# Essays on the Factor Content of Trade and Education

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# Dedication

To my parents.

## Abstract

This dissertation consists of three chapters. Chapter 1 contains a revision of the literature regarding the factor content of trade, and in specific human capital as a productive factor. The main theoretical approach regarding this topic was developed by Eli Heckscher and Bertil Ohlin, and is the well-known Heckscher-Ohlin framework. This theory implies that the factor content of the goods a country trades is related to its factor endowment. In this chapter I explore the relevance of this model and I study the diverse empirical tests supporting and also contradicting the theoretical predictions. In addition, I go over the different extensions of the framework that have been developed across time to improve the match between theoretical predictions and empirical findings.

In chapter 2 I document that the education intensity of the exported basket of goods is positively related to the education endowment a country has. In addition, I observe that for the case of imports there is no relation. Even though the first empirical finding matches what the Heckscher-Ohlin model predicts, the second does not match. In the model the relation between imports and education endowments is negative. I propose an extension of the original framework including a continuum of goods, a large number of countries and a costly education, where the productive factors are low and high educated workers. This model predicts a positive relation between the fraction of high educated workers and education intensity of the exported basket of goods, and no relation with the education intensity of the imported basket of goods. In addition, I observe that there is dispersion in the data. I show that this dispersion can be generated if the factor content of production in exports is different from the factor content of local absorption. As an example I extend the framework to include a nontraded good that is produced by the government. It is interesting to note that an important contribution of this chapter is the construction of an education intensity index for 92 industries in the United States.

Chapter 3 explores the relation between natural resources and the education content of trade. It aims at generating part of the dispersion observed. The idea is that a country that has natural resources ends up exploiting them and exporting them regardless of their labor composition. What really matters in the production of goods like oil,

minerals, or fish is whether you have the raw materials. I extend the model with a continuum of goods, a large number of countries and a costly education from chapter 2, to include a traded good that requires natural resources in its production. Adding this ingredient provides part of the dispersion observed in the data.

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# Chapter 1

# Human Capital and the Factor Content of Trade: A Literature Review

## 1.1 Introduction

The question of how different endowments of productive factors shape international trade patterns has been around for a very long time. The original insights of Eli Heckscher and Bertil Ohlin from the 1920's were translated in a mathematical model by Paul Samuelson that has been widely used. Under this set up there are two countries, two factors of production and two goods. Basically, differences in country endowments of productive factors predict the patterns of international trade. The Heckscher-Ohlin theory states that a country will export the good that requires in its production a higher proportion of the more abundant factor in that country, and will import the good that requires a lower proportion of that factor. The Heckscher-Ohlin model has been first generalized to include a large number of goods and factors by Vanek (1968). Later, it has been extended to include a continuum of goods by Dornbusch et al. (1980).

This framework has been largely tested empirically with mixed results. One of the very first attempts of testing the Heckscher-Ohlin model was made by Leontief (1953). He found that, for the United States, the capital to labor ratio required to produce a representative bundle of exported goods was lower than the ratio needed to produce the representative bundle of the import competing goods. Given that back then it was accepted as common knowledge that the United States was a capital abundant country, this finding was rather puzzling and got to be known as "The Leontief Paradox".

Leontief's finding gave rise to a large number of studies that would either reject or support the Heckscher-Ohlin framework. At first, studies like Kreinin (1965) and Kenen (1965) would aim at finding whether the United States was actually abundant in capital or labor. It was soon noticed that not all workers were equal. As a result, the separation of the labor component into unskilled and skilled workers became a common practice, which led to researchers to apply diverse methods to account for the human capital component. The results regarding what factor was relatively more abundant were mixed. Additionally, the empirical tests started including other countries, as in Keesing (1965, 1966).

During the seventies there was an important change in these empirical tests. It was noted by Harkness and Kyle (1975) that with a multifactor approach the volume of trade, which had been the dependent variable so far, cannot be predicted. According to the authors, what can be predicted is the direction of trade. The ingredient that other studies were missing is the demand for goods.

During the eighties another important shortcoming of previous studies was noticed. Until that point in time, empirical studies did not include independent data on factor endowments; in fact, it was inferred from other sources. Maskus (1985) and Bowen et al. (1987) are the first studies performing a complete test that includes factor endowment data, and they conclude that the Heckscher-Ohlin-Vanek theorem does not empirically hold.

After a massive string of rejections, researchers started to relax some of the assumptions of the original framework with some positive findings, as in Trefler (1993). As mentioned earlier, studies were not analyzing the role of the demand. Davis et al. (1997) actually look separately to the production and the absorption component of the model. Combining this with a relaxation of the original assumptions, they rescue the Heckscher-Ohlin-Vanek framework.

Another effort to understand the factor content of trade has addressed the importance of intra-industry trade. Studies like Davis and Weinstein (001b) and Schott (2003) depart from the idea of all goods in a given industry being produced with the same factor requirements, which explains why countries would trade goods from the same industry. Finally, the importance of trade in intermediate goods has been addressed by studies like Trefler and Zhu (2010).

The rest of chapter 1 is devoted to explain in more detail the development of the factor content of trade literature, putting special interest in the importance of human capital as a productive factor.

## 1.2 Seminal Work

The importance of the differences in education in workers as a determinant of comparative advantage was first noticed by two different studies: Leontief (1956) and Kravis (1956). Leontief (1953) found that the capital to labor ratio required to produce a representative bundle of exported goods was lower than the ratio needed to produce the representative bundle of import competing goods. This finding, which was named the Leontief paradox, was at odds with what was stated by the Heckscher-Ohlin theory since the U.S. was believed to be a capital abundant country. The explanation he provided was that a U.S. worker is more productive than a foreign worker.

In a later study, Leontief (1956) separates the labor requirements in five skill and occupational categories and he compares the man-year needed to produce a million dollar worth of the exporting bundle with the man-year required to produce the same amount of a domestic good competing with foreign imports. He concludes that the fraction of higher skilled workers is greater in the production of exported goods than in the production of the competing imported goods. As a result, he draws attention to the importance of disaggregating the labor input by its skill level.

To test Leontief's conclusion, Kreinin (1965) creates a survey to obtain data regarding the differences between the labor input in the United States and abroad and sends it to firms that have subsidiaries in foreign countries. Among other questions, he asks them about the labor time required in the production of a unit of output under a similar environment (organization, mechanization) in the U.S. and abroad. Using this information, he arrives to the conclusion that while it is true that the U.S. labor is more efficient, these differences are not enough to convert the U.S. into a labor abundant country.

## 1.3 Measuring Human Capital

The first studies trying to calculate the level of skills embedded in trade flows can be divided among the ones that look at wages, the ones that divide the labor input by occupations, and the ones that measure human capital through the cost of acquiring education.

On the first strand of the literature we find the second seminal study stating the importance of differentiating labor, Kravis (1956). The rationale behind analyzing wages is that workers receiving higher wages must be more skilled, which implies that human capital can be measured through wages.

Following this idea, Kravis (1956) compares the leading exporting industries and the leading importing competing industries and finds that labor earnings are higher in the exporting industries. One of the limitations of his work arises from his definition of leading firms. He only considers industries exporting $50 million or more (in either 1947 or 1952), and industries competing with imports above $30 million. This definition creates a bias against small industries that might be exporting a large fraction of their output. In order to overcome this difficulty, Waehrer (1968) reproduces Kravis' work for the year 1960 but defines variables and classifies the data differently. One of the changes she proposes is to have a relative measure of the value of imports instead of an absolute one in order to classify industries in exporter or importer competing. For 59 manufacturing industries she calculates the ratio of the value of exports to the value of output, and the ratio of the value of competitive imports to the value of output. In addition, instead of looking at hourly wages, she examines average yearly earnings per employee. She finds that the average wage paid in export industries is 14.5% higher than the wage paid in import competing industries. She even goes one step further and tries to explain where the difference in wages comes from. She classifies occupations into skilled or unskilled, and looks at the percent of skilled employees in each industry. The author finds a positive correlation between the inter-industry differences in wages and the inter-industry differences in the skill content. Since she establishes that higher wages in the export sector actually reflect higher skills, she validates the logic in Kravis

(1956) .

Following the line of analyzing wages, Kenen (1965) obtains an estimate of the value of the human capital embedded in the production of exported goods and in the production of imported competing goods. He assumes that you can transform an unskilled worker into a skilled one by utilizing capital. By analyzing the wages of these two types of workers, he comes up with the value of human capital. Then, he proceeds to add his estimates of human capital to the estimates of physical capital and observes how Leontief's paradox is reserved. In other words, he finds that the U.S. exports capital intensive goods.

Applying Kenen's approach, Bharadwaj and Bhagwati (1967) compute human capital estimates for India and add them to the measure of physical capital using input-output tables of 1953-1954. They find that even though India's exports are labor intensive, when adjusting for human capital the labor intensity decreases, contrary to what was expected.

However, Kenen's method has raised some concerns. As noted in Baldwin (1971), in order to combine human capital and physical capital we must assume that in the long run capital moves freely between physical goods and workers. Such an assumption does not seem plausible, in particular for less developed countries. In addition, Branson and Monoyios (1977) point to the lack of substitutability between human and physical capital in the productive process.

Also following the tradition of measuring human capital by looking at wages, Roskamp and McMeekin (1968) study the case of West-Germany analyzing input-output tables of 1954. They document that Leontief's paradox disappears when human capital is introduced as a third factor of production.

On the other hand, there are studies that instead of looking at labor earnings, they analyze the occupational composition of the labor force. In addition, the early research was focused on studying the nature of the trade flows in specific for the U.S. The first attempt to calculate a universal measure of skill intensity for different industries is done by Keesing (1965, 1966). In these studies, it is assumed that all traded manufactured goods are produced with a single combination of labor skills (different for each industry). The author looks at the composition of workers by their occupation in thirteen industries in the Unites States for the year 1957, and he assumes that other countries use the same composition when producing that particular good. Combining this information with trade flows data, he calculates the skill intensity of exports and imports for several countries. In his study, the skill level of a worker is not measured as the level of formal education; instead, it is measured as the type of tasks he performs. The author concludes that the availability of labor skills has a strong influence over trade patterns. The difference between these two studies is that in the latter one, by analyzing data of 1960 he includes more occupations (seven), more industries (forty-six), and more countries (fourteen). One of the concerns was the validity of the assumption of labor requirements for a given industry being the same across countries. In Keesing (1971) rather than just looking at U.S. labor requirements, he explores labor requirements in nine different countries. He concludes that qualitatively, the results obtained using different countries labor requirements are very similar. As a consequence, previous studies using only US labor requirements are validated.

In order to contrast the two views, Branson and Junz (1971) compare the wage differential approach with the skills approach. They find that human capital measured through wage differentials is a better measure to explain net exports in the U.S. than the fraction of skilled workers. The authors consider that computing human capital through wages is correct as long as earnings fully reflect differences in productivity. Finally, they conclude that U.S. net exports are intensive in human capital and not in physical capital.

Lastly, Fareed (1972) measures human capital by computing educational costs. Using the United States Census data of 1947, the author obtains for each occupation the number of school-years completed by its average member. He combines this information with direct schooling costs and obtains the direct cost associated with human capital in each industry. In addition, the author estimates the indirect cost of education; that is, the forgone expected income of going to school. Once he obtains a measure of human capital, he analyzes the intensity of this factor in exports and import competing industries. He concludes that exports are more human capital intensive than imports.

## 1.4 The Importance of the Multifactor Approach

### Theoretical development

Even though in the empirical analysis more productive factors were being included, the Heckscher-Ohlin model only applied to the two factor scenario. Given this limitation, Vanek (1968) generalizes the original Heckscher-Ohlin model to include a large number of productive factors and goods. The author remarks the difficulty of measuring relative factor intensities of goods when there are more than two factors of production. However, he notices how it is possible to restate the original theorems for the two factor case in relation to the factor services embedded in the trading flows instead. By taking this approach he overcomes the problem of the multiplicity of ordering of products and instead he proposes a unique ordering of trade factor intensities. In short, even though the pattern of trade could be undetermined, the net factor content of trade can actually be determined.

### Empirical studies

Harkness and Kyle (1975) introduce a multifactor factor version of the Heckscher-Ohlin model. The authors draw attention to the fact that in a multifactor proportions model with more goods than factors and incomplete factor price equalization, the volume of trade cannot be predicted. In fact, they can only predict the direction of trade. As a result, they question the choice of previous studies of selecting volume of trade as the dependent variable. They consider that volume will be determined by the interaction with the demand for goods, while previous models have been ignoring this fact. In their analysis they measure the impact of factor intensities on whether an industry will be a net exporter or not. Using the same data as in Baldwin (1971), for the United States they find that the probability of an industry being an exporter is positively correlated with physical capital. In contraposition, Baldwin (1971) finds that net exports are negatively correlated with physical capital.

Given all this literature pointing towards the importance of studying human capital as a determinant of trade, Branson and Monoyios (1977) determine that aggregation between physical and human capital is not possible. They find that U.S. net exports are positively correlated with human capital, negatively correlated with labor, and also negatively correlated with physical capital. Given the difference between the correlation with both types of capital they conclude that aggregating them is not correct. Therefore, the two-factor model of production is not appropriate and a three-factor set up including physical capital, human capital, and raw labor should be used. Furthermore, they also try changing their dependent variable following Harkness and Kyle (1975) suggestion and when analyzing their own data, they do not find a reversal in the direction of physical capital.

## 1.5 Dynamics

In the previous studies the attention was focused in determining comparative advantages in a determined point of time. In Heller (1976) a scenario with a shift in endowments is analyzed. The author looks at the case of Japan and how there was a rapid change in their factor endowment during the postwar period of 1956 to 1969. Japan evolved from being a labor abundant country into a capital abundant one. Additionally, the fraction of skilled workers also increased. This study concludes that with the endowment change, the comparative advantage also changes. In particular, the exported bundle is more intensive in capital and skilled workers. Interestingly, the author documents that even though the endowment of physical capital has increased at a faster pace than human capital, exports intensity in human capital is rising faster than in physical capital. However, in Heller's study there is no theory behind the change of endowments.

Findlay and Kierzkowski (1983) is the first study analyzing the dynamic nature of human capital. The authors combine the two factor two-good Heckscher-Ohlin model with formation of human capital through education. In their framework, each country has two types of endowment: workers ($N$) and an education specific input ($K$). Workers live for a fixed length of periods and they decide to remain unskilled or to become skilled. In order to become skilled they have to spend certain number of periods in school (which prevents them from working). In addition, education requires the specific input $K$. Therefore, the cost of education has three components: foregone unskilled wages while studying, cost of the specific education input, and forgone unskilled wages after completing his education. A worker deciding whether to become skilled or not will take these costs into account and compare them with the present value of his income as a skilled worker. In equilibrium, lifetime earnings for both groups of workers is the same. In addition, there are two types of goods produced using only skilled and unskilled workers in different intensities.

Countries only differ in their endowment ratio of education specific input to workers ($K/N$). The authors show that the specific education input endowment abundant country will export the skilled intensive good. The idea is that if the education input $K$ is abundant, its price is lower than in the other country. A lower price implies a lower cost of education. In equilibrium, if the cost of becoming skilled is lower, the wage premium will also be lower. This implies that this specific country will be the lower cost producer of the skilled intensive good. As a final note, their study is very interesting since it provides a theoretical background to the dynamics of human capital accumulation and its relation to the factor content of trade.

In a more recent paper, Fitzgerald and Hallak (2004) recognize that factor endowments are the result of an accumulation process. In particular, they point out to the effects of productivity in factor accumulation. The authors explain that studies that do not control for productivity differences across countries have biased results. Overcoming this mistake and analyzing data for OECD countries, they find that the factor proportion model predicts 2/3 of the difference in manufacturing specialization between poor and rich countries.

## 1.6 Adding Endowments

The previous studies would analyze different industries factor content of trade but would not compare it with the factor endowment of the country of interest. This in fact, constitutes only a partial verification of the Heckscher-Ohlin theorem. The first approach to obtain factor endowments was to input them from trade data, as suggested by Leamer (1980). However, it was later proved that this inference was not completely correct and studies aimed at obtaining factor endowments directly from the data.

Maskus (1985) is the first study doing a complete test of the Heckscher-Ohlin-Vanek theorem. The author analyzes data for the United States in 1958 and 1972. The productive factors considered are highly skilled labor (scientists and engineers), unskilled labor (production workers), other labor (nonproduction labor other than scientists and engineers), physical capital stocks, and human capital stocks (measured through discounted wages differentials). This study concludes that the Heckscher-Ohlin-Vanek theorem is inconsistent with the available data. The author points out that a possible explanation is that factor endowments are not measured directly, they are trade-imputed following Leamer (1980)'s approach. Additionally, he admits that it could be promising to relax some of the assumptions of the original framework.

Bowen et al. (1987) tested the Heckscher-Ohlin-Vaneck theorem in a multi-country multi-factor setting. They test the relationship among industry input requirements, country resource supplies, and international trade using data for twenty seven countries and twelve factors of production in 1967. The factors they study include net capital, total labor, seven workers categories, and three types of land[1] . They follow three key assumptions: Commodity prices are the same for all individuals, preferences are homothetic and identical, and the factor requirements for each industry are the same for all countries. Input requirements are computed for the United States, and following the third assumption, they are held constant for the rest of the countries. In particular, to compute each type of labor input requirements they use occupational data from the 1971 U.S. Survey of Occupational Employment and the 1970 U.S Census of Population. The three land type's requirements are obtained from the U.S. input-output table, and the capital requirement is constructed from industry data. Finally, data on trade flows in 1967 is obtained at the four and five digit Standard International Trade Classification and matched to the input-output industry classification. Additionally, factor endowments are obtained for every country for 1966. Their findings do not support the Heckscher-Ohlin-Vaneck theoretical predictions and they favor weakening the assumptions to include technological differences and measurement errors.

Harrigan (1995) gathers panel data for twenty OECD countries from 1970 to 1985 for the ten largest manufacturing industries, and explores the relation between factor supplies and the production of goods across countries. In particular, the factors of production considered include capital, skilled and unskilled labor, and four types of

[1] Worker categories: professional/technical workers, managerial workers, clerical workers, sales workers, service workers, agricultural workers, and production workers. Land categories: arable land, pastureland, and forestland.

land[2] . The author concludes that capital abundance and unskilled labor abundance are a source of comparative advantage for most of the studied industries, skilled labor abundance is a source of small comparative disadvantage, and land has a negligible effect on output. In addition, he finds that the model in general performs poorly. The author provides several possible explanations for this, which include missing factors, scale economies, or government policy.

Other complete tests of the Heckscher-Ohlin-Vaneck framework were performed by Brecher and Choudhri (1988), Staiger (1988) and Kohler (1991) and also rejected this model. The results were pretty discouraging and confidence on such framework was eroded.

## 1.7 Relaxing the Assumptions

Given the empirical rejections of the Heckscher-Ohlin-Vanek model two lines of thought emerged. On one side certain economists dismissed this model thinking it was useless. On the other side efforts were made to introduce some modifications to it so the model would reconcile with the empirical findings.

One of the efforts towards rescuing the Heckscher-Ohlin-Vanek framework was conducted by Trefler (1993). He notices that one of the characteristics of international trade is that there are persistent differences in factor prices across countries. He introduces a productivity related modification to the original model, which allows it to explain much of the factor content of trade and the variation in factor prices across countries. In particular, in his model technological differences are introduced so that labor endowment is transformed into labor endowment productivity equivalent units. He departs from the United States technology matrix and assumes that all differences in technology across countries are caused by these labor augmenting international productivity differences. From here it can be seen how wages are going to depend on productivity and therefore, they will be different across countries. His method consists on calculating the productivity differences that are necessary so the Heckscher-Ohlin-Vanek theorem fits the data on endowments and factor content of trade. This productivity differences

[2] Skilled workers are defined as professional, technical, and managerial workers. The four types of land are tropical rainy climates, steppe/desert, Mediterranean/humid sub-tropical/marine east coast, and humid micro-thermal.

have implications on factor prices, which can actually be compared with data.

To empirically corroborate this generalization of the original model, the author uses data for 1983. He analyzes 33 countries and ten factors of production (capital, seven categories of workers, pasture and cropland). One of the limitations of his analysis is the lack of data availability on wages by occupation. As a first approach the author uses aggregate labor. After this, he introduces four criteria to evaluate the plausibility of the labor augmenting technology when disaggregating labor by occupation, and concludes favorably. The technology differences needed to validate the Heckscher-Ohlin-Vanek theorem are consistent with the factor prices observed in the data. Interestingly, the results hold independently of labor being disaggregated by occupation or not.

After defending the Heckscher-Ohlin-Vanek framework, Trefler ended up empirically rejecting it two years later. In Trefler (1995) he documents that the factor service trade is much smaller than its factor endowments prediction. Trefler names this as "the case of the missing trade". He tries to identify hypotheses that perform better than Heckscher-Ohlin-Vanek. The author considers several alternatives, including ones with capital accumulation, nontradables, trade in services, and linear expenditure demand. To test these different versions he uses the same data set as in Trefler (1993), and considers as factors of production capital, pastures, cropland, and six categories of labor[3] . One of his main contributions is to identify pronounced patterns in the deviation from the Heckscher-Ohlin-Vanek theorem. He considers that it is not enough to say that the original model fails; we need to understand why it actually fails. The importance of this finding lies on the fact that knowing how the deviations from the data look, we can start thinking about the possible ways to amend the theory to match the empirical observations. Finally, by analyzing different alternative hypothesis the author finds that a model that allows for home bias in consumption and international differences in technology dominates the Heckscher-Ohlin-Vanek model.

[3] Professional and technical workers, clerical workers, sales workers, service workers, agriculture workers, and production, transport, and unskilled workers

## 1.8 Production versus Absorption

The original Leontief paradox rested on the comparison between the capital to labor ratio embodied in exports and the one embodied in imports. Leamer (1980) notes that although it holds iwhen net exports of labor services and net imports of capital services are of opposite sign, it does not hold when they have the same sign. Under this scenario the correct comparison is between the capital per worker embodied in net exports and the capital per worker embodied in consumption. When applying the correct comparison for the United States, the author finds that there is no paradox since net exports are actually more capital intensive than consumption.

Following this line, another effort to reconcile the original framework with the data is done by Davis et al. (1997). So far, as mentioned by Leamer (1984), Heckscher-Ohlin-Vanek only related three elements: trade, technology, and endowments. Davis et al. (1997)'s approach is different to all previous work since it considers four elements instead. That is, rather than focusing on the pattern of trade, they focus separately on predictions concerning the location of production and the pattern of absorption.

Performing a step by step test allows them to pin down the sources of difficulties. They start with the stricter version of Heckscher-Ohlin-Vanek and relax one assumption at a time to see where the problems arise. To do so, they use international data and also regional data for Japan. The advantage of using regional data is that technology, tastes, and factor prices should not vary. The first assumption they check is if all countries use the same input coefficients. Although the model performs poorly when using data for all countries, it fares much better with the regional data for Japan. Next they turn to study the pattern of consumption assuming that Japanese regional absorption is proportional to world net output. They find that the model works for describing the data. Lastly, they put all the elements together. As expected, the Heckscher-Ohlin-Vanek theory does not perform well when applying it to various countries. However, using regional data for Japan they show that the Heckscher-Ohlin-Vanek is a good predictor of the factor content of trade. It is worth noting that they clarify that even their study does not imply that the Heckscher-Ohlin-Vanek framework can be blindly applied to international data. However, it validates the use of the underlying general equilibrium structure as a good description of national data.

Going back to the idea of human capital as a factor of production, it is important to notice that the studies I have mentioned so far would divide the labor force by occupations and occasionally they would consider separately scientists and engineers from production workers. Interestingly, Davis et al. (1997) looks at education instead. They characterize the labor input as college and noncollege graduates.

Davis and Weinstein (2001) extends the regional findings from Davis et al. (1997) into an international set up. They modify the Heckscher-Ohlin-Vanek model allowing for technical differences, a breakdown of factor price equalization, the existence of nontraded goods, and costs of trade. When analyzing data for ten OECD countries and a rest-of-world aggregate, they find that the relaxed version of the original model is consistent with the data. Interestingly, the publication of the 1995 OECD's input-output database allowed them to construct technology matrices with two factors of production (capital and labor) for different countries. This leads them to reject the assumption of identical technologies and additionally, they find a strong correlation between factor abundance and industry input usage. As a consequence, factor price equalization does not hold. For these reasons, now the presence of nontradable goods is not neutral. When the original assumptions hold, adding nontradable goods has no effect on the factor content of trade. In the case of a lack of factor price equalization, countries that are abundant in capital will use more capital per worker in non-traded sectors, which diminishes the residual available for production of tradables, and in turn, diminishes the predicted capital content of trade. Finally, since the predicted trade volumes are higher in the original model than the ones observed in the data, they include trade costs. They conclude that with certain modifications the Heckscher-Ohlin-Vanek works well.

## 1.9 Intra-Industry Trade

Traditionally, although trade within different regions was explained by factor endowments, trade within similar regions was not. This generated a puzzle for the factor endowment theory. Economists started developing models where the Heckscher-Ohlin trade theory was combined with elements of the industrial organization theories. This new approach to international trade was called "the new trade theory". In particular, researchers started thinking that international trade patterns are driven by productivity differences among producers within industries, imperfect competition, and consumers' taste for variety.

As noted by Krugman (1981), the nature of trade between countries depends on how similar they are in terms of factor endowment. He determines that trade shifts from inter-industry to intra-industry as countries become more similar. At that time it was believed that intra-industry trade was the exchange of very similar goods. Therefore, the question is why would a country import and export very similar goods. The author develops a model to shed some light on this problem. His explanation is that intra-industry trade arises for two reasons: the existence of economies of scale, and consumers' preference for acquiring diverse goods.

Helpman (1981) combines the Heckscher-Ohlin approach to international trade with an approach to product differentiation, economies of scale, and monopolistic competition in the spirit of Chamberlin. He also concludes that intra-industry trade is not determined by factor endowments.

On the contrary, Davis and Weinstein (001b) demonstrate that the puzzle in the factor endowment theory does not exist. In fact, they empirically verify that intra-industry trade consists in exchanging goods that are systematically different in their factor content. Moreover, these differences are a reflection of endowment differences. It is worth noting that they do not deny the importance of other factors like economies of scale and product differentiation, they just state that factor endowments also matter. Finally, regarding the importance of intra-industry trade, the authors show that for the typical country, this type of trade accounts for approximately 40 percent of total net factor trade.

In the same spirit, Schott (2003) also supports that intra-industry trade takes place between goods that differ in their factor content. The author analyzes data for the 3-digit ISIC manufacturing industries and finds that industries present variation in terms of input intensity and price across countries. He interprets this finding as that there exists intra-industry product heterogeneity. One of the implications of this observation is that assumptions of the Heckscher-Ohlin framework are violated, which puts into doubt the empirical tests rejecting the Heckscher-Ohlin model. The problem arises from the way ISIC aggregates goods. Within an industry, output is grouped loosely according to similarity of end use. However, this does not necessarily match the conceptualization of goods in the original Heckscher-Ohlin framework. Schott proposes an aggregation mechanism where goods are grouped according to input intensity. In addition, he proposes a model where each country specializes in a unique subset of goods depending upon relative endowments, allowing for multiple cones of diversification. Once he tests this model with the new aggregation mechanism, he concludes that there is strong support to the Heckscher-Ohlin implication of output being a function of endowment.

In a second paper Schott explores the role of specialization within products. Schott (2004) analyzes import data for the United States and realizes that they import the same products from both high and low wage countries. What is interesting is that unit values within these products vary with exporter relative factor endowments and production techniques. This empirical observation implies the rejection of across product specialization but also implies the acceptance of within product specialization. In particular, capital and skill abundant countries use their comparative advantage in endowment to produce varieties of a product that are more intensive in their abundant factors of production, and possess better features or a higher quality. For these reasons the price of that particular variety ends up being higher than the one of a different variety of the same good produced by a low labor abundant country.

In a recent study, Nishioka (2012) finds that even though production techniques are different across countries, they differ much less across industries within a country. While in Davis and Weinstein (001b) in order to determine production is in crucial the country-factor-industry component, Nishioka shows how the industry component is not essential. This leads him to conclude that factor content of trade does not come from specialization.

## 1.10 Accounting for Trade in Intermediate Goods

It was clear that trade in intermediate goods was important. The question was how we should measure factor content in the presence of trade of inputs. Several studies have tried to come up with a relevant measure of factor content taking into account traded inputs.

Trefler and Zhu (2000) consider a framework with intermediate traded goods and technology differences. However, they stick to the assumption of factor price equalization, which has been discredited by several studies.

Reimer (2006) develops a framework where trade of intermediate goods is reconciled with a general equilibrium characterization of trade, production, and endowments including differences in production techniques. The author provides an algorithm for tracking factor content including intermediate goods for two countries. In order to extend this framework, Trefler and Zhu (2010) generalize this algorithm to compute, for an arbitrary number of countries, what was considered the actual factor content of trade by Deardorff (1982). These algorithms consider good flows and whether they are final or intermediate goods, and they weight them using the producing country's technology. The limitation of these studies is that with their data they cannot observe from which country inputs come from and in which industry they are being used. Therefore, they impute the input-output coefficients using a proportionality assumption.

To overcome the previous shortcoming, Puzzello (2012) uses survey-based input-output coefficients from the Asian input-output tables that contain bilateral detail. She concludes that Trefler and Zhu (2010) overstates countries' use and relative use of foreign intermediate goods, which has the effect of overstating the use of domestic factors. Therefore, net factor trade is actually small.

## 1.11 Conclusions

In this chapter I have reviewed studies of the factor content of trade, and in specific the role of human capital as a productive factor. It is clear that since the development of the Heckscher-Ohlin framework, the factor content of trade has been a widely studied topic. The outcome of empirical research has been quite mixed, with certain studies supporting the original framework, certain studies rejecting it, and other studies proposing theoretical modifications to overcome the mismatch with the data.

Even though the framework has some shortcomings, it is true that part of the comparative advantage of a country is given by its productive factor endowment. Therefore, we would expect that a country with more skilled workers exports goods requiring high skilled workers. Or that if a country is endowed with natural resources, it exports them. The Heckscher-Ohlin model should not be dismissed and with certain modifications it can be useful to predict the factor content of trade.

# Chapter 2

# Education Intensity in Trade Flows

## 2.1 Introduction

The question of what determines the type of goods countries trade among each other has been largely studied. In particular, the concept of factor content of trade has been of great interest since the original work of Eli Heckscher and Bertil Ohlin in the twenties and thirties. In their work, mathematically formalized by Paul Samuelson, they state that factor content of trade is related to factor endowment.

Factor content of trade reflects the proportion of different factors required to produce a basket of traded goods. The original factors of production were considered to be capital and labor. Other factors were later included, as land and natural resources. Interestingly, it was early noted that not all workers were equally productive. In one of the first attempts to empirically verify the Heckscher-Ohlin theorem, performed by Leontief (1953), it was noted that contrary to popular belief the United States' exports were more labor abundant than competing imports. Since it was thought that the United States was a capital abundant country, this was clearly at odds with the theorical framework. This finding was so shocking that it even got a name: "The Leontief Paradox". Leontief pointed to the idea of American workers being more productive than workers abroad. Measuring labor as efficient units would make the U.S. a labor abundant country, which would discard the paradox. An interesting question is what made American workers more productive in comparison to workers in other countries.

Following the idea of capturing workers productivity, empirical analysis started to separate the labor component into different occupational categories. These included occupations like professional/technical workers, managerial workers, clerical workers, sales workers, service workers, agricultural workers, and production workers. Often the categories would be aggregated into skilled and unskilled workers. Some of the studies would look at the fraction of each type of workers employed in different sectors. Studies of this type include Keesing (1965, 1966). A second strand of the literature tried to measure productivity by analyzing wages. Kravis (1956) concluded that wages were higher in exporting industries than in importing competing ones, work that was later validated by Waehrer (1968). Other examples of this approach include Kenen (1965), Bharadwaj and Bhagwati (1967), and Roskamp and McMeekin (1968). In general, these studies drew attention to the importance of human capital as a productive factor that can determine the nature of trade.

All the previous studies did not analyze the dynamic nature of human capital as a factor that a country accumulates over time. The first study combining the literature of human capital formation and international trade was Findlay and Kierzkowski (1983). They incorporate the formation of labor skills in a two-sector general equilibrium model of international trade. They show that the country where education costs are lower, will become abundant in skilled workers and will end up exporting the good that is skill intensive.

In this paper, I want to explore the relation between the amount of human capital that a country has (fraction of the population with tertiary education) and the level of this productive factor that is embedded in its trade flows. We would expect, as predicted by the Heckscher-Ohlin model, that a country exports goods that are relatively intensive in the factor of production that is relatively abundant in that country. This means that if a country has a population that is relatively very educated, they would export goods that require relatively more educated workers to be produced. Exactly the opposite would happen for imports, since they would import goods that are intensive in the scarce factor of production. In other words, such a country would import goods that are intensive in workers with less formal education. However, when we look at the data only the first relation holds; that is, the abundance of high educated workers is positively correlated with the level of education embedded in exports. Contrary to what was expected, countries seem to be importing a basket of goods that contains a very similar embedded level of education, independently of the level of education of its population.

The contribution of this paper is threefold. First I construct an education intensity index for 92 industries in the United States. Second, I document that while exports education intensity is positively related to endowment, imports education intensity shows no relation. Lastly, I extend the Heckscher-Ohlin model with a continuum of goods, a large number of countries, and costly education, and I show how its predictions regarding the relation between education intensity and the abundance of educated workers can qualitatively match the data.

This paper is organized as follow. Section 2.2 explores the data. Section 2.3 presents a Heckscher-Ohlin model with a continuum of goods and shows how its predictions regarding the relation between imports education intensity and abundance of educated workers do not match the data. Section 2.4 presents an extended version of the Heckscher-Ohlin model with a continuum of goods, $N$ countries, and costly education that matches the data (qualitatively). In section 2.5 I add government expenditure as a source of dispersion. Section 2.6 concludes.

## 2.2 Data

### 2.2.1 Education Intensity Index by Industry

Since I am interested in exploring the relation between the education intensity required to produce baskets of traded goods (imported and exported), and the education abundance of a given country, the first step is to find a suitable education intensity index by industry. Peneder (2007) classifies how educationally intensive each industry is using the International Standard Industrial Classification (ISIC)[1] . For doing this, he looks at data for five countries (USA, Germany, France, UK, Austria), and different time frames (1979-2000 depending on the country). Data include measures of composition of the labor input (in terms of education level) per industry as a share in total employment, as a share in total wages, and as a share in hours worked. Taking all this information he

[1] Revision 3, two digit aggregation level.

performs a statistical cluster analysis and classifies each industry into one out of seven categories of education intensity. The problem with his index is that it is a qualitative measure. For this reason I construct my own education intensity index.

The first step in this analysis is to compute the education intensity for each industry. Although it has been argued that different countries use different factor proportions in the production of similar items[2] , for simplicity I will assume that the United States factor requirement matrix can be used for all countries[3] .

In order to construct this index I require information about the labor composition employed in each industry. I obtain such data, for the United States, from the Current Population Survey (CPS) for the years 2003 to 2008. Data contain information about workers, the industry they work at, and their level of education. I classify workers into one out of three categories of education: not attained upper secondary education (low), upper secondary education (med), and tertiary education (high). In addition, I calculate the relative earnings among these three groups[4] . The index for each year is constructed as a weighted average of the labor composition for each industry:

$$e_{j,t} = \frac{\sum_{h=1}^{3} N_{h,t}^{j} \omega_{h,t}}{\sum_{h=1}^{3} N_{h,t}^{j}},$$

where $j \in \{1, ..., J\}$ is each industry, $h \in \{1, 2, 3\}$ is the education level, and $t \in \{2003, ..., 2008\}$ is the year; $e_{j,t}$ is the education intensity index for industry $j$ at year $t$; $N_{h,t}^{j}$ is the quantity of workers with education $h$ in industry $j$ for the year $t$; and $\omega_{h,t}$ is the relative earnings of workers with education $h$ at year $t$.

Weighting workers by relative earnings according to their education level is important since it gives a measure of how much each type of worker contributes to final output, or in other words, how efficient each type of worker is. The final education index for each industry is the weighted average of the index for the years 2003 to 2008:

$$e_j = \frac{\sum_{t=2003}^{2008} e_{j,t}}{6},$$

The index across years for a given industry does not show great variance. However, I take the average since it provides a more accurate measure. This index is normalized

[2] See Trefler (1993) and Davis and Weinstein (2001).
[3] As in Keesing (1971).
[4] See table A.1 in appendix A.1.

between zero and one. When it equals zero, it reflects the case where a given industry employs only workers with low education. Similarly, an index of one represents an industry where only high educated workers are employed. The normalized index ranges from 0.32 to 0.87 across the 92 industries studied. It is interesting to see that the three industries that require the highest proportion of educated workers are:

- Computer and peripheral equipment manufacturing (0.87)
- Pharmaceutical and medicine manufacturing (0.87)
- Aerospace product and parts manufacturing (0.86)

And the three industries that require the least educated workers are:

- Animal slaughtering and processing (0.32)
- Leather tanning and products, except footwear manufacturing (0.34)
- Logging (0.37)

As expected, there are no industries employing only one type of workers. A complete list of the 92 industries can be found in table A.2 in appendix A.1.

### 2.2.2 Education Intensity of the Basket of Traded Goods by Country

One of the main challenges is that data from different sources do not classify industries in the same fashion. Therefore, concordances need to be developed. I gather trade flows data from Comtrade for the year 2005[5] using the Standard International Trade Classification (SITC revision 2, 5-digit level); and in order to combine the information, both the trade data and the CPS education intensity by industry need to be translated into the North American Industry Classification System (NAICS)[6] . With this information, the education intensity for a traded basket of goods is calculated as the following weighted average:

[5] I choose this specific year since it is one of the most recent years we have data on before the financial crisis that started in 2007. I have performed similar analysis for 1970, 1980, 1990, 1995, 2000, 2010 and the results do not change. Figures for the year 1995 can be found in appendix A.1

[6] The concordance concordance tables employed are: SITC Revision 2 to NAICS 1997; NAICS 1997 to NAICS 2002; CPS 2003-2008 to NAICS 2002

$$\text{Education Intensity in Exports}_{\ i} = \frac{\sum_j e_j Q_{j,i}^{exp}}{\sum_j Q_{j,i}^{exp}}$$

$$\text{Education Intensity in Imports}_{\ i} = \frac{\sum_j e_j Q_{j,i}^{imp}}{\sum_j Q_{j,i}^{imp}}$$

where $i$ is each country, $e_j$ is the education intensity index for industry $j$, $Q_{j,i}^{exp}$ is the value of the exports for country $i$ and industry $j$, and $Q_{j,i}^{imp}$ the value of imports for country $i$ and industry $j$.

To complete the analysis we need information about the labor composition by education, which is obtained from the Barro-Lee data set.

Figure 2.1 represents, for 127 countries, the relation between education intensity in exports and the fraction of the population with tertiary education completed for 2005. As we can see, there is a positive relation between both variables. That is, countries with a higher proportion of the population enjoying tertiary education export a basket of goods that is more education intensive than countries with a lower education endowment. Figure 2.2 shows the same relation but with the education intensity of the imported baskets of goods. In this case we notice that there is no relation between these two variables. Countries import a basket of goods with a fairly similar education intensity composition regardless of their own endowment of education. The importance of these findings is that, as explained later in section 2.3, they are at odds with the original Heckscher-Ohlin framework.

It is also interesting to note that there is greater dispersion among the education intensity of the exported basket of goods than among the imported basket of goods across countries. This implies that in terms of education intensity, the basket of imported goods is more similar across countries than the basket of exported goods.

Additionally, when calculating the concentration index for these countries, we see that typically exports are more concentrated that imports. In other words, countries tend to export a smaller number of goods than what they import. This can be seen in Figure 2.3[7] .

[7] In appendix A.1 figures representing the same information as in this section but using labels instead can be found.

Figure 2.1: Exports education intensity vs percent of the population with tertiary education

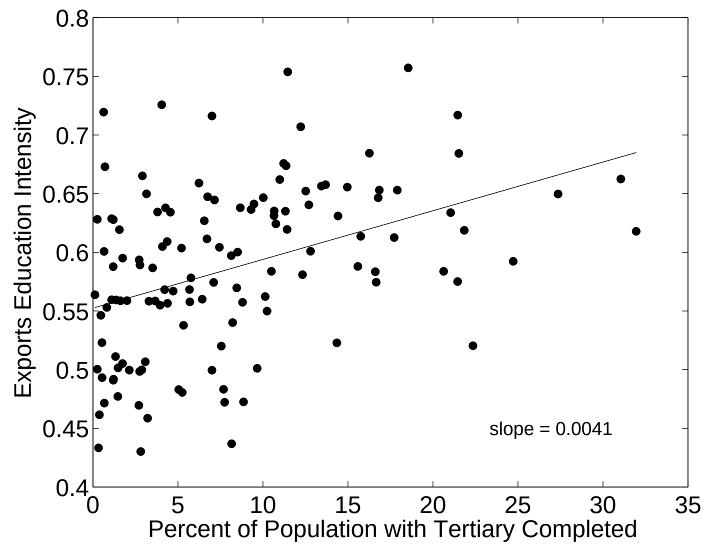



Figure 2.2: Imports education intensity vs percent of the population with tertiary education

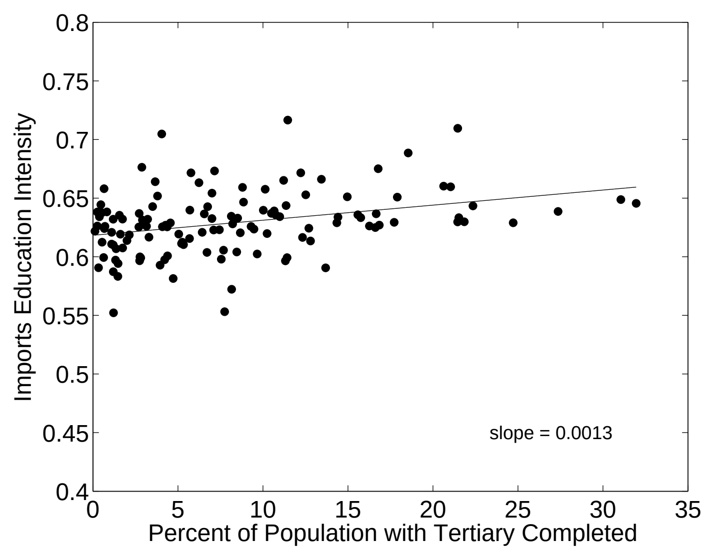
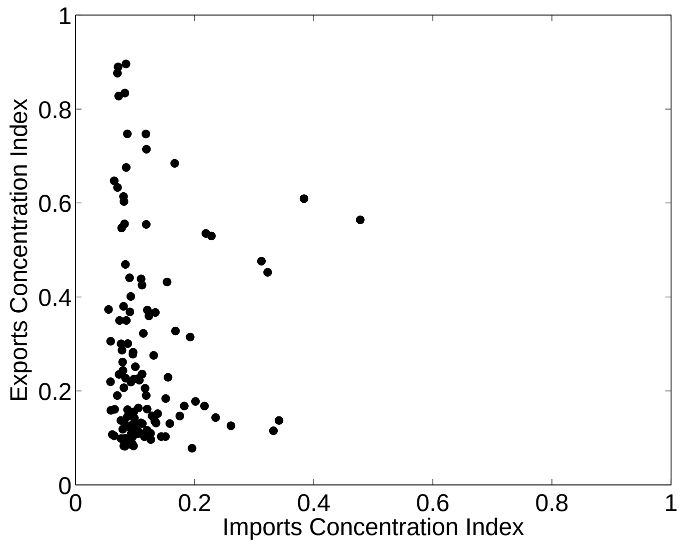


Figure 2.3: Concentration index (Herfindahl)




## 2.3 Heckscher-Ohlin Model with a Continuum of Goods

The departing point to explain the empirical findings documented in the previous section is the extension to the Heckscher-Ohlin model developed by Dornbusch et al. (1980). In that model there are two countries, a continuum of goods, and two factors of production. Considering the productive factors as high and low educated workers, the outcome of their framework does not match the earlier described empirical findings.

In particular, depending on factor endowments there are two possible solutions. If endowments are sufficiently different, there is no factor price equalization across countries and countries fully specialize in producing a subset of the goods. On the other hand, if endowments are not sufficiently different, there is factor price equalization and the pattern of production is not uniquely determined. Studies like Trefler (1993) have tested whether factor prices equalization holds in the data concluding that it does not.

It is important to note that when endowments are such that there is specialization, there is a positive relation between factor content of exports and endowments, and a negative one between factor content of imports and endowments.

In our context, recall that the factors of production are low educated workers and high educated workers. Vanek (1968) extended de Heckscher-Ohlin framework to include a large number of factors. However for simplicity in this analysis I abstract from physical capital and other productive factors. Therefore, if we order goods by their factor requirement we will have that there exist a cutoff good $\bar{z}$, so that the country with relatively more low educated workers would produce the goods that require more low educated workers than the cutoff good. Similarly, the country with relatively more high educated workers will produce all the goods that require more educated workers in order to be produced than the cutoff good. That being said, when endowments are sufficiently different specialization leads to the prediction that a country will export the goods that are intensive in the factor of production that it is relatively abundant in, and will import the other goods. Going back to the empirical findings only the one regarding exports is satisfied.

One could think that a possible solution is to include a large number of countries. Under this scenario each country would be small and specialize in a small subset of goods, which would imply that a large subset of goods ends up being imported[8] . With enough countries we would have that exports factor content would be positively related to endowment while imports would have no relation with endowment. As discussed at the end of the section, this solution will not work since we will end up with endowments not being sufficiently different, which implies that factor price equalization holds and that there is not a unique equilibrium with full specialization.

Now we will start outlying the model. Countries are denoted by $i$ and only differ in their factor endowment. The factors of production are high educated workers, $H$, and low educated workers, $L$. Goods are denoted by $z$ and differ in the factor intensity required to produce them, $\alpha$.

Good $z$ is produced using a Cobb-Douglas technology, which is equal for all countries:

$$y^i(z) = \left(h^i(z)\right)^{\alpha(z)} \left(l^i(z)\right)^{1-\alpha(z)}$$

where $\alpha(z) \in (0,1)$.

[8] Assuming taste for variety.

The representative firm producing good $z$ in country $i$ minimizes costs as follows:

$$\begin{aligned} c^i(z, w_h^i, w_l^i) = \min_{h^i(z), l^i(z)} \quad & w_h^i h^i(z) + w_l^i l^i(z) \\ s.t. \quad & \left(h^i(z)\right)^{\alpha(z)} \left(l^i(z)\right)^{1-\alpha(z)} \geq y^i(z) \\ & h^i(z), l^i(z) \geq 0 \end{aligned} \tag{2.1}$$

where $w_h^i$ is the wage paid to high educated workers and $w_l^i$ is the wage paid to low educated workers.

In addition, the fraction of the population that is high educated ($H^i$), and low educated ($L^i$), in each country $i$, is given exogenously and countries do not vary in size,

$$H^i + L^i = 1.$$

There are two types of consumer in each country, the high and the low educated ones. Each of them supplies one unit of labor inelastically. Preferences are identical across countries and the aggregate consumer in country $i$ maximizes utility given its resource constraint:

$$\begin{aligned} \max_{C^i(z)} \quad & \int \psi \log C^i(z) dz \\ s.t. \quad & \int p(z) C^i(z) dz \leq W^i \\ & C^i(z) \geq 0 \end{aligned} \tag{2.2}$$

where $W^i = w_h^i H^i + w_l^i L^i$ is aggregate income. With Cobb-Douglas preferences the consumption of every good $z$ must be strictly positive, and what is more, they end up spending a constant share of their income in each good,

$$p(z) C^i(z) = \psi W^i. \tag{2.3}$$

The market clearing condition states that labor supplied is equal to labor demanded for both low and high educated workers in each country $i$, that is,

$$\int l^i(z) dz = L^i$$

$$\int h^i(z) dz = H^i.$$

In addition, the goods market also clears; that is, world production equals world consumption:

$$C^1(z) + C^2(z) = y^1(z) + y^2(z) \qquad \forall z.$$

Note that for each good $z$ prices are determined by the country that offers the lowest unit cost.

$$p_z = \min\left\{c(z, w_h^1, w_l^1), c(z, w_h^2, w_l^2)\right\}$$

As mentioned earlier, each good $z$ requires a factor intensity of $\alpha(z)$ in its production. A low value for $\alpha(z)$ implies that good $z$ requires a high intensity in low educated workers. Similarly, a high $\alpha(z)$ indicates that for producing good $z$ a high fraction of high educated workers is needed. We can order the goods starting from the one that requires the highest intensity of low educated workers in its production, to the one that requires the highest intensity of high educated workers. In other words, we can index the goods by their factor requirement. For this reason we can directly index goods by their factor requirement, $z = \alpha(z)$.

Recall that when endowments are sufficiently different, there is a cutoff good $\bar{z}$ so that the country relatively abundant in low educated workers is able to offer the lowest price for all goods in $[0, \bar{z}]$. Similarly, the country relatively abundant in high educated workers produces all goods in $[\bar{z}, 1]$. For now on, let's assume that country one is relatively abundant in low educated workers,

$$\frac{H^1}{L^1} < \frac{H^2}{L^2}.$$

To find the particular cutoff value $\bar{z}$, we will use the fact that $\bar{z}$ has the particularity of being the good for which both countries face the same production cost. That is,

$$c^1(\bar{z}, w_h^1, w_l^1) = c^2(\bar{z}, w_h^2, w_l^2).$$

In addition, we have to include in our set up the trade balance condition, which implies that the value of imports of country one must equal the value of exports to country two and vice versa. Combining it with the demand for each good reflected in equation (2.3),

$$\int_{z \notin Z^1} \psi(w_h^1 H^1 + w_l^1 L^1) dz = \int_{z \in Z^1} \psi(w_h^2 H^2 + w_l^2 L^2) dz,$$

where $Z^i$ denotes the set of goods produced and exported by country $i$. With all this information we can pin down the cutoff value $\bar{z}$, which in turn pins down the factor prices $w_h^i$ and $w_l^i$ and the rest of the variables. In appendix A.2 it is explained how the model is solved. As it was mentioned earlier, in order to obtain a solution where production location is fully determined, endowments need to be sufficiently different. The following proposition indicates how different the endowments need to be:

**Proposition 1** *Given symmetric endowments, there exist a unique equilibrium where factor prices do not equalize and production location is determined, if and only if endowments satisfy*

$$L^1 = H^2 > \frac{3}{4}.$$

The proof can be found in appendix A.3.

To see whether this model matches the empirical findings or not, we need to compute the factor content of the traded baskets. Let's denote by $x^{ij}(z)$ the exports from country $i$ to country $j$ of good $z$. The factor content of exports $\eta_x$ is then calculated as the following weighted average,

$$\eta_x^i = \frac{\int_{z\in Z^i} zp(z)x^{ij}(z)dz}{\int_{z\in Z^i} p(z)x^{ij}(z)dz}.$$

This implies that the export factor intensity of the country relatively abundant in low educated workers is given by

$$\eta_x^1 = \frac{\bar{z}}{2},$$

and the export factor intensity of the country relatively abundant in high educated workers is

$$\eta_x^2 = \frac{1}{2}(1+\bar{z}).$$

In addition, let $m^{ij}(z)$ denote the imports from country $i$ to country $j$ of good $z$. Since there are only two countries, exports from country $i$ to country $j$ are exactly equal to the imports from country $j$ to country $i$. Therefore,

$$\eta_m^1 = \eta_x^2$$

$$\eta_m^2 = \eta_x^1.$$

From these expressions it is straight forward to see that there is a positive relation between factor endowments and exports factor intensity. That is, a country that is relatively more abundant in high educated workers will produce and export a basket of goods that is intensive in utilizing high educated workers. In addition, there is a negative relation between factor endowment and imports factor intensity. In particular, with symmetric endowments that satisfy proposition 1 we obtain that the cutoff value is equal to 0.5 and that:

$$\eta_x^1 = \eta_m^2 = 0.25$$

$$\eta_x^2 = \eta_m^1 = 0.75$$

These predictions are at odds with what it is observed in the data. Adding more countries does not fix the issue. As we can see from proposition 1 endowments must be considerably different to obtain an equilibrium were factor price equalization does not hold and there is full specialization. In fact, for the symmetric endowments case country one's low educated workers have to amount to at least 75% of the labor force, and for country two to less than 25%. The problem arises because with more countries, there is a point where endowments cannot be sufficiently different from each other to have a unique equilibrium with no factor price equalization where production location is determined.

To overcome this difficulty and achieve a full specialization equilibrium when adding a large number of countries, in the next section I add a cost associated to transform workers from low to high educated.

## 2.4 Costly Education

Since the Heckscher-Ohlin model with a continuum of goods developed by Dornbusch et al. (1980) and explained in the previous section cannot account for the empirical findings, I modify it by adding a cost of education that is different across countries. This cost of education pins down relative factor prices in each country, which in turn determines relative abundance of productive factors. In this case we always obtain the full specialization equilibrium where factor prices are not equalized and the location of production is determined independently of the number of countries we add.

Each country is endowed with the same number of workers, which are all born with low education. They choose whether to achieve a high level of education or stay as they are. To transform themselves and acquire high education they have to spend a fraction of their time educating themselves, $\theta^i$. A low educated worker supplies inelastically one unit of time in the labor market while a high educated worker only supplies the time that he has left $(1-\theta^i)$ after investing in his education.

The technology for transforming low educated into high educated workers is so that an individual chooses

$$\begin{aligned} \max_s \quad & s(w_h^i(1-\theta^i)) + (1-s)w_l^i \\ s.t. \quad & s \in \{0,1\} \end{aligned}$$

In equilibrium workers are indifferent between becoming high educated or not. Therefore, we have that the cost of education determines the relative factor price

$$\frac{w_h^i}{w_l^i} = \frac{1}{1-\theta^i}. \tag{2.4}$$

The more costly it is to become educated, the higher the wage premium is. The cost minimization problem of the firm that produces good $z$ in country $i$ remains as described in equation (2.1). The aggregate consumer problem also remains unchanged, as in (2.2). However, since each high educated worker only provides $(1-\theta^i)$ units of labor, the disposable income is now

$$W^i = w_h^i(1-\theta^i)H^i + w_l^i L^i. \tag{2.5}$$

For this same reason, while the market clearing condition for the low educated workers labor market remains without change, the one for the high educated workers labor market becomes for each country $i$

$$\int h^i(z)dz = (1-\theta^i)H^i.$$

Finally, the market clearing condition for goods is

$$\sum_{i=1}^{N} C^i(z) = \sum_{i=1}^{N} y^i(z) \qquad \forall z.$$

Trade balance between countries implies that the value of country $i$'s imports must equal the value of its exports, which combined with the demand for goods expressed in equation (2.3) and disposable income from equation (2.5),

$$\int_{z \notin Z^i} \psi \left( w_h^i (1-\theta^i) H^i + w_l^i L^i \right) dz = \sum_{j \neq i} \int_{z \in Z^i} \psi \left( w_h^j (1-\theta^j) H^j + w_l^j L^j \right) dz \quad \forall i \in \{1, N\}. \tag{2.6}$$

With all this information we can pin down the cutoff values $\{\bar{z}_i\}_{i=1}^{N-1}$, which in turn determine production, and exports and imports patterns. The details regarding how to solve this model can be found in appendix A.4.

In the previous section we assumed that the factor intensity in the production of goods went from zero to one. In order to generalize, we can state here that in fact it goes from $z_{min}$ to $z_{max}$[9] .

Finally, following the procedure described earlier we can compute the factor content of the traded baskets of goods. The factor content of exports $\eta_x$ is then calculated as the following weighted average:

$$\eta_x^i = \frac{\sum_{j \neq i} \int_{z \in Z^i} z (w_h^j H^j + w_l^j L^j) dz}{\sum_{j \neq i} \int_{z \in Z^i} (w_h^j H^j + w_l^j L^j) dz}.$$

Therefore, for country $i = 1$ we have that

$$\eta_x^1 = \frac{\bar{z}_1^2 - \bar{z}_{min}^2}{2(\bar{z}_1 - \bar{z}_{min})},$$

for countries $i \in \{2, N-1\}$

$$\eta_x^i = \frac{\bar{z}_i^2 - \bar{z}_{i-1}^2}{2(\bar{z}_i - \bar{z}_{i-1})},$$

and for country $i = N$

$$\eta_x^N = \frac{\bar{z}_{max}^2 - \bar{z}_{N-1}^2}{2(\bar{z}_{max} - \bar{z}_{N-1})}.$$

Similarly, the basket of goods that country $i$ imports is equal to the sum of the fraction of income they spend in each imported good $z$,

$$\eta_m^i = \frac{\int_{z \notin Z^i} z (w_h^i H^i + w_l^i L^i) dz}{\int_{z \notin Z^i} (w_h^i H^i + w_l^i L^i) dz}.$$

[9] Both of these values are between zero and one.

Therefore, for country $i = 1$ we have that

$$\eta_m^1 = \frac{1}{2}\frac{z_{max}^2 - \bar{z}_1^2}{z_{max} - \bar{z}_1}$$

for countries $i \in \{2, N-1\}$

$$\eta_m^i = \frac{1}{2}\frac{\bar{z}_{i-1}^2 - z_{min}^2 + z_{max}^2 - \bar{z}_i^2}{\bar{z}_{i-1} - z_{min} + z_{max} - \bar{z}_i}$$

and for country $i = N$

$$\eta_m^N = \frac{1}{2}\frac{\bar{z}_{N-1}^2 - z_{min}^2}{\bar{z}_{N-1} - z_{min}}.$$

Setting the minimum and maximum values of factor requirement to match the data described earlier ($z_{min} = 0.32$, $z_{max} = 0.87$), and setting a cost of education $\theta$ that goes from 0.1 to 0.6, with 100 countries we obtain figures 2.4 to 2.6.

In figure 2.4 we can see the relation between the cost of education and the fraction of the population that becomes high educated. It is clear that as the cost increases, less workers find it profitable to obtain and education. In addition, from equation (2.4), we see that the education premium also increases.

Figure 2.5 depicts the relation between the fraction of workers with high education and the education intensity of the exported baskets of goods. As it is shown, there is a positive relation between factor endowment and factor content of exports, which is in line with the empirical observations.

Lastly, figure 2.6 pictures the relation between the fraction of workers with high education and the education intensity of the imported basket of goods. We can observe that the relation is almost flat. This means that independently of the country's factor endowment, countries end up importing a very similar basket of goods in terms of the factor composition. This prediction is also in line with what we observe when exploring the data.

Figure 2.4: Cost of education and proportion of high educated workers (model)

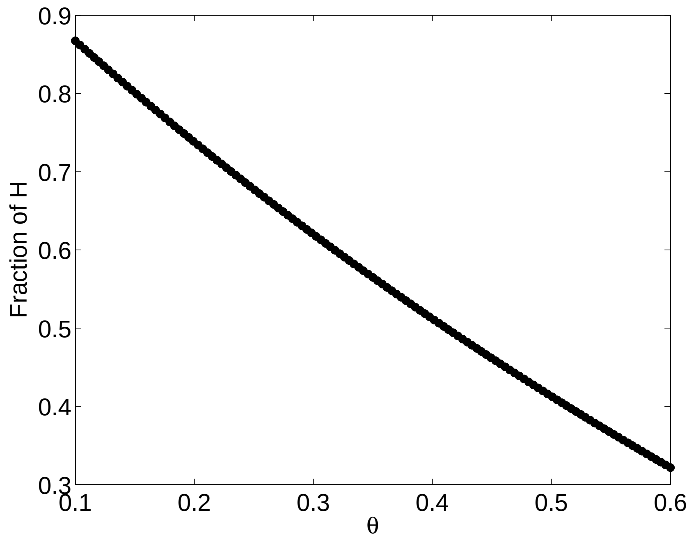



Figure 2.5: Exports education intensity and proportion of high educated workers (model)

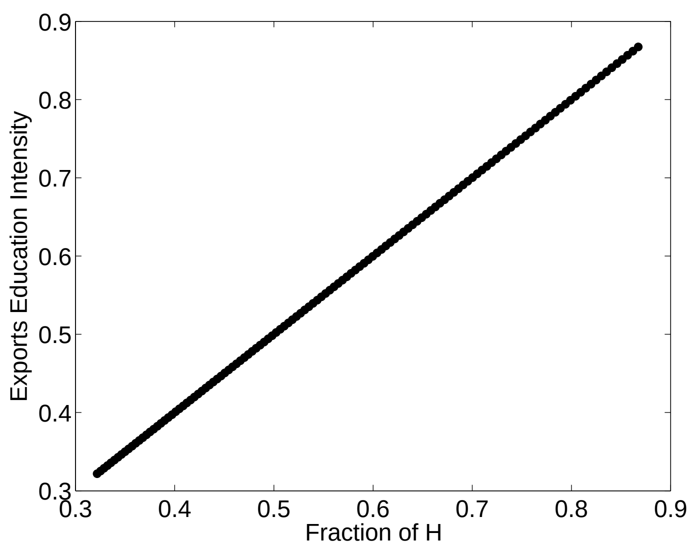
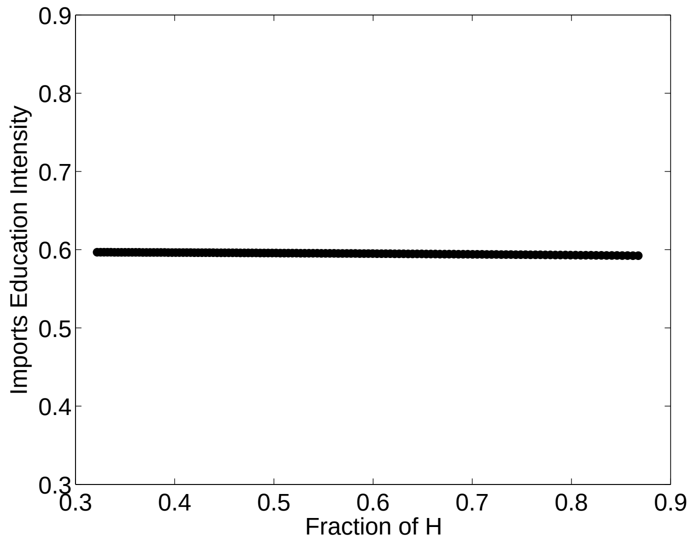


Figure 2.6: Imports education intensity and proportion of high educated workers (model)




## 2.5 Government Expenditure

In the previous section I showed how we can obtain a positive relation between the factor content of the exported basket of goods and the amount of productive factors in the country. In addition, I showed that there is not a negative relation in the case of imports. Another empirical finding that we have not discussed yet is that we observe high dispersion on the data.

Why is it the case where two countries that have the same amount of productive factors end up exporting a basket of goods that looks different in terms of factor content? As we studied in the previous section, with a continuum of goods if all the goods in the economy are traded, it is the case where the factor composition of exports equals the distribution of productive factors. Therefore, a promising answer to this question is to introduce goods that are not traded. In this section we will discuss that adding a government sector that incurs in different levels of expenditure across countries can make two countries with similar composition of productive factors export different baskets of goods in terms of factor intensity.

In this framework, countries are different along two dimensions. As in the previous section each country faces a different cost of education $\theta^i$, and additionally, there is an exogenous level of government expenditure $\bar{G}^i$. This variable can be interpreted as a public good. Consumers do not pay for it but it provides them with certain utility. The cost of education determines the wage premium, which in turn determines the subset of goods that each country produces. The government produces the government good $y^i(g)$ using both types of workers,

$$y^i(g) = \left(h^i(g)\right)^{\alpha(g)} \left(l^i(g)\right)^{1-\alpha(g)}$$

where $\alpha(g) \in (0,1)$ denotes the factor intensity required to produce the government good. The sector producing this good solves the following cost minimization problem,

$$\begin{aligned} c^i(g, w_h^i, w_l^i) = \min_{h^i(g), l^i(g)} \quad & w_h^i h^i(g) + w_l^i l^i(g) \\ s.t. \quad & \left(h^i(g)\right)^{\alpha(g)} \left(l^i(g)\right)^{1-\alpha(g)} = \bar{G}^i \\ & h^i(g), l^i(g) \geq 0 \end{aligned} .$$

Factor demand depends on the factor intensity requirement, the wage premium, and the government expenditure level,

$$l^i(g) = \bar{G} \left( \frac{w_h^i}{w_l^i} \frac{(1-\alpha(g))}{\alpha(g)} \right)^{\alpha(g)}$$

$$h^i(g) = \bar{G} \left( \frac{w_h^i}{w_l^i} \frac{(1-\alpha(g))}{\alpha(g)} \right)^{\alpha(g)-1} .$$

It is important to note that government expenditure does not affect the cutoff values since they depend solely on the education cost $\theta^i$. In addition, since cutoff values do not change, neither do the exports and imports factor intensity. However, government expenditure would have an effect on the fraction of productive factors.[10]

When government expenditure is equal to zero, the amount of productive factors is determined by the demand from the firms producing the goods $z \in Z^i$. If government expenditure is positive, we also need to take into account their factors demand. This

[10] In appendix A.5 there is an outline of the solution of this extension of the model.

means that a country will potentially have a different composition of workers depending on its government expenditure. As an example, let's think of country one, which is the one with the highest cost of education. This country will produce the most low educated workers intensive goods. Assume now that the education intensity of the government good is equal to a half. If country one has positive government spending, the relative demand of high educated workers is now higher than in the case of no government expenditure. This implies that the fraction of workers with high education is now higher. However, the factor intensity of the exported basket of goods does not change since country one is exporting the same range of goods $z$.

Figures 2.7 to 2.9 represent a scenario where the education costs are the same as in the previous section but now government expenditure is positive (and small) for some countries and zero for others. From figure 2.7 we can observe that countries having different education costs can end up with a similar fraction of educated workers. In figure 2.8 we obtain the relation between exports education intensity and the proportion of educated workers. As before, we obtain a positive relation between these two variables. However, we can see that there can be countries that have a similar fraction of high educated workers but end up exporting a basket of goods with different factor content. Finally, figure 2.9 shows the relation between imports education intensity and the proportion of educated workers. Again, we obtain that there is no relation between these two variables but we do not observe dispersion.

Figure 2.7: Cost of education and proportion of high educated workers with government expenditure (model)

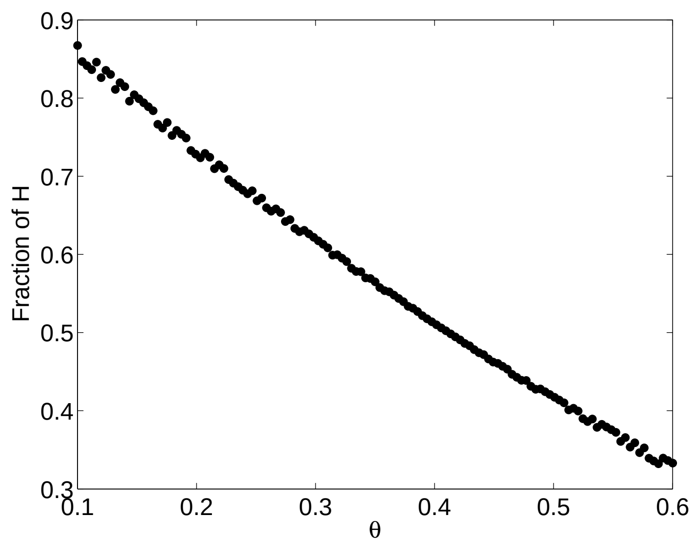



Figure 2.8: Exports education intensity and proportion of high educated workers with government expenditure (model)

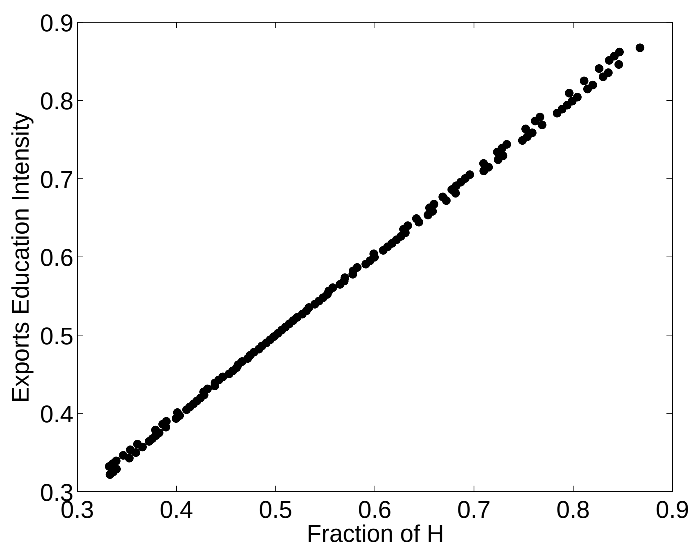
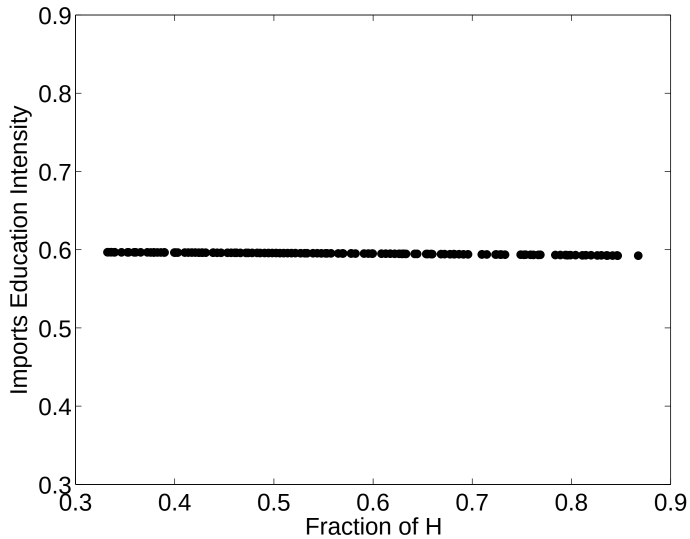


Figure 2.9: Imports education intensity and proportion of high educated workers with government expenditure (model)




## 2.6 Conclusions

When exploring data for a large selection of countries I find that education intensity in exports is positively correlated with the fraction of the population with tertiary education completed, and that education intensity in imports is not correlated with this same variable. I have analyzed how under a standard Heckscher-Ohlin framework with a continuum of goods only the first observation holds. The main shortcoming of this basic framework is that it cannot be extended to a large number of countries and maintain a unique equilibrium where location of production is determined and factor prices do not equalize. In this paper, I showed that when incorporating a cost of transforming low educated into high educated workers the second observation also holds. In addition I document that there is greater dispersion among the education intensity of the exported basket of goods than among the imported basket of goods across countries. This extended version of the Heckscher-Ohlin model cannot account for this fact.

To try to understand sources of dispersion I extend the model to include the scenario were governments have different levels of expenditure. This modification of the framework can generate some dispersion for exports, but not for imports.

The next step is to find more sources of dispersion. Why do two countries that have the same proportions of productive factors export a basket of goods with a different level of factor intensity? A possible explanation could come from the fact that we are not taking into account the quality of education. Having a college degree in one country can have very different implications than having it somewhere else. Other explanations could be related to different natural resource endowments or different country sizes.

For future work, it would be interesting to include in a more serious way human capital formation and to study if there is a relation between the nature of trade flows and the evolution of human capital accumulation.

# Chapter 3

# Education Intensity in Trade Flows and Natural Resources

## 3.1 Introduction

Natural resources as a determinant of international trade is a topic that has been widely studied. It is a source of comparative advantage in the production of certain goods, and it is clear that if a country does not have certain resources it cannot export them.

As discussed in the previous chapters, Leontief found that even though the United States was a capital abundant country, its exports were labor intensive. One of the possible explanations that could resolve the Leontief paradox was the existence of a third factor of production, natural resources. Vanek (1959) is one of the first studies analyzing the natural resource content of foreign trade in the United States and the abundance of that productive factor. He finds that the factor structure of exports and competing imports in the U.S. reflects the relative scarcity of natural resources rather than that of the capital factor. In addition, he finds that capital and natural resources seem to be complements. Therefore, it could be the case where capital is actually abundant but it is used in large amounts in conjunction with natural resources, which are the scarce factor. This leads to exports being less capital intensive than imports. Finally, since the original Heckscher-Ohlin model was framed under the existence of only two factors of production, the author cannot go in deeper detail on its analysis.

With the development of extensions to Heckscher-Ohlin including more factors of production, different studies have emphasized the importance of natural resources and the factor content of trade. In this chapter, rather than analyzing the factor content of trade in terms of natural resources, I study the effects of natural resources on the education intensity of traded baskets of goods.

I develop an extension of the costly education model outlined in section 2.4 where a good that requires natural resources and only one type of workers in its production is added. With this modification I obtain certain level of dispersion; that is, two countries with a similar distribution of workers trade baskets of goods with different factor content. Now exports education intensity is not only determined by the education of the workers, and differences arise from production and absorption not being equal in their proportion of factor content.

## 3.2 Data

In addition to the data gathered in chapter 2, I need to obtain natural resources data. When looking at trade data transformed into the CPS industry classification, natural resources are considered as the categories reflected in table 3.1.

Table 3.1: Categories of natural resources

| Code | Description |
|---|---|
| 0180 | Forestry except logging |
| 0270 | Logging |
| 0280 | Fishing, hunting, and trapping |
| 0370 | Oil and gas extraction |
| 0380 | Coal mining |
| 0390 | Metal ore mining |
| 0470 | Nonmetallic mineral mining and quarrying |

The question is why countries with a similar education endowment end up exporting a basket of goods that is different in terms of education content. In order to provide an example, let's compare Australia and Ireland. The percent of the population with tertiary education in 2005 is 20.6 and 18.5 respectively. However, the education intensity of the basket of goods they export is 0.76 for Ireland and 0.58 for Australia. In this case, Ireland has a slightly smaller fraction of high educated people but exports a basket of goods with higher education content. In table 3.2 we can see the top five categories in terms of industries for exported goods and their education intensity.

Table 3.2: Top exports by industry: Australia vs Ireland, 2005

| Australia | | | | Ireland | | |
|---|---|---|---|---|---|---|
| Category (CPS) | Education Index | Share on Exported Basket | | Category (CPS) | Education Index | Share on Exported Basket |
| Coal mining* | 0.51 | 12.2 | | Industrial and miscellaneous chemicals | 0.75 | 23.1 |
| Metal ore mining* | 0.66 | 10.3 | | Pharmaceutical and medicine manufacturing | 0.87 | 16.8 |
| Petroleum refining | 0.74 | 10.2 | | Petroleum refining | 0.74 | 9.1 |
| Logging* | 0.37 | 8.3 | | Computer and peripheral equipment manufacturing | 0.87 | 8.3 |
| Railroad rolling stock manufacturing | 0.71 | 7.6 | | Logging* | 0.37 | 7.5 |
| Total | | 48.6 | | Total | | 64.8 |

* Categories included in natural resources

It is interesting to note that five categories account for a big fraction of total exports. When analyzing these two countries it can be seen that for Australia three out of five categories are natural resources related (first, second and fourth most exported), while for Ireland only the fifth category is related to natural resources. Ireland exports goods from industries that are intensive in high educated workers. To produce goods like coal or metal what matters is to have those specific natural resources. Education as a productive factor is not that relevant to determine comparative advantage in these specific industries. This is a plausible reason explaining the different behavior in exports education intensity observed in Australia and Ireland.

## 3.3 Heckscher-Ohlin Model with a Continuum of Goods and Natural Resources

As learned in chapter 2, the extension of the Heckscher-Ohlin model with a continuum of goods and costly education cannot generate dispersion. This means that there is not an scenario where two countries with a very similar proportion of productive factors end up exporting a basket of goods with an education intensity index that is significantly different. However, when we look at the data we observe that data points are quite disperse. To overcome this limitation of the previous model, I extend the model described in section 2.4 by adding another good in the economy: a good produced using natural resources.

As in the previous case there is a cost of education that is different across countries, which pins down the relative wages between high and low educated workers. Additionally, each country is endowed with one unit of low educated workers that choose to become educated or not:

$$\max_{s} \quad s(w_h^i(1-\theta^i)) + (1-s)w_l^i$$
$$s.t. \quad s \in \{0,1\}$$

where $w_h^i$ and $w_l^i$ are the wage of low and high educated workers respectively, and $\theta$ represents the fraction of time a worker needs to spend to become high educated. Clearly, a worker facing a high education cost will only be willing to acquire high education if the payoff of doing so is also high. In equilibrium workers are indifferent between staying low educated and investing in their education; that is, the return to education is equal to its cost. The wage ratio is given by

$$\frac{w_h^i}{w_l^i} = \frac{1}{1-\theta^i}. \tag{3.1}$$

This implies that as the cost of becoming educated increases, so does the wage premium.

In this model in addition to a continuum of tradable goods $z$, there is also a good $e$ that requires natural resources as an input of production. For simplicity, we will think of good $e$ as energy and of natural resources as petroleum. Each country is endowed with a different amount of natural resources $\bar{E}$. To simplify the analysis we will assume that only low educated workers are required in the production of energy $e$. The production function is given by the following Cobb-Douglas function:

$$y^i(e) = \left(E^i\right)^{\beta} \left(l^i(e)\right)^{1-\beta},$$

where $E$ is natural resources, $l$ is low educated workers, and $\beta$ exists between zero and one and governs factor intensity. The representative firm chooses the quantity of workers and the quantity of natural resources so costs of production are minimized.

$$\begin{aligned} c^i(e, w_l^i, r^i) = \min_{l^i(e), E^i} \quad & w_l^i l^i(e) + r^i E^i \\ s.t. \quad & \left(E^i\right)^{\beta} \left(l^i(e)\right)^{1-\beta} \geq y^i(e) \\ & l^i(e) \geq 0, \end{aligned}$$

where $r$ is the price of the natural resource used as an input of production. The cost minimization problem of the firm that produces good $z$ in country $i$ remains as described in the previous chapter.

$$\begin{aligned} c^i(z, w_h^i, w_l^i) = \min_{h^i(z), l^i(z)} \quad & w_h^i h^i(z) + w_l^i l^i(z) \\ s.t. \quad & \left(h^i(z)\right)^{\alpha_z} \left(l^i(z)\right)^{1-\alpha_z} \geq y^i(z) \\ & h^i(z), l^i(z) \geq 0 \end{aligned}$$

The aggregate consumer chooses how much to consume of each variety $z$ and how much to consume of the good that requires natural resources in its production, $s$, so utility is maximized

$$\begin{aligned} \max_{C^i(z), C^i(e)} \quad & \gamma \int \psi \log C^i(z) dz + (1-\gamma) \log(C^i(e)) \\ s.t. \quad & \int p(z) C^i(z) dz + p(d) C^i(e) \leq W^i \\ & C^i(z), C^i(e) \geq 0, \end{aligned}$$

where $W^i = w_h^i(1-\theta^i)H^i + w_l^i L^i + r^i \bar{E}^i$ is aggregate income. There are $H$ high educated workers providing each $(1-\theta)$ units of time and receiving a wage of $w_h$ and $L$ low educated workers providing one unit of time and receiving a wage of $w_l$. In addition, workers are the owners of the natural resources, which they sell for a price of $r$ to the representative firm producing good $e$.

After having explained what each type of agent does in this economy, we can proceed with the market clearing conditions. High educated workers are only employed in the sector producing the varieties of $z$. Therefore,

$$\int h^i(z)dz = (1 - \theta^i)H^i.$$

On the other hand, low educated workers are employed in both sectors of the economy. The market clearing condition is represented by

$$\int l^i(z)dz + l^i(e) = L^i.$$

Finally, the market clearing condition for goods is so that the addition of the demand for each variety $z$ across countries is equal to the addition of its production,

$$\sum_{i=1}^{N} C^i(z) = \sum_{i=1}^{N} y^i(z) \qquad \forall z.$$

And similarly for energy,

$$\sum_{i=1}^{N} C^i(e) = \sum_{i=1}^{N} y^i(e).$$

Lastly, the trade balance between countries implies that the value of what country $i$ imports must be equal to the value of its exports,

$$\int_{z \notin Z^i} p(z)^i C^i(z)dz + p(e)\left(C^i(e) - y^i(e)\right) = \sum_{j \neq i} \int_{z \in Z^i} p(z)^j C^j(z)dz \qquad \forall i \in \{1, N\}. \tag{3.2}$$

Note that $Z^i$ denotes the set of goods that country $i$ produces. In equilibrium each variety $z$ is produced by one country exclusively, the lowest cost producer. However, energy $e$ is produced by the countries with a positive endowment $\bar{E}$. Even countries that are endowed with natural resources will end up importing energy if their own production falls short to cover local demand. Naturally when production exceeds local demand, the surplus will be exported to other countries. When the second term of the previous equation is positive, country $i$ is importing energy. Similarly, when it is negative country $i$ is an energy exporter.

With all this information we can pin down the cutoff values $\{\bar{z}_i\}_{i=1}^{N-1}$. This in turn determines the fraction of high educated to low educated workers, production, and trade patterns. The details regarding how to solve this model can be found in appendix B.1.

Finally, following the same procedure as in section 2.4, we can compute the factor content of the traded baskets of goods. The factor content of exports $\eta_x$ is then calculated as the following weighted average:

$$\eta_x^i = \frac{\sum_{j\neq i} \gamma W^j \int_{z\in Z^i} z dz + \alpha(e) \max\left\{0, p(e)y^i(e) - \dfrac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}}{\sum_{j\neq i} \gamma W^j \int_{z\in Z^i} dz + \max\left\{0, p(e)y^i(e) - \dfrac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}}.$$

The first term in the numerator is the weighted average of the value of exports of goods $z$. The second term contains the difference between the value of the production of energy minus the value of the demand multiplied by its factor intensity (in this case $\alpha(e)$ is equal to zero since we do not use high educated workers in the production of $e$). If it is positive, then country $i$ is exporting the good. In the denominator we have the value of exports. Therefore, for country $i = 1$ we have that

$$\eta_x^1 = \frac{\sum_{j\neq 1} \gamma W^j \frac{1}{2}\left(\bar{z}_1^2 - \bar{z}_{min}^2\right)}{\sum_{j\neq 1} \gamma W^j \left(\bar{z}_1 - \bar{z}_{min}\right) + \max\left\{0, p(e)y^1(e) - \dfrac{(1-\gamma)W^1}{\gamma(\psi-1)+1}\right\}},$$

for countries $i \in \{2, N-1\}$

$$\eta_m^i = \frac{\gamma \sum_{j\neq i} W^j \frac{1}{2}\left(\bar{z}_{i-1}^2 - z_{min}^2 + z_{max}^2 - \bar{z}_i^2\right)}{\sum_{j\neq i} \gamma W^j \left(\bar{z}_{i-1} - z_{min} + z_{max} - \bar{z}_i\right) - \min\left\{0, p(e)y^i(e) - \dfrac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}},$$

and for country $i = N$

$$\eta_x^N = \frac{\sum_{j\neq N} \gamma W^j \frac{1}{2}\left(\bar{z}_{max}^2 - \bar{z}_{N-1}^2\right)}{\sum_{j\neq N} \gamma W^j \left(\bar{z}_{max} - \bar{z}_{N-1}\right) + \max\left\{0, p(e)y^N(e) - \dfrac{(1-\gamma)W^N}{\gamma(\psi-1)+1}\right\}}.$$

Similarly, the value of the basket of goods that country $i$ imports is equal to the sum of the fraction of income they spend in each imported good $z$,

$$\eta_m^i = \frac{\gamma W^i\left(\int_{z_{min}}^{\bar{z}_{i-1}} zdz + \int_{\bar{z}_i}^{z_{max}} zdz\right) - \alpha(e)\min\left\{0, p(e)y^i(e) - \frac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}}{\gamma W^i\left(\int_{z_{min}}^{\bar{z}_{i-1}} zdz + \int_{\bar{z}_i}^{z_{max}} zdz\right) - \min\left\{0, p(e)y^i(e) - \frac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}}.$$

Therefore, for country $i = 1$ we have that

$$\eta_m^1 = \frac{\gamma W^1 \frac{1}{2}\left(z_{max}^2 - \bar{z}_1^2\right)}{\gamma W^1\left(z_{max} - \bar{z}_1\right) - \min\left\{0, p(e)y^1(e) - \frac{(1-\gamma)W^1}{\gamma(\psi-1)+1}\right\}},$$

for countries $i \in \{2, N-1\}$

$$\eta_m^i = \frac{\gamma W^i \frac{1}{2}\left(\bar{z}_{i-1}^2 - z_{min}^2 + z_{max}^2 - \bar{z}_i^2\right)}{\gamma W^i\left(\bar{z}_{i-1} - z_{min} + z_{max} - \bar{z}_i\right) - \min\left\{0, p(e)y^i(e) - \frac{(1-\gamma)W^i}{\gamma(\psi-1)+1}\right\}},$$

and for country $i = N$

$$\eta_m^N = \frac{\gamma W^N \frac{1}{2}\left(z_{N-1}^2 - \bar{z}_{min}^2\right)}{\gamma W^N\left(z_{N-1} - \bar{z}_{min}\right) - \min\left\{0, p(e)y^N(e) - \frac{(1-\gamma)W^N}{\gamma(\psi-1)+1}\right\}}.$$

We can observe that the higher the exports of energy are for a given country, the lower the education intensity of the exported basket of goods. Therefore, when we compare two countries with similar levels of education cost $\theta$ but with different endowment of natural resources $\bar{E}$, it is straight forward to see that the natural resource endowment can generate distortions regarding the final distribution of workers. In this case, if one of the countries has a large enough positive endowment to make him an energy exporter while the other has zero endowment, the first country will end up with a higher proportion of low educated workers. The reason is that the production of the natural resource good requires low educated workers, which results in a higher demand of that type of workers compared to the other country.

Additionally, two countries that end up with a similar distribution of workers can actually have different education intensity of traded baskets. In order to illustrate this implication, let's consider a case where one country has zero endowment of the natural resources while the other country has a positive endowment such they exactly consume the amount of energy they produce. Furthermore, let's assume that both countries end up having the same fraction of high educated workers $H$. Under this scenario even though both countries have the same distribution of labor, the education intensity of the exported basket of goods is different. The reason behind this difference is that in the second country a fraction of the low educated workers, $l(e)$, is being used in the production of energy, which is not exported. This leads the country to higher education intensity on the basket they export when comparing it to the first country.

To see how the model works, setting the minimum and maximum values of factor requirement to match the data described in section 2.2 ($z_{min} = 0.32$, $z_{max} = 0.87$), and setting a cost of education $\theta$ that goes from 0.1 to 0.6, with 127 countries we obtain figures 3.1 to 3.3. In figure 3.1 we can see the relation between the cost of education and the fraction of the population that becomes high educated. As in the case without natural resources, there is a negative relation: the higher the cost of becoming educated, the lower the proportion of workers with a high education. However, we see now that is not a one to one relation; that is, the education cost $\theta$ is not the only factor affecting the workers distribution. Now we observe dispersion, countries with a similar cost of education can end up having a different proportion of workers of each type. As explained earlier the distribution of labor also depends on each country's endowment of natural resources.

Figure 3.2 depicts the relation between the fraction of workers with high education and the education intensity of the exported basket of goods. When comparing it with the model without natural resources, we can observe that although the positive relation is maintained, now there is some dispersion. In addition, the exports education intensity is now below the minimum observed in the data for a given industry (0.32). The reason is that we are assuming that the energy is produced using only low educated workers, which implies that the education intensity in that particular sector is equal to zero.

Finally, figure 3.3 reflects the relation between the education intensity of the imported basket of goods and the fraction of high educated workers for each country. Again, although the lack of relation between these two variables is preserved, now dispersion is added. All these observations are consistent with the empirical findings shown in chapter 2.

Figure 3.1: Cost of education and proportion of high educated workers (l)

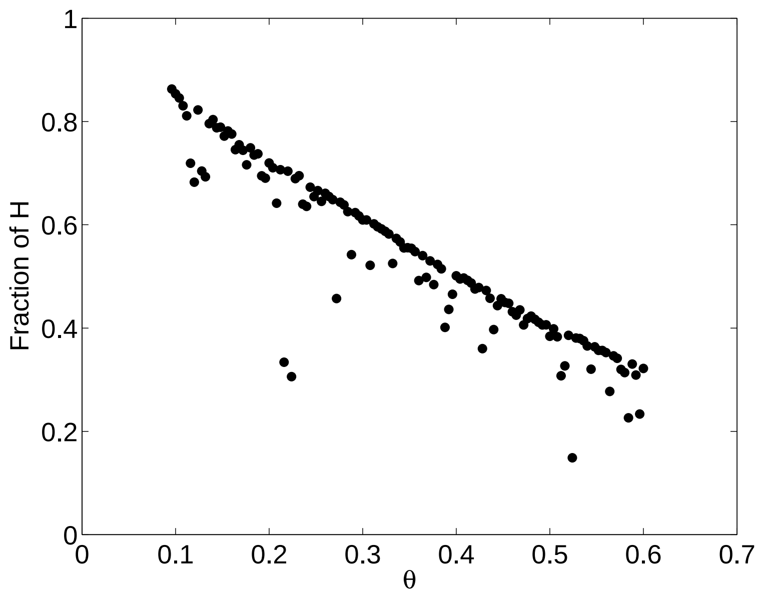



Figure 3.2: Exports education intensity and proportion of high educated workers (l)

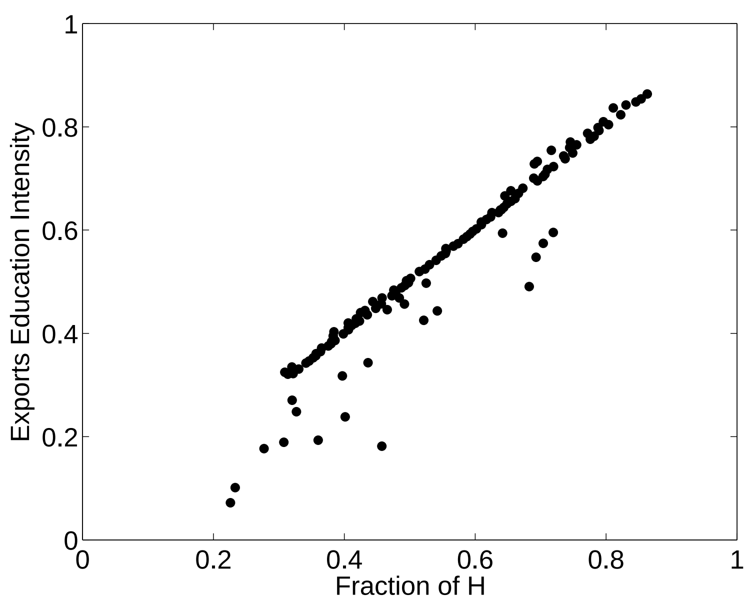
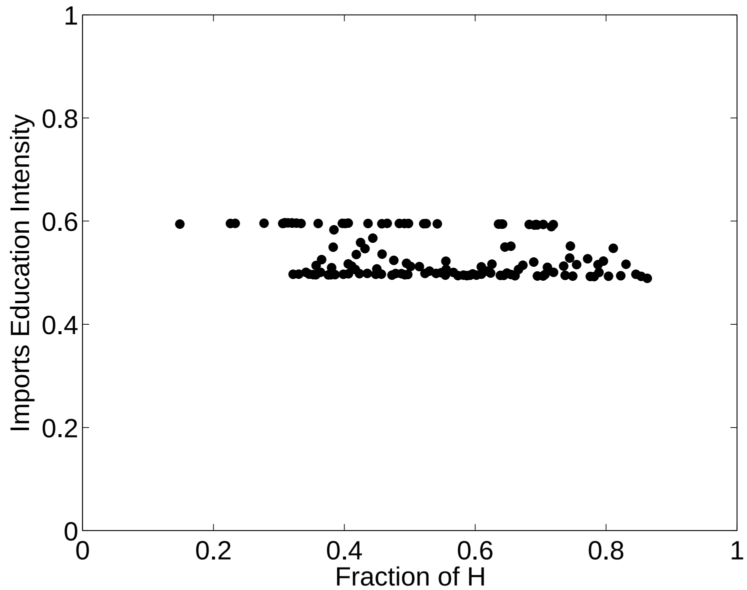


Figure 3.3: Imports education intensity and proportion of high educated workers (l)




During our previous analysis we assumed that for producing the natural resource good only low educated workers were employed. Similarly, we can assume that the technology is given by

$$y^i(s) = \left(E^i\right)^{\beta} \left(h^i(e)\right)^{1-\beta},$$

which means that only high educated workers are employed. Under this scenario we obtain figures 3.4 to 3.6. Figure 3.4 shows the relation between the cost of education and the fraction of high educated workers, figure 3.5 reflects the relation between exports education intensity and the fraction of high educated workers, and finally, figure 3.6 depicts the relation between imports education intensity and the fraction of high educated workers. The difference under this scenario lies in the direction of the dispersion and in the fraction of workers that end up having a higher education. In the previous case, the presence of natural resources in a given country would rise the demand for low educated workers and would move the education intensity of the exported basket of goods downward. In addition, a country importing the natural resources good would also see the education intensity of its imports decrease. In the case where only high educated workers are required in the production of natural resources, education intensities will be higher and the proportion of high educated workers will also be higher. Since the original model with costly education described in section 2.4 overstates the fraction of the population that ends up completing tertiary education, the first specification where energy only requires low educated workers is preferred.

Figure 3.4: Cost of education and proportion of high educated workers (h)

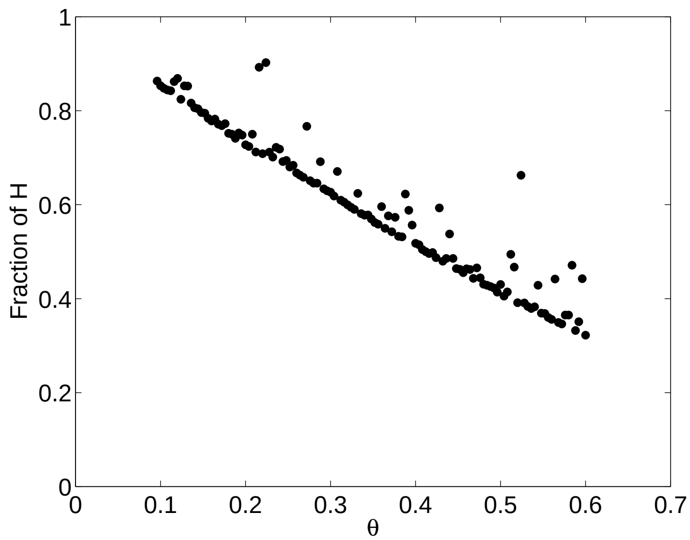


Figure 3.5: Exports education intensity and proportion of high educated workers (h)

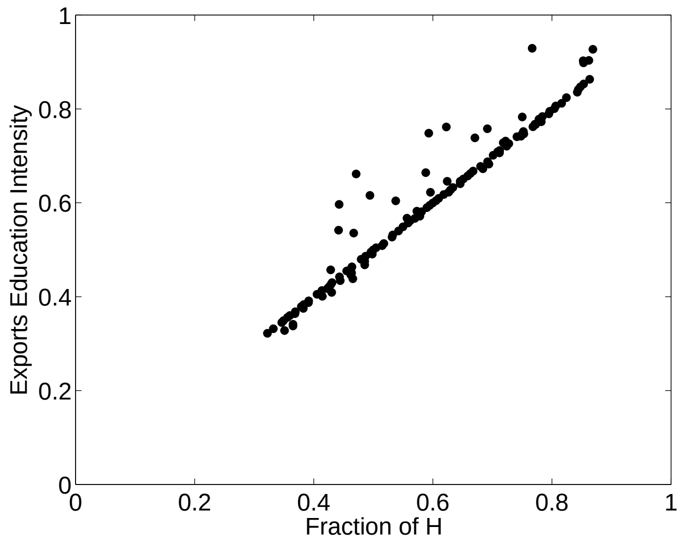
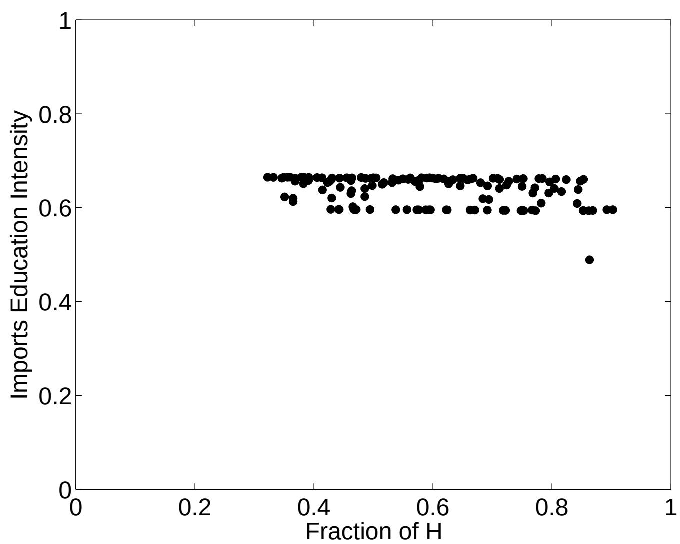



Figure 3.6: Imports education intensity and proportion of high educated workers (h)



## 3.4 Testing the Model

To see whether the model can match the data we would need information about the cost of education. Measuring it is a hard task. A lot of factors enter in such concept: government expenditure, tuition costs, infrastructure, institutions, number of students per professor, etc. However, the cost of education has a clear implication on the wage premium. In particular, recall that the wage premium is given by

$$\frac{w_h^i}{w_l^i} = \frac{1}{1-\theta^i}.$$

Given the difficulties of coming up with a clear measure of education costs, I will pin it down with wage premiums. This information is obtained from the OECD. The shortcoming of this approach is that I only have data for 27 countries, which is less than 20% of the number of observations I had originally. Figures 3.7 and 3.8 represent the data relating the fraction of the population with tertiary education completed with firstly exports, and secondly imports education intensity for this subset of countries. The empirical findings documented in section 2.2 can't be seen as clearly. For the case of exports the dispersion is quite high.

Figure 3.7: Exports education intensity vs percent of population with tertiary education

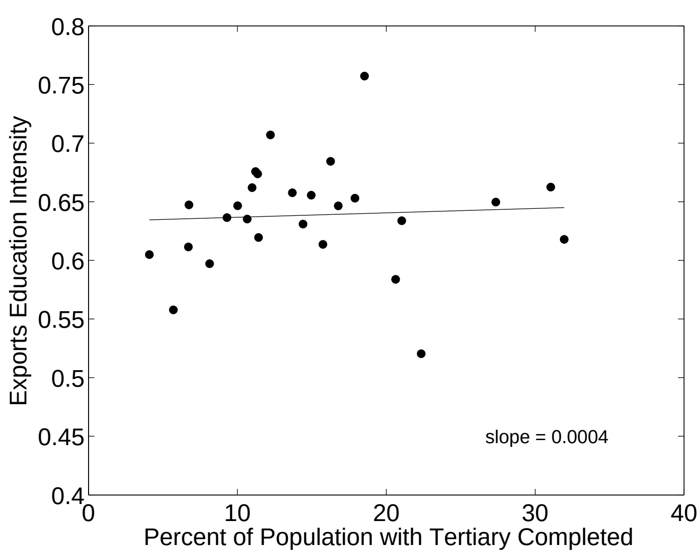


Figure 3.8: Imports education intensity vs percent of population with tertiary education

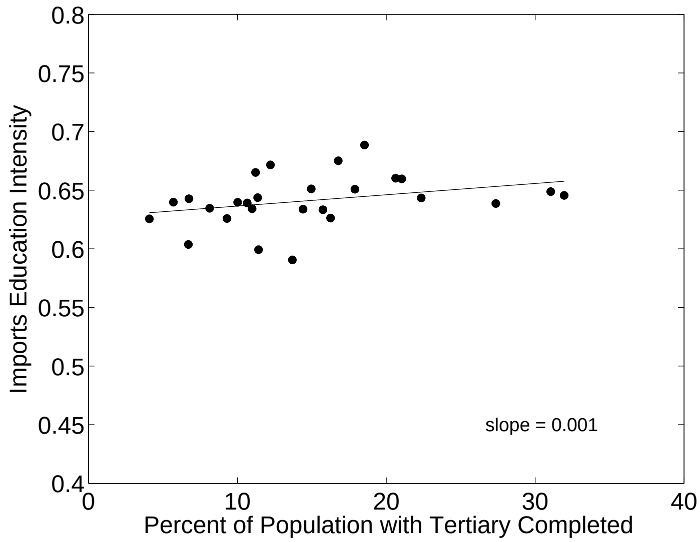



Figure 3.9: Exports education intensity vs fraction of population with tertiary education (model)

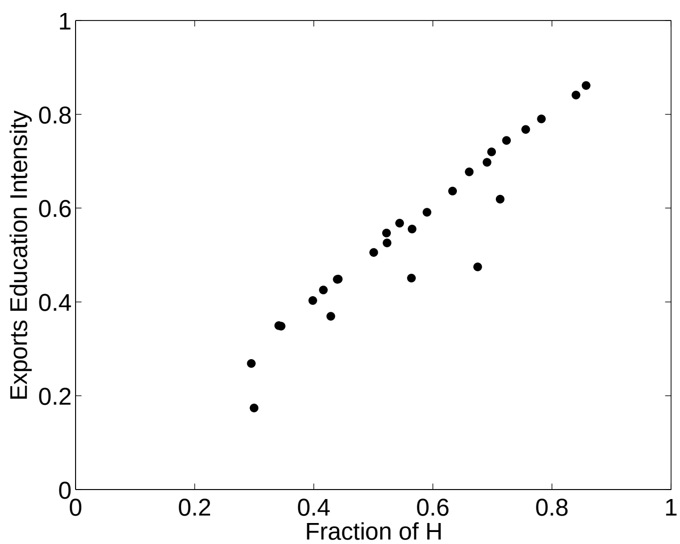
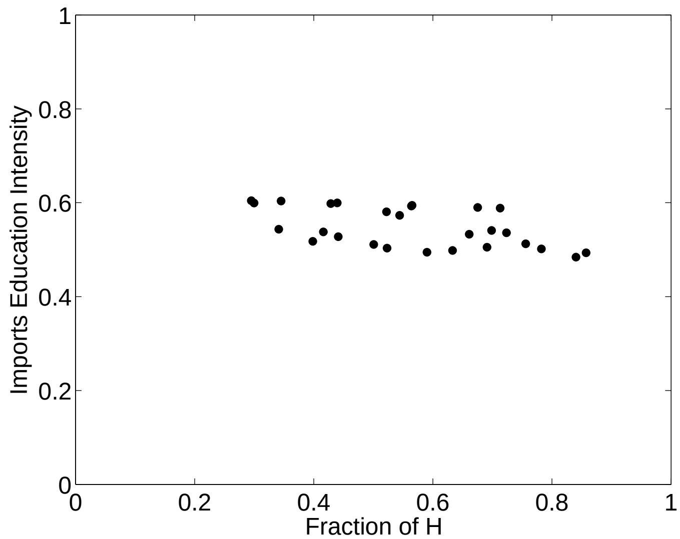


Figure 3.10: Imports education intensity vs fraction of population with tertiary education (model)




Figures 3.9 and 3.10 represent the outcome of the model when setting $\gamma$ equal to 0.9 and using teach country's wage premium and natural resource endowment level. As we can see, the model predicts a positive relation between the fraction of educated workers and education intensity, and no relation between the distribution of workers according to their level of education and imports.

## 3.5 Conclusions

In this chapter I included natural resources as a distortive factor in the education content of trade. The Heckscher-Ohlin model has been extended to include a large number of countries, a continuum of goods produced with low and high educated workers, and a tradable good produced with only one type of workers and natural resources. Countries differ in their cost of education and in their endowment of natural resources. This model generates a positive relation between the fraction of high educated workers and the education intensity of the exported basket of goods. It also generates no relation between the fraction of high educated workers and the education content of imports. Lastly, it generates some dispersion. This means that countries with a similar distribution of workers can behave differently in terms of the education content of their trade flows.

When testing the model against data, the main shortcoming is that information about education costs is hard to obtain. To go around this difficulty, this variable is pinned down with wage premiums. The problem is that there are only 27 countries for which there is wage premium data. The sample gets reduced to less than 20% the original size. Given such a small number of observations, the original findings are not that well represented.

For future work it would be interesting to create a measure of education costs for a larger number of countries.

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# Appendix A

# Appendix to Chapter 2

## A.1 Tables and Figures

Table A.1: Relative earnings

| Year | Low | Med | High |
|---|---|---|---|
| 2003 | 68.84 | 100 | 151.13 |
| 2004 | 68.20 | 100 | 146.53 |
| 2005 | 70.76 | 100 | 157.37 |
| 2006 | 75.00 | 100 | 158.37 |
| 2007 | 69.81 | 100 | 162.46 |
| 2008 | 72.28 | 100 | 156.64 |

Table A.2: Education intensity index by industry

| Ind code CPS | Educ Int | Description |
|---|---|---|
| 170 | 0.44 | Crop production |
| 180 | 0.51 | Animal production |
| 190 | 0.83 | Forestry except logging |
| 270 | 0.37 | Logging |
| 280 | 0.46 | Fishing, hunting, and trapping |
| 290 | 0.49 | Support activities for agriculture and forestry |
| 370 | 0.64 | Oil and gas extraction |
| 380 | 0.51 | Coal mining |
| 390 | 0.66 | Metal ore mining |
| 470 | 0.47 | Nonmetallic mineral mining and quarrying |
| 490 | 0.59 | Support activities for mining |
| 570 | 0.76 | Electric power generation, transmission and distribution |
| 580 | 0.74 | Natural gas distribution |
| 670 | 0.68 | Water, steam, air conditioning, and irrigation systems |
| 680 | 0.67 | Sewage treatment facilities |
| 1070 | 0.58 | Animal food, grain, and oilseed milling |
| 1080 | 0.50 | Sugar and confectionery products |
| 1090 | 0.48 | Fruit and vegetable preserving and specialty food manufacturing |
| 1170 | 0.57 | Dairy product manufacturing |
| 1180 | 0.32 | Animal slaughtering and processing |
| 1190 | 0.51 | Retail bakeries |
| 1270 | 0.49 | Bakeries, except retail |
| 1280 | 0.54 | Seafood and other miscellaneous foods, n.e.c. |
| 1370 | 0.69 | Beverage manufacturing |
| 1390 | 0.72 | Tobacco manufacturing |
| 1470 | 0.43 | Fiber, yarn, and thread mills |
| 1480 | 0.48 | Fabric mills, except knitting |

Table continues on next page

| Continuation of Table A.2 | | |
|---|---|---|
| Ind code CPS | Educ Int | Description |
| 1490 | 0.56 | Textile and fabric finishing and coating mills |
| 1590 | 0.47 | Textile product mills except carpets and rugs |
| 1670 | 0.57 | Knitting mills |
| 1680 | 0.40 | Cut and sew apparel manufacturing |
| 1690 | 0.51 | Apparel accessories and other apparel manufacturing |
| 1770 | 0.59 | Footwear manufacturing |
| 1790 | 0.34 | Leather tanning and products, except footwear manufacturing |
| 1870 | 0.62 | Pulp, paper, and paperboard mills |
| 1880 | 0.50 | Paperboard containers and boxes |
| 1890 | 0.62 | Miscellaneous paper and pulp products |
| 1990 | 0.61 | Printing and related support activities |
| 2070 | 0.74 | Petroleum refining |
| 2090 | 0.55 | Miscellaneous petroleum and coal products |
| 2170 | 0.60 | Resin, synthetic rubber and fibers, and filaments manufacturing |
| 2180 | 0.71 | Agricultural chemical manufacturing |
| 2190 | 0.87 | Pharmaceutical and medicine manufacturing |
| 2270 | 0.70 | Paint, coating, and adhesives manufacturing |
| 2280 | 0.66 | Soap, cleaning compound, and cosmetic manufacturing |
| 2290 | 0.75 | Industrial and miscellaneous chemicals |
| 2370 | 0.54 | Plastics product manufacturing |
| 2380 | 0.67 | Tire manufacturing |
| 1570 | 0.42 | Carpets and rugs manufacturing |
| 2390 | 0.55 | Rubber products, except tires, manufacturing |
| 2470 | 0.59 | Pottery, ceramics, and related products manufacturing |
| 2480 | 0.48 | Structural clay product manufacturing |
| 2490 | 0.58 | Glass and glass product manufacturing |
| 2570 | 0.49 | Cement, concrete, lime, and gypsum product manufacturing |
| Table continues on next page | | |

Continuation of Table A.2

| Ind code CPS | Educ Int | Description |
|---|---|---|
| 2590 | 0.59 | Miscellaneous nonmetallic mineral product manufacturing |
| 2670 | 0.56 | Iron and steel mills and steel product manufacturing |
| 2680 | 0.66 | Aluminum production and processing |
| 2690 | 0.62 | Nonferrous metal, except aluminum, production and processing |
| 2770 | 0.49 | Foundries |
| 2780 | 0.54 | Metal forgings and stampings |
| 2790 | 0.66 | Cutlery and hand tool manufacturing |
| 2870 | 0.56 | Structural metals and tank and shipping container manufacturing |
| 2880 | 0.52 | Machine shops, turned product, screw, nut, and bolt manufacturing |
| 2890 | 0.48 | Coating, engraving, heat treating and allied activities |
| 2970 | 0.61 | Ordnance |
| 2980 | 0.55 | Miscellaneous fabricated metal products manufacturing |
| 3070 | 0.60 | Agricultural implement manufacturing |
| 3080 | 0.67 | Construction mining and oil field machinery manufacturing |
| 3090 | 0.77 | Commercial and service industry machinery manufacturing |
| 3170 | 0.66 | Metalworking machinery manufacturing |
| 3180 | 0.72 | Engines, turbines, and power transmission equipment manufacturing |
| 3190 | 0.64 | Machinery manufacturing, n.e.c. |
| 3360 | 0.87 | Computer and peripheral equipment manufacturing |
| 3370 | 0.79 | Communications, audio, and video equipment manufacturing |
| 3380 | 0.81 | Navigational, measuring, electromedical, and control instruments manufacturing |
| 3390 | 0.79 | Electronic component and product manufacturing, n.e.c. |
| 3470 | 0.59 | Household appliance manufacturing |

Table continues on next page

| Continuation of Table A.2 | | |
|---|---|---|
| Ind code CPS | Educ Int | Description |
| 3490 | 0.68 | Electrical lighting, equipment, and supplies manufacturing, n.e.c. |
| 3570 | 0.64 | Motor vehicles and motor vehicle equipment manufacturing |
| 3580 | 0.76 | Aircraft and parts manufacturing |
| 3590 | 0.86 | Aerospace product and parts manufacturing |
| 3670 | 0.71 | Railroad rolling stock manufacturing |
| 3680 | 0.60 | Ship and boat building |
| 3690 | 0.63 | Other transportation equipment manufacturing |
| 3770 | 0.43 | Sawmills and wood preservation |
| 3780 | 0.55 | Veneer, plywood, and engineered wood products |
| 3790 | 0.48 | Prefabricated wood buildings and mobile homes |
| 3870 | 0.48 | Miscellaneous wood products |
| 3890 | 0.49 | Furniture and related products manufacturing |
| 3960 | 0.74 | Medical equipment and supplies manufacturing |
| 3970 | 0.63 | Toys, amusement, and sporting goods manufacturing |
| 3980 | 0.59 | Miscellaneous manufacturing, n.e.c. |
| End of Table | | |

Figure A.1: Exports education intensity vs percent of the population with tertiary education, 2005 (labels)

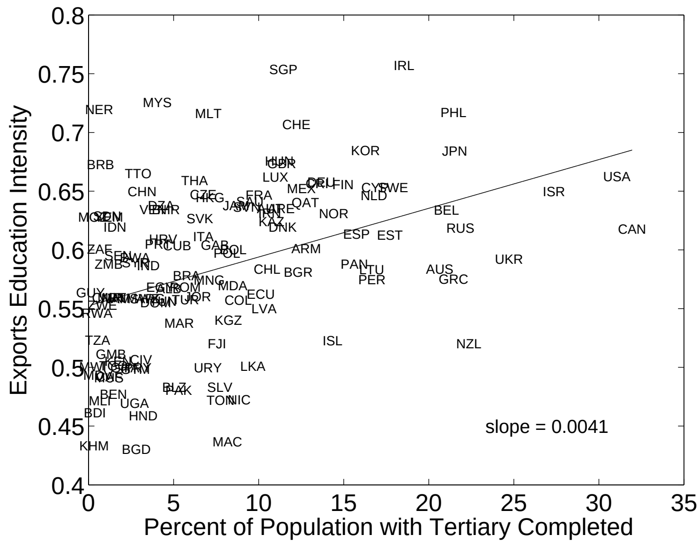



Figure A.2: Imports education intensity vs percent of the population with tertiary education, 2005 (labels)

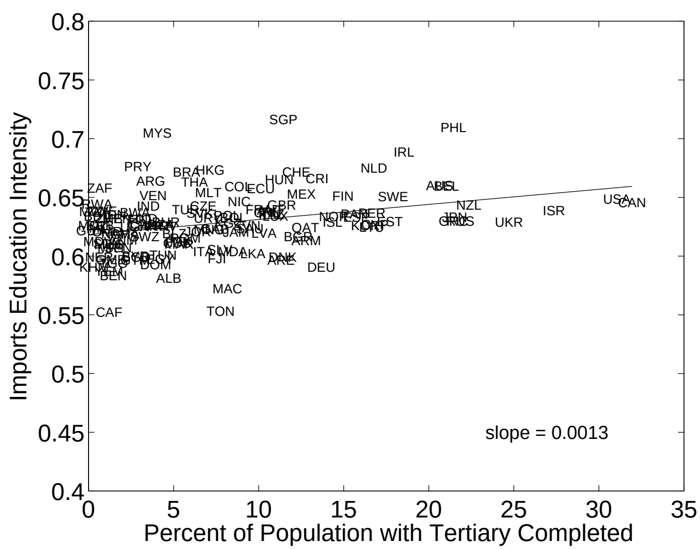


Figure A.3: Exports education intensity vs percent of the population with tertiary education, 1995

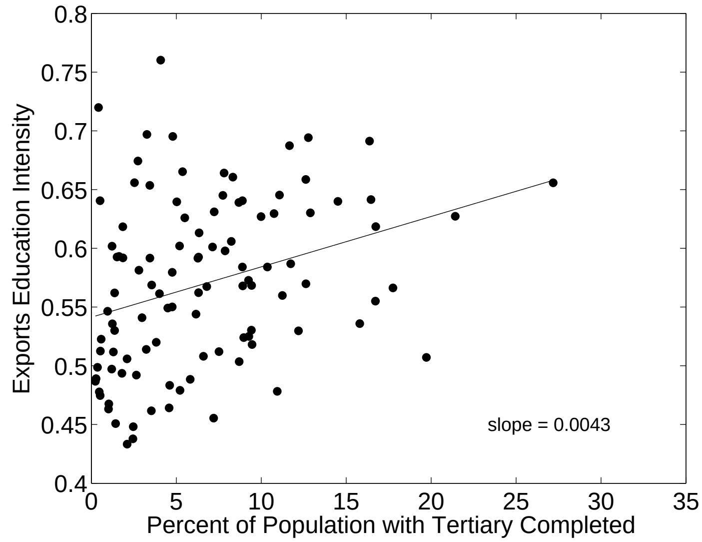



Figure A.4: Imports education intensity vs percent of the population with tertiary education, 1995

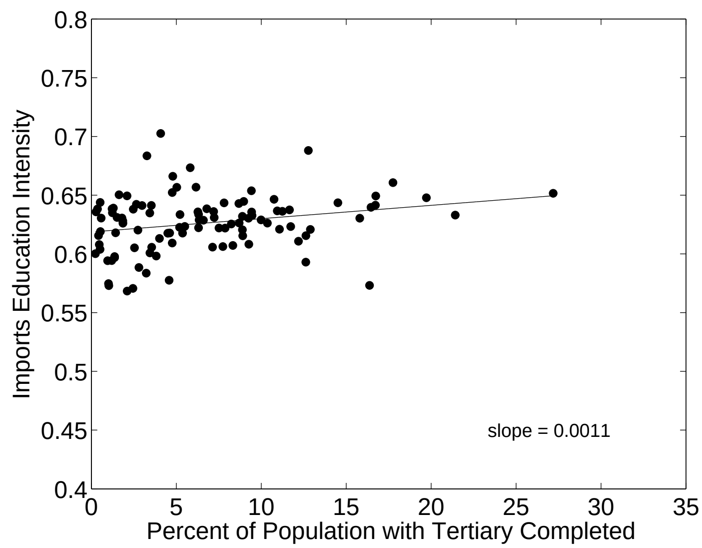


Figure A.5: Exports education intensity vs percent of the population with tertiary education, 1995 (labels)

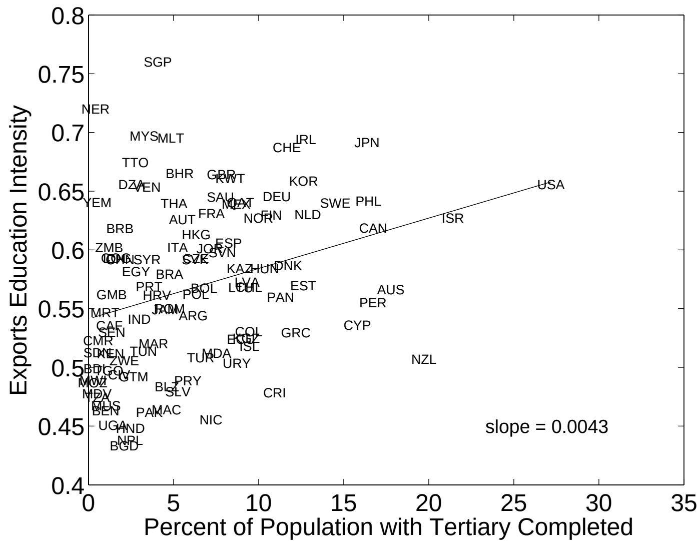



Figure A.6: Imports education intensity vs percent of the population with tertiary education, 1995 (labels)

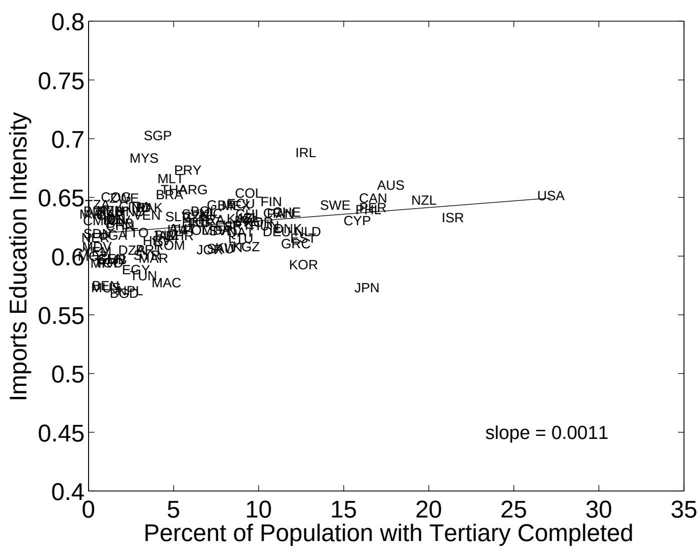
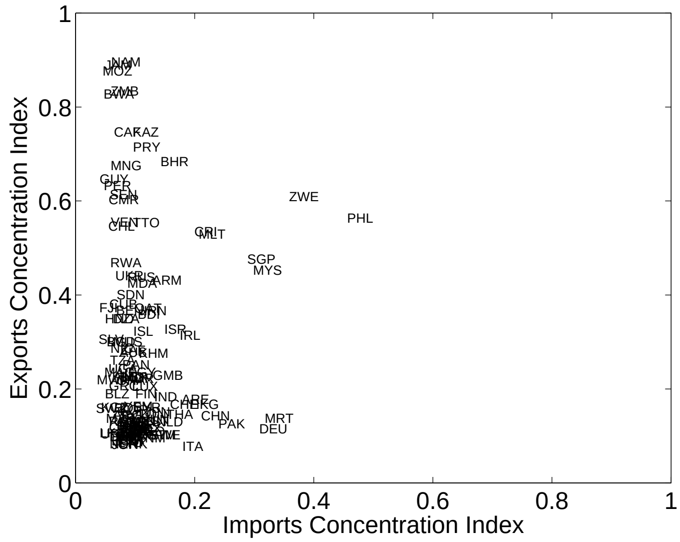


Figure A.7: Concentration index (Herfindahl), 2005 (labels)



## A.2 Solution to the Two Country, Two Factor, Continuum of Goods Case

We will start with the firm producing good $z$ in country $i$. Taking the first order conditions and combining them we obtain the relative demand for high to low educated workers in indsutry $z$,

$$\frac{h^i(z)}{l^i(z)} = \frac{w_l^i}{w_h^i} \frac{\alpha(z)}{(1-\alpha(z))}.$$

In addition, we find that the unit factor requirements for high and low educated labor, denoted by $a_h(z)$ and $a_l(z)$ are

$$a_l^i(z) = \left( \frac{w_h^i}{w_l^i} \frac{(1-\alpha(z))}{\alpha(z)} \right)^{\alpha(z)} \tag{A.1}$$

$$a_h^i(z) = \left( \frac{w_h^i}{w_l^i} \frac{(1-\alpha(z))}{\alpha(z)} \right)^{\alpha(z)-1}. \tag{A.2}$$

Note that the price of good $z$ is given by the unit cost of producing it. Therefore,

$$p(z) = w_h^i a_h^i(z) + w_l^i a_l^i(z),$$

which implies that the price is

$$p(z) = \left( \frac{w_h^i}{\alpha(z)} \right)^{\alpha(z)} \left( \frac{w_l^i}{(1-\alpha(z))} \right)^{1-\alpha(z)}.$$

From the consumer's problem we obtain that a proportional share of income is spent in the consumption of each good

$$p(z)C^i(z) = \psi W^i.$$

Recall that country one is the unique producer of goods $z \in [0, \bar{z}]$ and that country two is the unique producer of goods $z \in [\bar{z}, 1]$. Let $Z^i$ denote the set of goods produced by country $i$. Therefore, using the market clearing conditions for labor markets we have that the demand for labor is given by

$$\frac{L^i}{H^i} = \frac{\int_{z \in Z^i} a_l^i(z) y^i(z) dz}{\int_{z \in Z^i} a_h^i(z) y^i(z) dz}.$$

Combining it with the equations for labor requirement (A.1) and (A.2) and using the market clearing conditions for goods, we arrive to the following expression for relative factor endowment:

$$\frac{L^i}{H^i} = \frac{\int_{z\in Z^i}(1-z)dz}{\int_{z\in Z^i} zdz}.$$

This implies that ,

$$\frac{L^1}{H^1} = \frac{w_h^1}{w_l^1}\frac{(2-\bar{z})}{\bar{z}} \tag{A.3}$$

$$\frac{L^2}{H^2} = \frac{w_h^2}{w_l^2}\frac{1-\bar{z}}{1+\bar{z}}. \tag{A.4}$$

From the fact that the cutoff value $\bar{z}$ has the particularity of both countries facing the same production cost, we obtain the following relation among wages:

$$c^1(\bar{z}, w_h^1, w_l^1) = c^2(\bar{z}, w_h^2, w_l^2)$$

$$\left(w_h^1\right)^{\bar{z}}\left(w_l^1\right)^{1-\bar{z}} = \left(w_h^2\right)^{\bar{z}}\left(w_l^2\right)^{1-\bar{z}}. \tag{A.5}$$

And the expression of trade balance is

$$\int_{\bar{z}}^1 \psi(w_h^1 H^1 + w_l^1 L^1)dz = \int_0^{\bar{z}} \psi(w_h^2 H^2 + w_l^2 L^2)dz. \tag{A.6}$$

Equations (A.3), (A.4), (A.5), and (A.6) form a system of four equations and five unknowns. Normalizing the wage of low educated workers in country one equal to one ($w_l^1 \equiv 1$), we can reduce the previous system to one equation and one unknown

$$\frac{1}{\bar{z}} = \left(\frac{H^2}{H^1}\frac{\bar{z}}{1-\bar{z}^2}\right)^{\bar{z}}\left(\frac{L^1}{L^2}\frac{(1-\bar{z})^2}{2-\bar{z}}\right)^{\bar{z}-1} \tag{A.7}$$

When endowments are symmetric, the solution to equation (A.7) yields that $\bar{z} = \frac{1}{2}$. Recall that this is a solution as long as endowments are sufficiently different, that is, they satisfy proposition 1.

## A.3 Proof of Proposition 1

**Proof.** (Proposition 1) Using the solution of $\bar{z} = \frac{1}{2}$, from equation (A.3) we have that

$$\frac{L^1}{H^1} = 3\frac{w_h^1}{w_l^1}$$

And from equation (A.4)

$$\frac{L^2}{H^2} = \frac{1}{3}\frac{w_h^2}{w_l^2}$$

Symmetry implies that $L^1 = H^2$ and $H^1 = L^2$. This implies that in order for $\frac{w_h^1}{w_l^1} > \frac{w_h^2}{w_l^2}$ we need that

$$\frac{L^1}{H^1}\frac{1}{3} > \frac{L^2}{H^2}3$$

$$\frac{L^1}{H^1} > 3$$

Recall that $L + H = 1$, which implies.

$$L^1 > \frac{3}{4}.$$

■

## A.4 Solution to Costly Education

Consider $N$ countries with different education cost $(\theta^i)$. From the technology for transforming low educated workers into high educated ones we obtain the wage premium

$$\frac{w_h^i}{w_l^i} = \frac{1}{1-\theta^i} \quad \forall i. \tag{A.8}$$

We can order countries starting from the one with a higher education cost to the one with a lower cost. That is,

$$\theta^1 > \theta^2 > ... > \theta^N.$$

From equation (A.8) we can see that

$$\frac{w_h^1}{w_l^1} > \frac{w_h^2}{w_l^2} > ... > \frac{w_h^N}{w_l^N}.$$

The country with the lowest education cost is the country that has the lowest wage premium. Therefore, that country would be the one having the lower cost of production of the most high education intensive good. The equilibrium is going to be so that each country produces and exports the subset of goods where they have the lowest production cost. This implies that for each good $z$ the price is given by,

$$p(z) = \min\left\{c^i(z, w_h^i, w_l^i)\right\}.$$

There are $N-1$ cutoff values that determine which set of goods is each country producing. For each of these goods, there are two countries that have the same production cost:

$$c^i(\bar{z}_i, w_h^i, w_l^i) = c^{i+1}(\bar{z}_i, w_h^{i+1}, w_l^{i+1}) \quad \forall i \in \{1, N-1\}$$

$$\left(w_h^i\right)^{\bar{z}_i}\left(w_l^i\right)^{1-\bar{z}_i} = \left(w_h^{i+1}\right)^{\bar{z}_i}\left(w_l^{i+1}\right)^{1-\bar{z}_i} \quad \forall i \in [1, N-1]$$

Using the market clearing conditions for labor markets we have that the demand for labor is given by

$$\frac{L^i}{(1-\theta^i)H^i} = \frac{\int_{z\in Z^i} a_l^i(z)y^i(z)dz}{\int_{z\in Z^i} a_h^i(z)y^i(z)dz} \tag{A.9}$$

where $a_l$ and $a_h$ are factor unit requirements obtained from the producer of good $z$ problem. This implies,

$$\frac{L^1}{H^1} = \frac{\bar{z}_1(2-\bar{z}_1) - \bar{z}_{min}(2-\bar{z}_{min})}{\bar{z}_1^2 - \bar{z}_{min}^2} \tag{A.10}$$

$$\frac{L^i}{H^i} = \frac{\bar{z}_i(2-\bar{z}_i) - \bar{z}_{i-1}(2-\bar{z}_{i-1})}{\bar{z}_i^2 - \bar{z}_{i-1}^2} \quad \forall i \in \{2, N-1\} \tag{A.11}$$

$$\frac{L^N}{H^N} = \frac{\bar{z}_{max}(2-\bar{z}_{max}) - \bar{z}_{N-1}(2-\bar{z}_{N-1})}{\bar{z}_{max}^2 - \bar{z}_{N-1}^2}. \tag{A.12}$$

From the trade balance equations (2.6) we have that

$$(1-\bar{z}_1)\left(w_h^1(1-\theta^1)H^1 + w_l^1 L^1\right) = \bar{z}_1 \sum_{j\neq 1}\left(w_h^j(1-\theta^j)H^j + w_l^j L^j\right) \tag{A.13}$$

$$(1+\bar{z}_{i-1}-\bar{z}_i)\left(w_h^i(1-\theta^i)H^i + w_l^i L^i\right) = (\bar{z}_i - \bar{z}_{i-1})\sum_{j\neq i}\left(w_h^j(1-\theta^j)H^j + w_l^j L^j\right) \forall n \in \{2, N-1\} \tag{A.14}$$

And recall

$$H^i + L^i = 1 \qquad \forall i \tag{A.15}$$

Normalizing $w_l^1 \equiv 1$, equations (A.8) to (A.15) can be combined and simplified to obtain:

$$\frac{\left(1-\theta^i\right)^{\bar{z}_{i-1}}}{\left(1-\theta^1\right)^{\bar{z}_1}} \prod_{k=2}^{i-1} \left(1-\theta^k\right)^{\bar{z}_{k-1}-\bar{z}_k} =$$

$$(\bar{z}_i - \bar{z}_{i-1}) \left( \sum_{j=1}^{N} \frac{\left(1-\theta^j\right)^{\bar{z}_{j-1}}}{\left(1-\theta^1\right)^{\bar{z}_1}} \prod_{k=2}^{j-1} \left(1-\theta^k\right)^{\bar{z}_{k-1}-\bar{z}_k} \right) \qquad \forall i \in \{2, N\} \tag{A.16}$$

Equation (A.16) forms a system of $N-1$ equations an $N-1$ unknowns $(\{\bar{z}_i\}_{i=1}^{N-1})$. Once we find the cutoff values, we can pin down factor prices and the rest of the variables.

## A.5 Solution to Costly Education with Government

The solution to the extension with government expenditure follows the same procedure as the solution for the costly education scenario. For this reason here I will only stress the differences. Since consumers do not pay for the government good, the implications of their utility maximizing problem remain the same. Also, producers of all goods $z$ face the same problem and the cutoff values do not change. What is different now is the labor market clearing conditions, since workers are employed in the production of all $z$ goods and in the production of the government good:

$$\int l^i(z)dz + l^i(g) = L^i$$

$$\int h^i(z)dz + h^i(g) = (1-\theta^i)H^i$$

This implies that the relation expressed in equation A.9 is transformed to

$$\frac{L^i - l^i(g)}{(1-\theta^i)H^i - h^i(g)} = \frac{\int a_l^i(z)y^i(z)dz}{\int a_h^i(z)y^i(z)dz}.$$

Which implies

$$\frac{L^1 - l^1(g)}{(1-\theta^1)H^1 - h^1(g)} = \frac{1}{1-\theta^1} \frac{\bar{z}_1(2-\bar{z}_1) - \bar{z}_{min}(2-\bar{z}_{min})}{\bar{z}_1^2 - \bar{z}_{min}^2} \tag{A.17}$$

$$\frac{L^i - l^i(g)}{(1-\theta^i)H^i - h^i(g)} = \frac{1}{1-\theta^i}\frac{\bar{z}_i(2-\bar{z}_i) - \bar{z}_{i-1}(2-\bar{z}_{i-1})}{\bar{z}_i^2 - \bar{z}_{i-1}^2} \quad \forall i \in \{2, N-1\} \tag{A.18}$$

$$\frac{L^N - l^N(g)}{(1-\theta^N)H^N - h^N(g)} = \frac{1}{1-\theta^N}\frac{\bar{z}_{max}(2-\bar{z}_{max}) - \bar{z}_{N-1}(2-\bar{z}_{N-1})}{\bar{z}_{max}^2 - \bar{z}_{N-1}^2}. \tag{A.19}$$

Factor demand from the government sector is obtained from the cost minimization problem,

$$l^i(g) = \bar{G}^i\left(\frac{1}{1-\theta^i}\frac{(1-\alpha(g))}{\alpha(g)}\right)^{\alpha(g)} \tag{A.20}$$

$$h^i(g) = \bar{G}^i\left(\frac{1}{1-\theta^i}\frac{(1-\alpha(g))}{\alpha(g)}\right)^{\alpha(g)-1}. \tag{A.21}$$

Combining equations (A.17) to (A.21) with

$$H^i + L^i = 1 \qquad \forall i$$

determines the solution.

# Appendix B

# Appendix to Chapter 3

## B.1 Solution to the Natural Resource Extension

Consider $N$ countries with different education cost ($\theta^i$) and different natural resources endowment ($\bar{E}^i$). From the technology for transforming low educated workers into high educated workers we obtain the wage premium

$$\frac{w_h^i}{w_l^i} = \frac{1}{1-\theta^i} \quad \forall i. \tag{B.1}$$

As in the case with no natural resources, we can order the countries starting from the one with a higher education cost to the one with a lower cost. That is,

$$\theta^1 > \theta^2 > ... > \theta^N,$$

which implies

$$\frac{w_h^1}{w_l^1} > \frac{w_h^2}{w_l^2} > ... > \frac{w_h^N}{w_l^N}.$$

The country with the lowest education cost is the country that has the lowest wage premium. Therefore, that country would be the one having the lower cost of production of the most high education intensive good. The equilibrium is going to be so that each country produces and exports the subset of goods where they have the lowest production cost. This implies that for each good $z$ the price is given by,

$$p(z) = min\left\{c^i(z, w_h^i, w_l^i)\right\}$$

There are $N-1$ cutoff values that determine which set of goods is each country producing. For each of these goods, there are two countries that have the same production cost.

$$c^i(\bar{z}_i, w_h^i, w_l^i) = c^{i+1}(\bar{z}_i, w_h^{i+1}, w_l^{i+1}) \quad \forall i \in \{1, N-1\}$$

$$\left(w_h^i\right)^{\bar{z}_i}\left(w_l^i\right)^{1-\bar{z}_i} = \left(w_h^{i+1}\right)^{\bar{z}_i}\left(w_l^{i+1}\right)^{1-\bar{z}_i} \quad \forall i \in [1, N-1]$$

Combining it with (B.1) and normalizing $w_l^i \equiv 1$ we obtain

$$w_l^i = \frac{\left(1-\theta^i\right)^{\bar{z}_{i-1}}}{\left(1-\theta^1\right)^{\bar{z}_1}} \prod_{j=2}^{i-1} \left(1-\theta^j\right)^{\bar{z}_{j-1}-\bar{z}_j} \qquad \forall i \in [2, N] \tag{B.2}$$

From the aggregate consumer's problem we obtain that the demand for each variety $z$ is given by,

$$p(z)C^i(z) = \frac{\gamma\psi W^i}{\gamma(\psi-1)+1}.$$

And the demand for the natural resource good is

$$p(e)C^i(e) = \frac{(1-\gamma)W^i}{\gamma(\psi-1)+1}.$$

From the natural resource good minimization cost problem we obtain the following relation between factor prices:

$$\left(\frac{r^i}{r^j}\right)^{\beta} = \left(\frac{w_l^j}{w_l^i}\right)^{1-\beta} \qquad \forall i, j. \tag{B.3}$$

And we also obtain the requirement of the natural resource endowment to produce $y^i(s)$ units of the natural resource good,

$$l^i(e) = \frac{y^i(e)}{A}\left(\frac{r^i}{w_l^i}\frac{(1-\beta)}{\beta}\right)^{\beta} \tag{B.4}$$

$$E^i = \frac{y^i(e)}{A}\left(\frac{r^i}{w_l^i}\frac{(1-\beta)}{\beta}\right)^{\beta-1}.$$

Finally, we obtain the price of the natural resource good,

$$p^i(e) = \left(\frac{w_l^i}{(1-\beta)}\right)^{1-\beta}\left(\frac{r^i}{\beta}\right)^{\beta}. \tag{B.5}$$

From market clearing conditions we obtain that what is produced of one specific traded good $z$ is equal to the sum of the demand for that good in each country,

$$y^i(z) = \sum_i \gamma\psi \left( \frac{W^i}{\gamma(\psi - 1) + 1} \right) \frac{1}{p(z)}$$

In addition, the market clearing condition for the natural resource states that global supply is equal to global demand,

$$\sum_{i=1}^{N} \frac{(1-\gamma)W^i}{\gamma(\psi - 1) + 1} \frac{1}{p(s)} = \sum_{i=1}^{N} y^i(s)$$

which implies,

$$\sum_{i=1}^{N} \frac{(1-\gamma)\left(w_l^i + r^i \bar{S}^i\right)}{\gamma(\psi - 1) + 1} \frac{1}{p(s)} = \sum_{i=1}^{N} A\bar{E}^i \left( \frac{r^i}{w_l^i} \frac{(1-\beta)}{\beta} \right)^{1-\beta}. \tag{B.6}$$

The value of a country's imports is equal to the value of what that country exports to the rest of the world. From the trade balance equation we obtain

$$(z_{max} - z_{min})\gamma\psi W^i + (1-\gamma)W^i - (\gamma(\psi - 1) + 1)\, p(s) y^i(s) = (\bar{z}_i - \bar{z}_{i-1}) \sum_i \gamma\psi W^i, \tag{B.7}$$

where

$$y^i(s) = E^i \left( \frac{r^i}{w_l^i} \frac{(1-\beta)}{\beta} \right)^{1-\beta},$$

and

$$W^i = w_l^i + r^i E^i.$$

Finally, the market clearing conditions for labor imply

$$\frac{L^i - l^i(s)}{(1-\theta^i)H^i} = \frac{\int a_l^i(z) y^i(z) dz}{\int a_h^i(z) y^i(z) dz},$$

where $a_l^i(z)$ and $a_h^i(z)$ are the labor requirements to produce one unit of good $z$. This implies

$$\frac{L^1 - l^1(e)}{H^1} == \frac{\bar{z}_1(2 - \bar{z}_1) - \bar{z}_{min}(2 - \bar{z}_{min})}{\bar{z}_1^2 - \bar{z}_{n-1}^2} \tag{B.8}$$

$$\frac{L^i - l^i(e)}{H^i} == \frac{\bar{z}_i(2 - \bar{z}_i) - \bar{z}_{i-1}(2 - \bar{z}_{i-1})}{\bar{z}_i^2 - \bar{z}_{i-1}^2} \quad \forall i \in \{2, N-1\} \tag{B.9}$$

$$\frac{L^N - l^N(e)}{H^N} == \frac{\bar{z}_{max}(2 - \bar{z}_{max}) - \bar{z}_{N-1}(2 - \bar{z}_{N-1})}{\bar{z}_{max}^2 - \bar{z}_{N-1}^2}. \tag{B.10}$$

**Algorithm**

1. Find cutoff values $\bar{z}$

   (a) Initial guess of all the cutoff values $\bar{z}$

   (b) Normalize $w_l^1 \equiv 1$ and compute all $w_l^i$using equation (B.2)

   (c) Compute all $w_h^n$ using (B.1)

   (d) Find $r^i$ and $p(r)$:

      i. Initial guess for $r^1$

      ii. Compute the rest of $r$'s using (B.3)

      iii. Compute $p(s)$ using (B.5)

      iv. Check if equation (B.6) holds (supply equals demand)

      v. If it does not hold update the guess for $r^i$ and repeat until equation (B.6) holds

   (e) Verify if the initial guess was a solution for the cutoff values using (B.7)

   (f) If it does not hold, update the guess for the cutoff values $\bar{z}$ and repeat until equation (B.7) holds

2. Obtain $l^i(e)$ using equation (B.4)

3. Obtain $H^i$and $L^i$using equations (B.8) to (B.10) and the fact that $H^i + L^i$ equals to one for all $i$

## B.2 Figures

Figure B.1: Exports education intensity vs percent of population with tertiary education (labels)

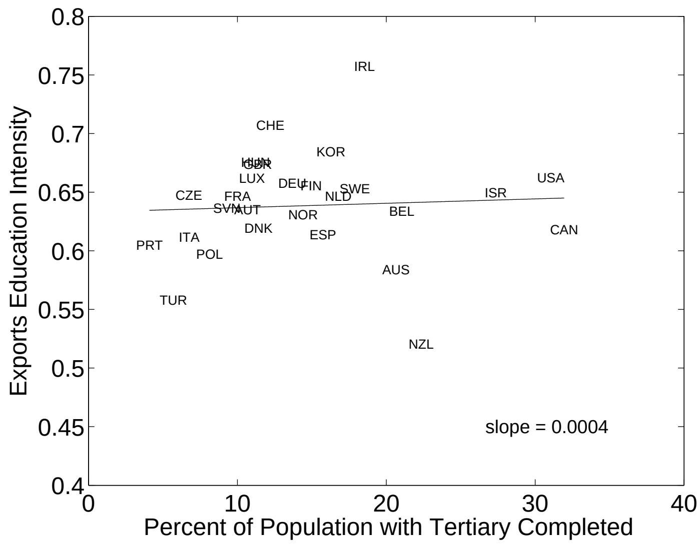


Figure B.2: Imports education intensity vs percent of population with tertiary education (labels)