Does complexity explain the structure of trade?

Asier Minondo (Deusto Business School - University of Deusto. Camino de Mundaiz, 50; 20012 San Sebastián - Spain; E-mail: aminondo@deusto.es)

Francisco Requena (University of Valencia. Avda del Tarongers s/n. 46022 Valencia - Spain; E-mail: francisco.requena@uv.es)

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, complexity seems to provide a better explanation of countries' commodity trade structure than the one offered only by skill intensity.

JEL Codes: F11, F12, F14

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

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1. Introduction

One of the features of the globalization process is the increasing number of developing countries firms 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 developed countries firms. 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 developing countries firms 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 in goods and services between developed and developing countries.

Products 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 manage a business school is much larger than the number of different tasks needed for 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 (medical diagnoses, software writing or special garments) 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

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

product. Usually, in order to build these additional attributes, firms have to incorporate additional skilled tasks 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, engines' 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.

[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. Costinot (2009) also defines complexity as the number of tasks that are required to produce a good. However, in his model these tasks can be performed only by a 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 developed countries, contract enforcement costs will be lower, yielding them comparative advantage in complex goods. 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). 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 this paper, we do not focus on the tradability of tasks, but rather on how the number of skilled tasks that participate in production may be relevant to account for differences in the structure of trade across 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 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:

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

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,

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

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

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

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.

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 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

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

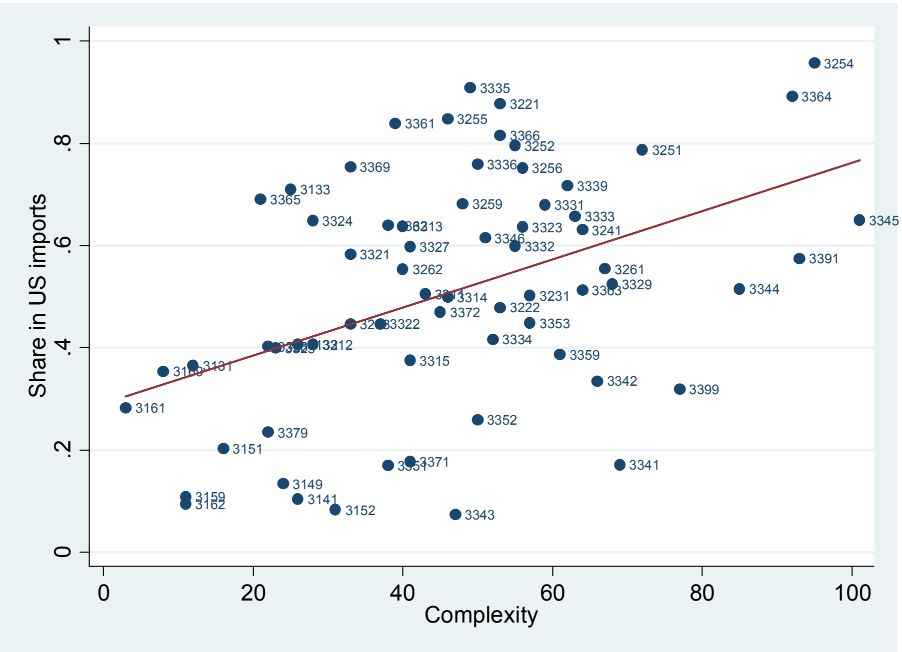
where x_{ijz} is the share of northern country *i* in northern country's *j* total imports of commodity *z*. The term z also denotes the complexity level, defined as the number of different tasks that are performed in production; *u* is the error term.

To estimate this equation, we need first an indicator of the complexity of goods. We get this indicator 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. We also 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 alternative complexity measures to test the robustness of the empirical results. Following the assumptions of the model, we consider that all countries have access to the same technology.

To make our estimations comparable to Romalis (2004), we take United States as the reference northern country; the rest of northern countries are identified as those with a GDP per capita equal or above 50 per cent of the US GDP per capita. Detailed data on US imports, in the HS 6-digit nomenclature, is obtained from UN Comtrade database. To transform these data to the NAICS classification followed by OES, we use Pierce and Schott (2009) correspondence tables. The analysis is performed using data for the years 2002 and 2007.

In the first empirical test, we aggregate US imports from all other northern countries for each commodity z, and analyze whether there is a positive relationship between the share in imports and goods' complexity. Figure 1 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, electromedical and other instruments manufacturing.[3]

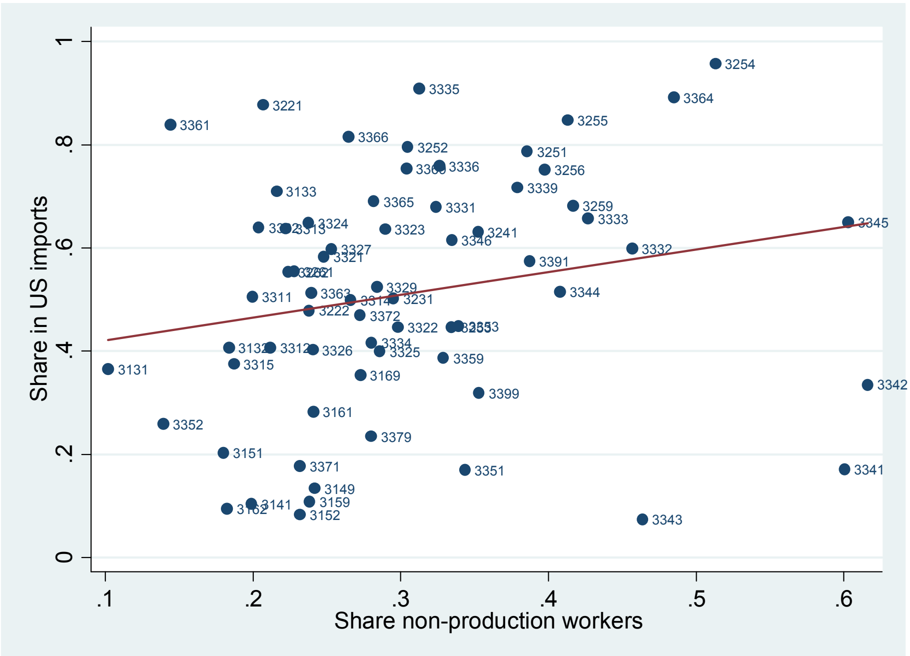
Figure 1. Share of northern countries in US imports and products' complexity, 2007



[3] The average complexity is 43 and the standard deviation 21.

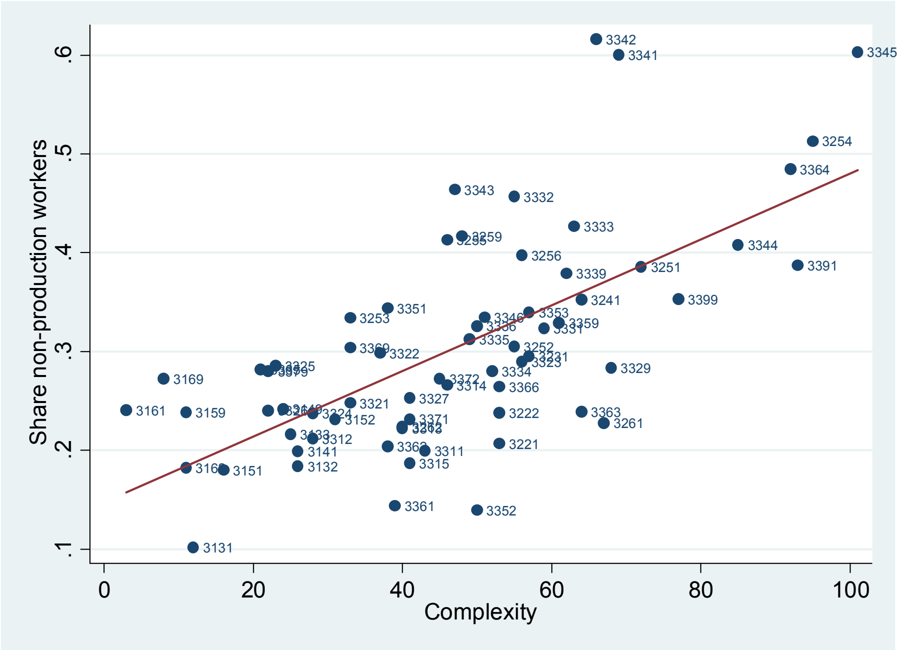
In Figure 2, we analyze the relationship between the share of northern countries in US exports and skill-intensity, measured as the share of non-production workers in total employment.[4] As predicted by the factor proportions theory, the share of northern countries rises with products' skill-intensity. 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, where the share of nonproduction workers is above 60%.[5] Finally, Figure 3 shows the relationship between complexity and skill-intensity. We can see that there is a positive relationship between both variables; however, we also observe that there are substantial differences in skill-intensity for a given complexity level.

Figure 2. Share of northern countries in US imports and products' skill-intensity, 2007



[4] Data on the share of non-production workers is obtained from the 2007 Economic Census.
[5] The average share of non-production workers is 29% and the standard deviation 11%.

Figure 3. Relationship between skill-intensity and complexity, 2007



To test the role of complexity and skill-intensity in explaining countries' commodity trade pattern, we estimate equation (12) in three alternative ways. First, import shares are regressed on products' complexity; second, import shares are regressed on skill-intensity; finally, we include both complexity and skill-intensity as independent variables in the regression. To perform the econometric analyses we pool observations for the years 2002 and 2007.[6] In Columns (1) to (3) we estimate the model with all manufactures, and in Columns (4) to (6) with narrow manufactures, removing from the sample those industries where natural resources may also play a role in determining comparative advantage.[7] As shown in Table 1-Column 1, the complexity coefficient is positive and statistical significant. This result confirms the prediction of the model. In Column 2, we can see that the coefficient for skill-intensity is also positive and statistically significant. This result is in line with

[6] Results are not altered when we perform the analysis independently for each year.
[7] In addition to agricultural and mineral raw materials, we also exclude from the sample food and beverages, wood products and non-metallic minerals.

that obtained by Romalis (1994: Table 8-Two factors), although the size of our coefficient is almost half of that obtained by Romalis: 0.93.[8] It is interesting to observe that the fit of the model is much higher when complexity is used as explanatory variable than when skill-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

Table 1. Regression results on the relationship between the share of northern countries in US imports, complexity and skill-intensity (year 2002 and 2007)

	(1)	(2)	(3)	(4)	(5)	(6)
Complexity	0.004***		0.004***	0.005***		0.005***
	(0.001)		(0.001)	(0.001)		(0.001)
Skill-intensity		0.502***	0.066		0.507***	-0.064
		(0.187)	(0.218)		(0.208)	(0.241)
R-squared	0.17	0.10	0.17	0.21	0.10	0.21
Sample	All	All	All	Narrow	Narrow	Narrow
Observations	170	170	170	132	132	132

Note: Regressions include year-specific dummy variables (not reported). Robust standard errors in parentheses. ***: statistically significant at 1%.

[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 use in our study.

complexity provides a better description of countries' commodity trade structure than the one offered only by skill intensity. We can see, as well, that results are not altered when we estimate the model with the sample of narrowly defined manufactures (Columns 4 to 6); moreover, there is an improvement in the fit of the model. As narrowly defined manufactures are more suitable to test the predictions of our model, we will only report the results of the empirical analyses for this sample.[9]

To test the robustness of our benchmark results, we perform three sets of sensitivity analyses. The first set uses alternative indicators to proxy commodities' complexity level. In the second set we use an alternative indicator to proxy commodities' skill-intensity. In the third set, we perform additional analyses on the relationship between commodities complexity level and countries participation in trade. Finally, in the fourth set, we run again all estimations using another country, Germany, as the reference northern country. To start with the first sensitivity analyses set, we should remember that in the benchmark analysis the product complexity measure is built on the assumption that mistakes can only happen in skilled tasks; we also assumed that all skilled tasks have the same probability of committing mistakes. In the first 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 with 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 if the worker does not have enough human capital. To calculate the new complexity measure we add-up all occupations in each industry, weighting each task by the importance of solving

[9] Results for the whole sample can be requested from the authors.

complex problems in that task.[10] As shown in Table 2 - Columns 1.1. and 1.2, the complexity measure is positive and statistically significant. The skill-intensity measure is positive, but remains statistically not significant.

Table 2. Alternative complexity measures (year 2002 and 2007)

	Occupations weighted by complex problem solving skills		Occupations weighted by wage	
	(1.1)	(1.2)	(2.1)	(2.2)
Complexity	0.253***	0.234***	0.250***	0.236***
	(0.042	(0.049)	(0.039)	(0.046)
Skill-intensity		0.152		0.102
		(0.207)		(0.208)
R-squared	0.23	0.23	0.24	0.24
Observations	132	132	132	132

Note: Complexity measures are in natural logs. Regressions include year-specific dummy variables (not reported). Robust standard errors in parentheses. *** statistically significant at 1%.

Another way of measuring the likelihood of committing mistakes in each task and the importance of those mistakes in the product's final value is to use the average wage paid in each task. The assumption is that those tasks that are critical to keep the value of a product should command higher wages. The OES database provides data on the average annual wage for each occupation and industry. We calculate a second alternative complexity measure as the sum of all occupations weighted by their wage. As shown in Columns 2.1 and

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

2.2, 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.[11]

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 is 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 3, the coefficient for occupation-based skill-intensity is positive and statistically significant. However, when we introduce complexity as an additional

Table 3. Alternative skill-intensity measure (years 2002 and 2007).

	Complexity coefficients	Skill-intensity coefficients
Complexity		0.005 (0.001)***
Occupation-based skill-intensity	0.444 (0.216)**	-0.064 (0.241)
R-squared	0.10	0.21
Observations	132	132

Note: Regressions include year-specific dummy variables (not reported). Robust standard errors in parentheses. ***, **: statistically significant at 1% and 5% respectively.

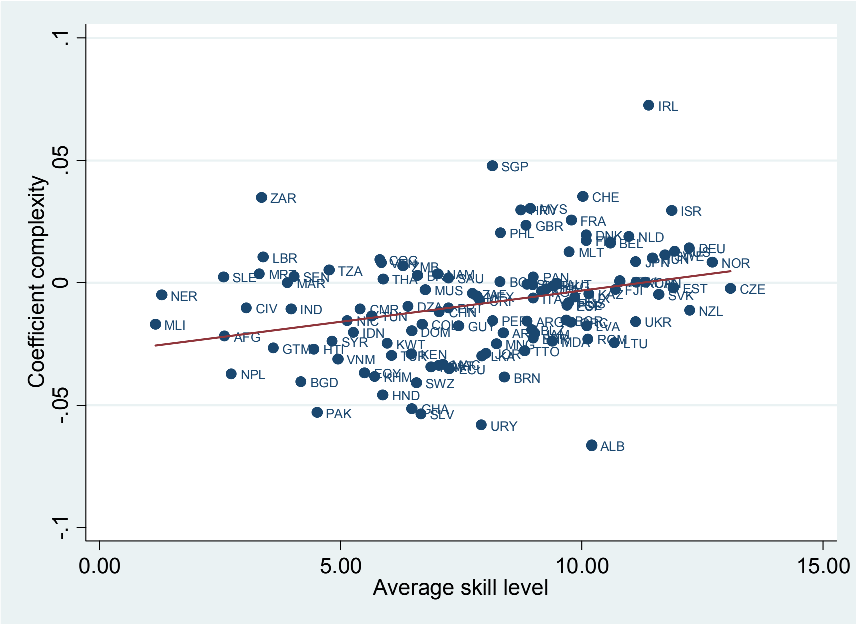
[11] Results not reported. They can be requested from the authors.

explanatory variable, it is this latter variable which is positive and statistically significant, whereas skill-intensity becomes statistically not significant.

In the third set of sensitivity analyses, we use an alternative procedure to test the relationship between countries participation in trade and complexity of products. In particular, to ensure that benchmark results are not driven by some large trading partners, we estimate equation (12) for each northern and southern country included in the sample. Then, we draw the relationship between the estimated coefficients and the average skills of workers. The assumption is that the coefficient for complexity estimated in the first stage should be positive for those countries where human capital is high; in contrast the coefficient for complexity should be negative for those countries where human capital is low. We proxy workers' human capital using average years of schooling of the population with 25 years of more (from Barro and Lee, 2010). To make the coefficients comparable across countries, the dependent variable (share of country *i* in US imports of commodity *z*), is divided by the average share of country *i* in US imports across industries. As shown in Figure 4, there is a positive correlation between the estimated coefficients for complexity and countries' average skills. To confirm this positive relationship, complexity coefficients are regressed on countries' average skills.[12]

[12] Following Romalis (2004), we use weighted least squares to control for higher heteroskedasticity in countries with less diversified exports.

Figure 4. Relationship between estimated complexity coefficients and average skills, 2007



As shown in Table 4, average skills explain the differences in complexity coefficients across countries. We observe that average skills also explain the differences in skill-intensity coefficients across countries.

Table 4. Regression results on the relationship between estimated coefficients and average skills per worker (years 2002 and 2007).

	Complexity coefficients	Skill-intensity coefficients
Average skills per worker	0.003 (0.001)***	0.428 (0.090)***
Constant	-0.035 (0.005)***	-5.065 (0.708)***
R-squared	0.12	0.09
Observations	230	230

Note: Weighted least squares, where weights are the number of exported products by each country to the US. Robust standard errors in parentheses. ***: statistically significant at 1%.

Finally, in the fourth set of sensitivity analysis, we re-run all estimations using Germany, the second largest importer among developed countries, as the reference northern country. As shown in Table 5, there are no changes in results.

4. Conclusions

During the last years we observe an increasing number of developing countries' firms competing with 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 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.

Table 5. Regression results with Germany as the reference northern country (years 2002 and 2007)

	Benchmark			Occupations. weighted by complex-problem solving		Occupations weighted by wage		Occupation-based skill-intensity		Country-level coefficients	
	(1.1)	(1.2)	(1.3)	(2.1)	(2.2)	(3.1)	(3.2)	(4.1)	(4.2)	(5.1)	(5.2)
Complexity	0.004***		0.003***	0.178***	0.154***	0.176***	0.156***		0.004***		
	(0.001)		(0.001)	(0.031)	(0.035)	(0.029)	(0.033)		(0.001)		
Skill-intensity		0.421***	0.030		0.186		0.154	0.346**	-0.082		
		(0.151)	(0.182)		(0.158)		(0.159)	(0.170)	(0.204)		
Average skills										0.004***	0.566***
										(0.001)	(0.133)
R-squared	0.23	0.14	0.23	0.22	0.24	0.24	0.24	0.13	0.23	0.15	0.09
Observations	132	132	132	132	132	132	132	132	132	192	192
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	WLS	WLS

Note: Complexity measures in Column 2.1, 2.2, 3.1 and 3.2 are in natural logs. All regressions, except (5.1) and (5.2) include year-specific dummy variables (not reported). Robust standard errors in parentheses. ***, **: statistically significant at 1% and 5% respectively.

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