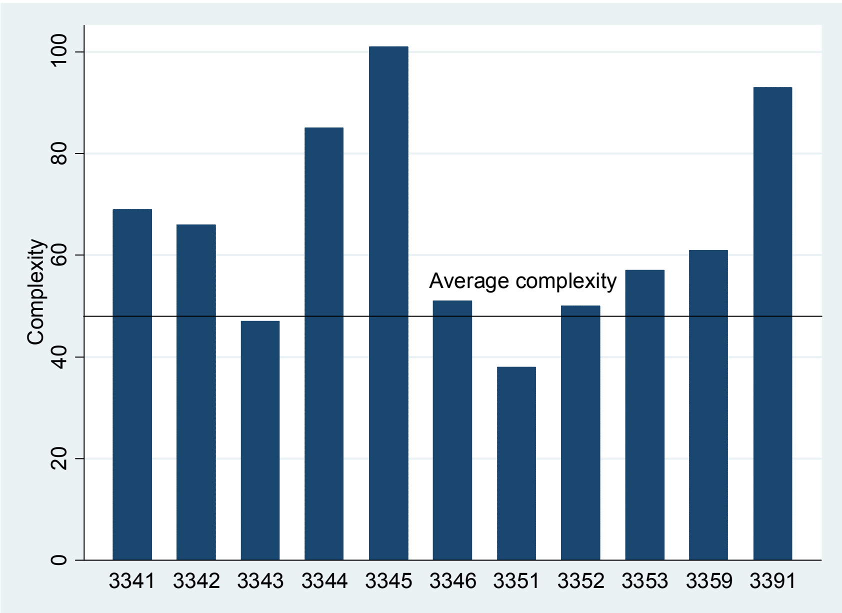
As mentioned before, the offshoring of the assembly process to southern countries might compromise the prediction of the model if the components that are incorporated into the final good have a high complexity level. Figure 1 presents the complexity indexes of the eleven industries in the OES database that belong to electronic and optical instruments sector. We can observe that most of the industries belonging to electronic and optical equipment have a complexity level which is above the mean in the manufacturing sector, which lies at 45 different skilled tasks. There are three sectors that outstand in terms of complexity: NAICS 3344 Semiconductor and other electronic component manufacturing, NAICS 3391 Medical equipment and supplies manufacturing, and NAICS 3345 Navigational, measuring,

[5] See also Ma and van Assche (2010), and IDE-JETRO and WTO (2011).

electromedical and control instruments manufacturing. In the econometric analyses, we will control for the bias that these industries might introduce in the estimations.

Imports data come from the BACI database. This database, developed by CEPII, reconciles the exporter and importer declarations on value and quantity at the HS 6-digit level provided by the United Nations Statistical Division Comtrade database for the period 1995-2007 (Gaulier and Zignago, 2010). Imports data is transformed to the NAICS classification followed by OES, using correspondence tables in Pierce and Schott (2009).

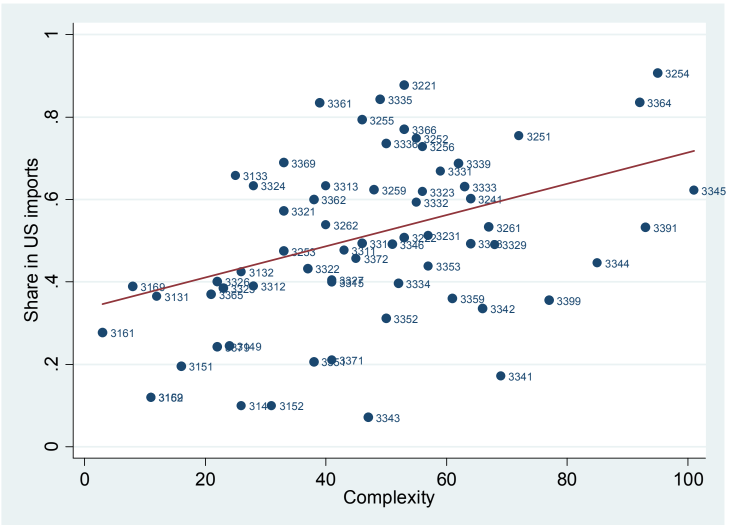
Figure 1. Complexity in electronic and optical equipment industries, 2007



In the empirical analyses we assess the relative contributions of complexity and skill-intensity to explain countries' commodity trade structure. This latter variable is proxied by the share of non-production workers in total employment. Data on the share of non-production workers is obtained from the US Economic Census for the years 2002 and 2007. Hence, we restrict our empirical analysis to these years.

Figure 2 presents the relationship between products' complexity and the share of northern countries in US total imports for the year 2007. As shown in the figure, there is a strong positive relationship between both variables: the share of northern countries is larger the higher the complexity of the good. We also observe that there is a large variation in complexity across industries. The lowest complexity level is found in NAICS code industry 3161, leather and hide tanning and finishing, where only three skill tasks are performed. In contrast, the industry with a larger number of skilled tasks (101) is NAICS code 3345, navigational, measuring, electro-medical and other instruments manufacturing, which belongs to the electronic and optical equipment sector.

Figure 2. Share of northern countries in US imports and products' complexity, 2007



In Figure 3, we analyze the relationship between the share of northern countries in US exports and skill-intensity, measured, as explained before, by the share of non-production workers in total employment. As predicted by the factor proportions theory, the share of northern countries rises with products' skill-intensity. We also observe that there is a large variation in skill-intensity across industries. The lowest skill-intensity is found in fiber, yarn and thread mills (code 3131), where the share of nonproduction workers is 10%; the highest skill level is found in communications equipment manufacturing (code 3342), where the share of nonproduction workers is above 60%.

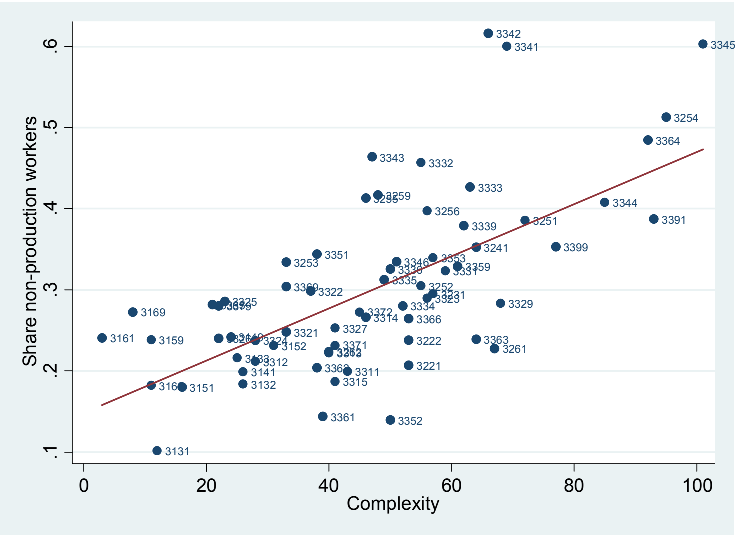
Finally, Figure 4 shows the relationship between complexity and skill-intensity. We can see that there is a positive relationship between both variables: industries with a large number of skilled tasks also have a large share of non-production workers in total employment. However, we also observe that there are substantial differences in skill-intensity for a given complexity level. For example, plastic product manufacturing (NAICS 3261) and communication equipment manufacturing (NAICS 3342) have almost the same complexity: 67 and 66 respectively. However, skill intensity in communication equipment manufacturing (62% of non-production workers) is almost three times larger than in plastic product manufacturing (23% of non-production workers). This variation in skill-intensity allows to test whether, as argued in this paper, complexity also plays a significant role in determining countries' trade commodity structure. The econometric analyses presented below aim to answer this question.

Our estimates of Equation (12) are distributed in two main sets. In the first set, we aggregate all northern countries imports for each manufacturing industry. In the second set, we estimate equation (12) with industry-level bilateral imports data. In each set, equation (12) is estimated for three different samples. First, to compare our results with Romalis (2004), we consider the US as the reference northern country. We estimate whether the share of other northern countries in US imports increases with the complexity of the good. We consider northern countries as those with a GDP per capita equal or above 50 per cent of the US GDP per capita. Second, we calculate the share of northern countries in each northern country's imports, and estimate the equation pooling all observations.[6] Finally, as equation (12) is symmetric for non-northern countries, we also estimate the model pooling observations of the

[6] The countries included in this group are Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Hong-Kong, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom and the United States.

Figure 3. Share of northern countries in US imports and products' skill-intensity, 2007

Figure 4. Relationship between skill-intensity and complexity, 2007



share of northern countries in world (northern and southern countries) imports.[7] Table 1 presents the results of the first set of econometric estimates. In each sample, import shares are regressed on products' complexity; then, import shares are regressed on skill-intensity; and finally, we include both complexity and skill-intensity as independent variables in the regression. In all estimations we introduce a dummy variable to control for the industries that belong to the electronic and optical equipment sector. To perform the econometric analyses we pool observations for the years 2002 and 2007.

Columns (1) to (3) present the results when estimating the model with the US as the reference importer. As shown in Table 1-Column 1, the complexity coefficient is positive and statistical significant. This result confirms the prediction of the model: the share of northern countries in US imports rises with the complexity of goods. According to this result, a one standard deviation increase in complexity leads to a 12 percentage points increase in the share of northern countries in US imports (0.647 * 0.185). As expected, the coefficient for electronic and optical equipment is negative. As the assembly of these goods is performed in southern countries, the share of northern countries in US imports is lower than expected taking into account these industries' complexity level. In Column 2, we can see that the coefficient for skill-intensity is also positive and statistically significant. The coefficient, 0.81, is in line with that obtained by Romalis (1994: Table 8-Two factors): 0.93.[8] In this case, a one standard deviation increase in skill-intensity leads to a 9 percentage points increase in the share of northern countries in US imports (0.812*0.110). It is interesting to observe that the fit of the model is much higher when complexity is used as explanatory variable than when skill-

[7] We include southern countries with at least a 0.1% participation in world trade. The group is composed by Algeria, Argentina, Bangladesh, Belarus, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica, Croatia, Czech Republic, Dominican Republic, Egypt, Guatemala, Hungary, India, Indonesia, Iran, Kazakhstan, Kuwait, Lebanon, Lithuania, Malaysia, Mexico, Morocco, Nigeria, Pakistan, Peru, Philippines, Poland, Romania, Russia, Saudi Arabia, Slovakia, South Africa, Thailand, Tunisia, Turkey, Ukraine, United Arab Emirates, Venezuela and Vietnam.

[8] Romalis estimates the model using imports data for year 1998 and skill-intensity data for year 1992, and with a sample of countries slightly different to that used in our study.

Table 1. Regression results on the relationship between the share of northern countries imports, complexity and skill-intensity.

Aggregated northern countries imports (year 2002 and 2007)

	USA (1)	USA (2)	USA (3)	North (4)	North (5)	North (6)	North+South (7)	North+South (8)	North+South (9)
Complexity	0.647		0.585	0.414		0.342	0.380		0.277
	(0.092)***		(0.115)***	(0.069)***		(0.086)***	(0.066)***		(0.075)***
Skill-intensity		0.812	0.188		0.585	0.220		0.611	0.316
		(0.208)***	(0.197)		(0.136)***	(0.140)		(0.124)***	(0.128)**
Electronic	-0.272	-0.260	-0.285	-0.090	-0.090	-0.105	-0.048	-0.059	-0.071
	(0.038)***	(0.052)***	(0.039)***	(0.027)***	(0.038)***	(0.030)***	(0.028)*	(0.037)	(0.031)**
Observations	132	132	132	3300	3300	3300	8976	8976	8976
R-squared	0.432	0.258	0.433	0.326	0.273	0.334	0.293	0.272	0.306

Note: Complexity in hundreds. Standard errors clustered by industry in parentheses. Regressions in Columns 1 to 3 include year-specific dummy variables; regressions in Columns 4 to 9 include year specific importer country dummies. ***, **, *: statistically significant at 1%, 5% and 10% respectively.

Tabla con formato

intensity is used as explanatory variable. Finally, when both independent variables are introduced in the regression (Column 3), the coefficient for complexity remains positive and statistically significant; however, the coefficient for skill-intensity, although positive, becomes statistically not significant. This result seems to point out that for the US, complexity provides a better description of the commodity trade structure than the one offered only by skill intensity.

In Columns 4 to 6, we calculate the share of northern country imports for each industry for a sample of northern countries. We pool all observations, and estimate equation (12) with year specific reference importing country fixed effects. As before, when entered separately, complexity and skill-intensity are positive and statistically significant. The dummy on electronic and optical equipment remains negative. In terms of magnitude, a one standard deviation increase in complexity leads to 8 percentage points increase in the share of northern countries in another northern country's imports; in the case of skill-intensity, a one standard deviation increase leads to a 6 percentage points increase in the share. However, as before, when complexity and skill-intensity enter simultaneously in the regression equation, complexity remains positive and statistically significant, but skill-intensity is not statistically significant.

Finally, in columns 7 to 9 we pool northern and southern reference importers' observations. As shown in the table, when entered separately complexity and skill-intensity are positive and statistically significant. Moreover, for the first time, when both variables enter simultaneously in the equation, skill-intensity is positive and statistically significant. According to the coefficients in Column 9, a one standard deviation in complexity increases the share of northern countries in a country's imports by 5 percentage points; in the case of skill-intensity, a one standard deviation raises the share by 3 percentage points.

In the second set of regression analyses, we estimate equation (12) with bilateral imports data, introducing year specific importer-exporter fixed effects. These fixed effects control for all the (gravity) variables that might influence the share of a northern country in a country's total imports from northern countries. As before, we estimate equation (12) for three different samples. Table 2 presents the results of the econometric analyses. As shown in Columns 1 and 2, the share of a northern country in US imports rises with the complexity and skill-intensity of the good. More specifically, a one standard deviation in complexity increases by 0.5 percentage points a northern country's share in US total imports from northern countries; a one standard deviation in skill-intensity, raises the share by 0.4 percentage points. When complexity and skill-intensity enter the equation simultaneously, complexity remains statistically significant, but skill-intensity is no longer statistically significant. According to this result, complexity plays a more significant role than skill-intensity in explaining the commodity-structure of US bilateral imports. As in the first set of econometric analyses, the dummy for electronic and optical equipment industries is negative.

The results for the pool of northern countries (Columns 4 to 6) are similar to those for the US: only complexity has a positive and statistically significant effect on the share of a northern country in another northern country's total imports from northern countries. In Column 7 to 9, we estimate equation (12) pooling the observations from northern and southern countries. We find that both complexity and skill-intensity have a positive and statistically significant impact on the share of a northern country in a country's total imports from northern countries. According to our results, a one standard deviation in the complexity of the product raises by 0.2 percentage points the share of an average northern country in another country's total imports from northern countries; in the case of skill-intensity, a one standard deviation increase also leads to a 0.2 percentage increase in the share.

Table 2. Regression results on the relationship between the share of northern countries in US imports, complexity and skill-intensity.

Bilateral imports (year 2002 and 2007)

	USA (1)	USA (2)	USA (3)	North (4)	North (5)	North (6)	North+South (7)	North+South (8)	North+South (9)
Complexity	0.027		0.024	0.018		0.014	0.016		0.011
	(0.004)***		(0.005)***	(0.003)***		(0.004)***	(0.003)***		(0.004)***
Skill-intensity		0.034	0.009		0.025	0.010		0.027	0.015
		(0.009)***	(0.008)		(0.006)***	(0.006)		(0.006)***	(0.006)**
Electronic	-0.011	-0.011	-0.012	-0.004	-0.004	-0.005	-0.002	-0.003	-0.003
	(0.002)***	(0.002)***	(0.002)***	(0.001)***	(0.002)***	(0.001)***	(0.001)*	(0.002)*	(0.001)**
Observations	3151	3151	3151	75590	75590	75590	195159	195159	195159
R-squared	0.194	0.190	0.194	0.636	0.625	0.626	0.575	0.574	0.575

Note: Complexity in hundreds. Standard errors clustered by industry in parentheses. Regressions in Columns 1 to 3 include year specific imports' origin country dummy variables; regressions in Columns 4 to 9 include year specific bilateral relationship dummy variables. ***, **, *: statistically significant at 1%, 5% and 10% respectively.

To sum up, empirical analyses with both aggregated and bilateral imports confirm the predictions of the model on the positive relationship between complexity and the share of northern countries in imports. Moreover, for some countries, complexity seems to provide a better explanation of the commodity structure of trade than skill-intensity.

To test the robustness of our benchmark results, we perform two sets of sensitivity analyses. The first set uses an alternative indicator to proxy commodities' complexity level. In the benchmark analysis, the product complexity measure was built on the assumption that mistakes can only happen in skilled tasks; we also assumed that all skilled tasks had the same probability of committing mistakes. In the alternative measure, we assume that mistakes can happen in all tasks; however, we consider that the likelihood of committing mistakes, and their impact in the product's final value, is related to the difficulty of the problems that have to be resolved in each task. To assess the difficulties faced by each occupation, we turn to the O*NET database, and draw information on how important the solving of complex problems is for each occupation. We assume that the higher the importance of solving complex problems the higher the probability of committing mistakes. To calculate the new complexity measure we add-up all occupations in each industry, weighting each task by the importance of solving complex problems in that task.[9] We estimate all the regression equations using this alternative complexity measure. As shown in Table 3, with the new complexity measure, both complexity and skill-intensity play a positive and significant role in all estimations. This happens both for estimations with aggregated imports (Columns 1-6), and for estimations with bilateral imports (Columns 7-12). These results confirm that complexity, along with skill-intensity, helps to explain the commodity structure of trade.

[9] Costinot et al. (2011) also combine the O*NET and the OES databases to calculate a measure of routineness at the industry level.

In the second set of sensitivity analyses, we use an alternative measure for skill-intensity. To compare our results with those obtained in Romalis (2004), in the benchmark analysis skill-intensity was proxied by the share of non-production workers in total employment. As suggested by previous authors, occupational data can provide an alternative, and better, proxy for skill-intensity (Autor et al., 2003; Winchester et al., 2006). Based on the data provided by the OES, we calculate skill-intensity dividing the employment in skilled occupations (code 11 to 29) by total employment. As shown in Table 4, the results are in line with those obtained in the benchmark analysis. Complexity has a positive and statistically significant impact on the share of imports from northern countries in all estimations. Skill-intensity is only significant when we pool observations from northern and southern countries. In Table 5 we re-run all regressions combining the alternative measure for complexity and the alternative measure for skill-intensity. Results are not altered. As an additional sensitivity test, when building the benchmark complexity measure, we only add skilled tasks as long as they overcome an employment threshold within the industry. This threshold is set at 0.1% of total employment in each occupation. Results are not altered either.[10]

4. Conclusions

During the last years we observe an increasing number of firms located in developing countries competing with firms located in developed countries in skill-intensive products and services. This trend points out that skill-intensity is not sufficient to explain the trade pattern between developed and developing countries. In this paper, we argue that product complexity, measured as the number of skilled tasks that are performed in production, might also play a role in explaining trade patterns. We argue that developed countries have comparative

[10] Results not reported. They can be requested from the authors.

Table 3. Sensitivity analysis I. Alternative complexity measure

	USA (1)	USA (2)	North (3)	North (4)	North+ South (5)	North+ South (6)	USA (7)	USA (8)	North (9)	North (10)	North+ South (11)	North+ South (12)
	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral
Complexity	0.280	0.231	0.171	0.128	0.149	0.100	0.012	0.010	0.007	0.006	0.006	0.004
	(0.048)***	(0.047)***	(0.040)***	(0.043)***	(0.041)***	(0.038)**	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)**
Skill-intensity		0.457		0.353		0.457		0.019		0.017		0.021
		(0.190)**		(0.139)**		(0.120)***		(0.008)**		(0.006)***		(0.006)***
Electronic	-0.203	-0.254	-0.044	-0.099	-0.005	-0.056	-0.009	-0.011	-0.002	-0.004	-0.001	-0.003
	(0.037)***	(0.042)***	(0.027)***	(0.031)***	(0.029)	(0.031)*	(0.002)***	(0.002)***	(0.001)***	(0.001)***	(0.001)*	(0.001)**
Observations	132	132	3300	3300	8976	8976	3151	3151	75590	75590	195159	195159
R-squared	0.372	0.411	0.292	0.318	0.260	0.297	0.193	0.194	0.626	0.626	0.574	0.575

Note: Complexity in natural logs. Standard errors clustered by industry in parentheses. Regressions in Columns 1 to 3 include year-specific dummy variables; regressions in Columns 4 to 9 include year specific importer country dummies. ***, **, *: statistically significant at 1%, 5% and 10% respectively.

Table 4. Sensitivity analysis II. Alternative skill-intensity measure

	USA (1)	USA (2)	North (3)	North (4)	North+ South (5)	North+ South (6)	USA (7)	USA (8)	North (9)	North (10)	North+ South (11)	North+ South (12)
	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral
Complexity		0.548		0.351		0.282		0.022		0.015		0.011
		(0.138)***		(0.098)***		(0.085)***		(0.006)***		(0.004)***		(0.004)***
Skill-intensity	0.875	0.269	0.559	0.172	0.578	0.266	0.037	0.012	0.024	0.008	0.025	0.013
	(0.228)***	(0.229)	(0.145)***	(0.148)	(0.133)***	(0.138)*	(0.010)***	(0.010)	(0.006)***	(0.006)	(0.006)***	(0.007)*
Electronic	-0.308	-0.301	-0.113	-0.108	-0.081	-0.077	-0.013	-0.013	-0.005	-0.005	-0.004	-0.004
	(0.051)***	(0.034)***	(0.039)***	(0.027)***	(0.038)***	(0.030)**	(0.002)***	(0.001)***	(0.002)***	(0.001)***	(0.002)**	(0.001)***
Observations	132	132	3300	3300	8976	8976	3151	3151	75590	75590	195159	195159
R-squared	0.300	0.439	0.272	0.330	0.270	0.302	0.191	0.194	0.625	0.626	0.574	0.575

Note: Complexity in natural logs. Standard errors clustered by industry in parentheses. Regressions in Columns 1 to 3 include year-specific dummy variables; regressions in Columns 4 to 9 include year specific importer country dummies. ***, **, *: statistically significant at 1%, 5% and 10% respectively.

Table 5. Sensitivity analysis III. Alternative complexity and skill-intensity measures

	USA (1)	North (2)	North+South (3)	USA (4)	North (5)	North+South (6)
	Aggregated	Aggregated	Aggregated	Bilateral	Bilateral	Bilateral
Complexity	0.215 (0.054)***	0.128 (0.043)***	0.097 (0.042)**	0.009 (0.002)***	0.005 (0.002)***	0.004 (0.002)**
Skill-intensity	0.527 (0.211)**	0.353 (0.139)**	0.421 (0.132)***	0.022 (0.009)**	0.015 (0.006)**	0.019 (0.006)***
Electronic	-0.285 (0.038)***	-0.099 (0.031)***	-0.071 (0.032)**	-0.012 (0.002)***	-0.004 (0.001)***	-0.004 (0.001)**
Observations	132	3300	8976	3151	75590	195159
R-squared	0.428	0.318	0.293	0.194	0.626	0.575

Note: Complexity in natural logs. Standard errors clustered by industry in parentheses. Regressions in Columns 1 to 3 include year-specific dummy variables; regressions in Columns 4 to 6 include year specific importer country dummies. ***, **, *: statistically significant at 1%, 5% and 10% respectively.

advantage in activities that demand the coordination of a large number of skilled workers performing different tasks. This advantage stems from the fact that small differences in productivity are magnified when a large number of skilled activities should be combined. However, developing countries will be able to compete in skill-intensive goods or services if they do not demand complex production processes.

To formalize this idea we develop a model that incorporates differences in average skills across countries and differences in complexity across commodities. The model predicts that the share of developed countries in world production increases with the complexity of goods. The empirical analyses provide ample support for this prediction. Moreover, we find that complexity complements the explanation provided by skill-intensity on country's commodity trade structure. Our analysis points out that both differences in technology and factor proportions are important to explain countries' trade pattern.

References

Autor, D.H., 2010. The Polarization of Job Opportunities in the U.S. Labor Market: Imlications for Employment and Earnings. *Center for American Progress and The Hamilton Project*.

Autor, D.H., Levy, F., Murnane, R.J., 2003. The Skill Content of Recent Technological Change: An Empirical exploration. *Quarterly Journal of Economics*, 118 (4), 1279-1333.

Baró, E., Villafraña, C., 2009. *The new industry: the core sector of the Catalan economy*. Generalitat de Catalunya, Barcelona.

Barro, R.J., Lee, J.W., 2010. A New Data Set of Educational Attainment in the World, 1950–2010. *NBER Working Paper 15902*, National Bureau of Economic Research, Cambridge, Mass.

Blinder, A.S., 2009. How Many US Jobs Might be Offshorable?. *World Economics*, 10 (2), 41-78.

Chor, D., 2010. Unpacking sources of comparative advantage: A quantitative approach. *Journal of International Economics*, 82 (2), 152-167.

Costinot, A., 2009. On the origins of comparative advantage. *Journal of International Economics*, 77 (2), 255-264.

Costinot, A., Oldensky, L., Rauch, J., 2011. Adaptation and the boundary of the firm. *Review of Economics and Statistics*, 93 (1), 298-308.

Dedrick, J, Kraemer, K.L. and Linden, G. (2010). "Who Profits from Innovation in Global Value Chains?: A Study of the iPod and Notebook PCs", *Industrial and Corporate Change*, **19**, 1, 81-116.

Gaulier, G. and Zignago, S. (2010). "BACI: International Trade Database at the Product-level. The 1994-2007 version", *CEPII Working Paper No 2010-23.*

Grossman, G.M., Rossi-Hansberg, E., 2008. Trading Tasks: A Simple Theory of Offshoring. *American Economic Review*, 98 (5), 1978-1997.

Hidalgo, C.A., Hausmann, R. 2009. The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106 (26), 10570-10575.

IDE-JETRO and WTO (2011). *Trade patterns and global value chains in East Asia: From trade in goods to trade in tasks*, World Trade Organization, Geneva.

Koopman, R., Wang, Z. and Wei, S. (2012), "Estimating domestic content in exports when processing trade is pervasive", *Journal of Development Economics*, doi: 10.1016/j.jdeveco.2011.12.004.

Kremer, M., 1993. The O-ring Theory of Economic Development. *Quarterly Journal of Economics,* 108 (3), 551-575.

Lancaster, K., 1979. *Variety, Equity, and Efficiency*. Blackwell, Oxford.

Linden, G., Dedrick, J. and Kraemer, K.L. (2009). "Innovation and Job Creation in a Global Economy: The case of Apple's iPod", *Working Paper*, Personal Computing Industry Center, UC Irvine.

Ma, A. and van Assche, A. (2010). "The role of trade costs in global production networks. Evidence from China's processing trade regime", *World Bank Working Paper 5490*.

Morrow, P. M., 2010. Ricardian-Heckscher-Ohlin comparative advantage: Theory and evidence. *Journal of International Economics*, 82 (2), 137-151.

OECD (2007). *Offshoring and Employment*, OECD, Paris.

Pierce, J.R., Schott, P.K., 2009. A Concordance Between Ten-Digit U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries. *Unpublished manuscript,* Yale University.

Romalis, J., 2004. Factor Proportions and the Structure of Commodity Trade. *American Economic Review*, 94 (1), 67-97.

Schott, P. K., 2004. Across-Product versus Within-Product Specialization in International Trade. *Quarterly Journal of Economics*, 119 (2), 647-678.

Winchester, N., Greenaway, D., Reed, G.V., 2006. Skill Classification and the Effects of Trade on Wage Inequality, *Review of World Economics*, 142 (2), 287-306.

Xing, Y. (2011). "How the iPhone widens the US trade deficit with China", www.voxeu.org, 10th April.