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Presentación

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Carlos Caballero Argáez
Director
Escuela de Gobierno

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Abstract

In this paper I develop a framework that provides a simple and explicit mechanism for understanding and quantifying the role of trade and technology in the rise of the skill premium in developing countries. The distinguishing features of the model can be summarized as follows: Under capital-skill complementarity, a rise in the demand for capital will increase the wage gap. Three different forces may spur demand for capital. First, increased trade, which may raise output as well as lower the cost of imported machinery and equipment. Second, technological change, understood as a decrease in the price of capital. Finally, structural reforms may also affect the demand for capital by changing its relative price. Based on the model, an empirical methodology is developed to quantify the contribution of each of these factors to the rise in the skill premium of the Colombian manufacturing sector. I find that trade liberalization accounted for a 17% of the rise in the skill premium and exogenous technological change explains 32%. The rest is explained by other structural reforms implemented as part of the general process of globalization, mainly changes in the exchange rate and foreign investment regimes.

Resumen

En este trabajo desarrollo un modelo que permite entender y cuantificar el papel jugado por la apertura comercial y el cambio tecnológico global en el incremento del diferencial salarial entre la mano de obra calificada y no calificada, en países en desarrollo. Las características principales del modelo se pueden resumir así: si el trabajo calificado es complementario con el capital (maquinarias y equipos), un incremento en la demanda por capital hará que aumente la demanda por mano de obra calificada y con ello su retorno (el salario de los trabajadores calificados), lo que a su vez incrementaría la brecha salarial. Tres fuerzas diferentes pueden presionar la demanda por capital. Primero, una mayor integración comercial, si esta se traduce en crecimiento del producto y en una reducción de los aranceles sobre el capital importado. Segundo, un cambio tecnológico global, entendido como una caída en el precio del capital por unidad de eficiencia del mismo. Finalmente, otras reformas estructurales también pueden afectar el precio del capital, al cambiar su precio relativo; por ejemplo, aquellas reformas que afecten la tasa de cambio. Con base en este modelo, se diseña una metodología para cuantificar la contribución de cada uno de estos factores al incremento de la brecha salarial de la industria manufacturera colombiana. Los resultados sugieren que la liberalización comercial explica un 17% del incremento y el cambio tecnológico global hace lo propio en un 32%. El resto se explica por otras reformas implementadas como parte del proceso de globalización de la economía colombiana, en particular las reformas al régimen cambiario y de capitales.

1. Introduction

Empirical studies have found coincidence between expanding trade and increased wage inequality in Latin America. Kremer and Maskin (2003), Wood (1997), and Robbins (1996) provide reviews of this evidence. Colombia has not been an exception.

From the perspective of standard trade theory, these results are puzzling. The simplest version of the Heckscher-Ohlin model predicts that expanding trade should reduce the wage gap in unskilled-intensive countries, by shifting production towards unskilled intensive industries. Other more complex versions of the Heckscher-Ohlin model may account for this rise in inequality, mainly if Latin America could be considered globally skill abundant (Wood, 1997) or if the unskilled intensive sectors were more protected before the reform, as was the case with many Latin American industries (Revenga, 1997; National Bureau of Economic Research, 2001; National Bureau of Economic Research, 1999). The main caveat of these theories is that the mechanism at work is a shift of production between industries of different skill intensities or protection levels. However, the evidence for Latin America suggests this has not occurred (Sánchez-Páramo & Schady, 2003). In particular, in the case of Colombia, Attanasio, Goldberg and Pavcnik (National Bureau of Economic Research, 2003), Cárdenas and Bernal (1999), and Santa María (Departamento Nacional de Planeación, 2001) find that interindustry production shifts were small, and interestingly they were smaller during the trade reform that in the pre-reform period[1]. Similarly, Eslava, Haltiwagner, Kugler, and Kugler (National Bureau of Economic Research, 2004), using plant level data, find that increased productivity was due to reallocation within industries and across businesses. Fernández (2007), using plant level data, also finds evidence that trade generated within plant productivity gains that appeared to be associated with increased skill labor intensity.

All this evidence suggests that, if expanding trade is the cause of the rise in the wage gap experienced by many Latin American countries, the Heckscher-Ohlin adjustment mechanism is not the driving force. This has lead these studies to conclude that it was not trade but exogenous technological change that generated the rise in the wage ratio, and that if trade had an impact it must have been by promoting technological adoption.

In this paper I develop a framework that provides a simple and explicit mechanism for understanding the role of increasing trade and technological change in the rise of the skill premium in small or developing economies, and an empirical methodology to quantify the contribution of each. The model relies on two key elements. The first one is capital-skill complementarity, which is not imposed but estimated. The second one is the effect of trade, technology, and other structural reforms, on the demand for capital.

[1] Moreover, Cárdenas and Bernal find no correlation between nominal tariffs in the pre-reform period and skill intensities.

Trade can increase the demand for capital by lowering the cost of imported machinery and technological change can make capital cheaper or more efficient. Finally, other structural reforms that were adopted in Latin America as part of the process of globalization also affected the price of capital, mainly through their effects on the exchange rate. Under capital-skill complementary a rise in the demand for capital translates into a wider wage gap.

I depart from the Heckscher-Ohlin model of trade, which relies on interindustry shifts of production among firms with different skill intensities. Instead, I use the new trade models that rely on firm heterogeneity. In particular, I use the model developed by Eaton and Kortum (2002), and expanded in Bernard, Eaton, Jensen and Kortum (2003). This framework allows me to link rising trade and increasing demand for capital via scale effects: if rising trade spurs output, then under constant returns to scale this should promote the demand for capital. Additionally, I assume that capital is imported instead of domestically produced, which is more in line with the reality of developing countries. Having capital being imported, allows yet another mechanism by which trade can spur the demand for capital: reduced barriers to imported capital goods directly reduce the price of capital an increase its demand.

Technological change is modeled as in Krusell, Ohanian, Ríos-Rull, and Violante (2000): technical change brings about a decrease in the price of capital per efficiency unit[2]. A fall in the price of capital should then increase the skill premium by increasing the demand for capital. Since capital is imported from developed countries I use the price of machinery and equipment in the US as a measure of technological change, which registered a decrease of 15% between 1990 and 2000. Finally, the third mechanism that promoted more capital-intensive production technologies and a rise in the wage gap was other reforms implemented as part of the broader process of globalization, mainly changes in the exchange rate and foreign investment regimes. These reforms generated an appreciation of the exchange rate that made capital imports cheaper, thus favoring investment.

Using data for the Colombian manufacturing sector, I decompose the fraction of the rise in the skill premium due to increased trade, technological change, and other structural reforms. I find that capital is indeed complement to skilled labor. The results also indicate that rising trade, technological change, and structural reforms played an important role in the significant rise of capital purchases evidenced by the Colombian manufacturing sector. The results suggest that although scale effects are important, the reduction of import barriers and export barriers on goods acted in opposite directions, almost canceling each other. On the other hand, the lower cost of capital brought about by lower import tariffs on capital

[2] The authors argue that technological change has occurred in the form of a reduction in the price of capital, and that capital-skill complemetarity has generated a spur in the demand for skills, thus increasing the wage ratio. They test their hypothesis by estimating a general equilibrium model with three factors of productions (skilled, unskilled and capital) and then performing counterfactual experiments. They find that most of the rise in the skill premium can be accounted for by variations in observable inputs.

goods had a more important effect on capital purchases. The results also show that technological change accounted for a significant increase of total capital purchases[3]. Finally, the appreciation of the exchange rate brought about by other structural reforms explains a very large proportion of the increase in the demand for capital, and accounts for half of the rise in the wage ratio.

Finally, in the context of the reforms, Colombia presents itself as an excellent case study for several reasons. The first is that it was among the Latin American countries that registered significant increases in the wage ratio[4]. The second is that is has available data on skilled and unskilled wages and employment, and more importantly on imports of capital goods for the manufacturing sector. Finally, it was one of the countries that implemented extremely rapid and profound trade liberalization and structural reforms.

The next section describes the trade and structural reforms, as well as the stylized facts on wages, employment, and capital. Section 3 presents the model. Section 4 describes the calibration strategy and its results. In Section 5 the decomposition exercises are described. Section 6 concludes.

2. Related Literature

Although there is a fair amount of papers dealing with the issues of capital skill complementary and rising wage inequality, and there are also several papers that analyze trade and technology adoption, to my knowledge this is the first paper that presents a unified framework analyzing both mechanisms.

Capital-skill complementarity and its impact on the skill premium has been previously analyzed both for Colombia and other countries. Cárdenas and Gutiérrez (1997), by estimating a translog production function using sector level data for the Colombian manufacturing sector, find evidence of capital-skill complementarity. Krusell, Ohanian, Rios-Rull, and Violante (2000) find evidence of capital skilled complementarity for the U. S., within the context of a nested CES production function. Flung and Hercowitz (2000), using a panel of several countries, find a strong effect of machinery investment on the relative demand for skilled labor and on relative wages. Duffy, Papageouriou, and Pérez-Sebastian (2004) estimate a nested CES production function, also finding evidence of capital-skill complementarity for a panel of developing and developed countries. The first three papers cited above also find that this complementarity is responsible for increases in the wage ratio. None of the above mentioned papers

[3] Acemoglu and Linn (2004) and Acemoglu (1998) endogenize the bias of technical change. The first one through market size for product and the second through relative size of the users of the technology (skilled or unskilled). While this is a relevant extension for Northern countries that develop technology, it is unlikely that relative abundance of skills or the size of the market in southern countries (by itself) has a significant impact on technological development.

[4] See World Bank (2003), Chapter 6.

considers trade as one of the forces promoting technological adoption, all of them focus instead on factors affecting the price of capital.

On the other hand, scale effects (i.e. larger markets) brought about by increasing trade have been considered previously as a driving force promoting technological adoption, mainly by Yeaple (2005), Manasse and Turrini (2001), and Eckholm and Midelfart (Centre for Economic Policy Research, 2001). The set-up of these papers, however, differs slightly from this paper. These papers concentrate on north-north trade, and results do not extend to north-south trade[5]. In addition, while in these papers trade induces a switch from a low-fixed-cost but high-marginal-cost technology to a high-fixed-cost but low-marginal-cost technology, in this paper trade affects the overall demand for capital. None of the above mentioned papers tries to empirically disentangle what is due to trade-induced changes in technology and what is due to exogenous technological change.

Several other papers have proposed new channels through which expanding trade can increase the wage gap in Southern economies. Feenstra and Hanson (1996), Jones (2000), and Kremer and Maskin (2003) have shown that price changes can encourage Northern firms to fragment, reallocating or outsourcing to the south the stages or products that are more unskilled intensive. These products or stages, however, end up being relatively skilled intensive in the south, thus increasing the skill premium. Empirical evidence on the relevance of this mechanism is controversial, as shown by Verhogeen (2004). Instead, his paper proposes "differential quality upgrading" as the main mechanism by which wage inequality rises. Verhogeen shows that incentives to trade with Northern economies may induce Southern firms to shift production to higher quality products demanded in the north. If production of quality is sufficiently sensitive to skills then the wage ratio will rise. He tests this hypothesis for Mexico using an exchange rate shock, a devaluation of almost 50%. One fact, however, makes this hypothesis not easily extendable to the Colombian case: Colombia experienced an appreciation of the exchange rate of 30%, which would have generated a decrease in the wage ratio according to this hypothesis. In this sense, the model presented herein might be complementary to the models mentioned above by presenting an alternative mechanism by which trade might have increased the wage ratio.

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[5] The argument can be sketched as follows: under monopolistically competitive markets or Cournot competition, globalization can rise skill intensity via scale effects. Low unit cost (unskilled labor) is associated with high fixed cost (in the form of skilled labor). Globalization is seen mainly as a reduction in trade barriers or export costs. Investment in the low unit cost technology is positively associated with the amount of output. With symmetric countries the decrease in price brought about by globalization boosts demand. This effect dominates the decrease in market share from competition, and so demand for skills increases. Neary (2000) on the other hand develops a general equilibrium oligopoly model with Cournot competition, in which the threat of trade generates overinvestment in technology to keep foreign competition out of the market. Investment takes the form of skilled labor. However, the implications of this model may not carry over in a north-south set-up. If the north has a lower cost structure and firms engage in Cournot competition, the north will end up being a net exporter, with the result that Southern firms will actually decrease technology adoption. Dasgupta and Stiglitz 1980 show that under an oligopolic market technology adoption will depend on market shares, hence if the north is a net exporter, firms in the south will see their market share reduced, and will reduce their level of technology. While in these papers gains from north-north trade unambiguously spur output, this is not the case in the model put forth in this paper, where the decrease in domestic demand might be big enough to offset the gains in foreign markets. Moreover, unilaterally decreasing barriers to exports might actually decrease the wage ratio.

3. Stylized Facts

3.1. Trade liberalization and structural reforms

The pace of structural reforms in Latin America was remarkable in the 1990's. Most countries reduced substantially tariff and non-tariff protection while subregional free trade agreements were signed at an unprecedented pace. Capital account transactions, especially in relation to foreign investment, were liberalized, and labor market reforms introduced more flexibility to the labor market[6].

Perhaps no other country adopted the reform package as rapidly and comprehensively as Colombia. Since 1990, a series of laws drastically modified the regimes related to trade, foreign exchange rate, foreign investment, social security, labor, and health. The reforms were motivated by a generalized disenchantment with the import-protection export-promotion regimes that had promoted inefficiencies and had failed to generate growth. Colombia's trade and balance of payments policies between 1980-2000 can be characterized by four different types of regimes.

Between 1981-1985, and after timid attempts of trade liberalization, an increased protection policy was adopted. During these years, most items were transferred to prior-licensing regimes and many imports were prohibited. Average nominal tariffs on capital goods jumped from 22% to 33%, and those on other manufactured imports went from 27% to 55%. Counter-trade schemes which forced importers to demonstrate that they had exported new products (or to new markets) in order to have access to foreign exchange were also adopted. These policies were the result of the debt crisis that forced severe balance of payments restrictions and prompted a radical macroeconomic adjustment.

By 1986, the economy was again under control and a moderate trade liberalization was started during the Barco administration (1986-1990). Although the reforms were concentrated on simplifying the import protection regime and lowering the dispersion of tariffs, average tariffs on capital goods and raw materials were reduced, the former from 45% to 18%.

But it was only until the Gaviria administration (1990-1994) that mayor changes in trade, foreign direct investment, and exchange rate regimes took place. Average tariffs were lowered to 12% and tariffs on imports of capital goods to 10%. Non trade barriers such as prior licensing and prohibitions were removed. By the end of 1992, 99% of items were under the free import regime. On the economic integration side, several subregional free trade agreements were signed, the Andean Pact was renewed,

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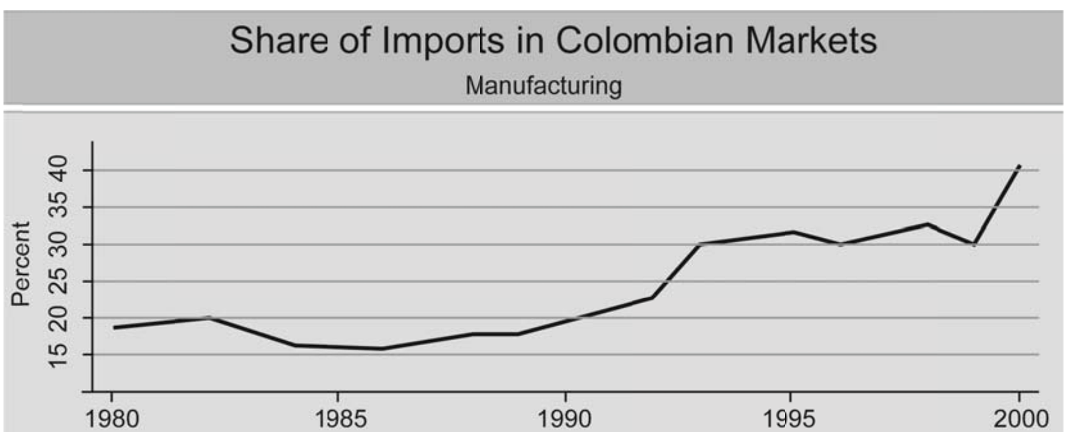
[6] For a complete review of these reforms see Fedesarrollo (1995); Homes, Montenegro, and Roda (1994), and Vallejo (1999).

Colombia signed the GATT in 1993, and enter the World Trade Organization in 1995[7]. Preferential access to US and EU markets was granted.

The exchange rate, previously controlled by the central bank, was allowed to float within bands, and restrictions on foreign direct investment and on capital investments by nationals abroad were eliminated. A series of privatizations of public services also took place[8]. These reforms coincided with a decrease in the profitability of investment abroad, so that a massive inflow of capital was observed.

From 1995 onward this policies have remained in place and no deepening of trade liberalization has taken place. Figure 1 illustrates the evolution of imports, exports and the exchange rate. Import penetration of manufactured goods rose rapidly and steadily during and after the last period of trade liberalization. Exports, on the other hand, started to rise during the first period of trade liberalization (1986-1989), due probably to the devaluation of the real exchange rate. The lower plot of the figure illustrates the evolution of the real exchange rate, which appreciated 30% during the first half of the 90's. Surprisingly, exports continued to increase.

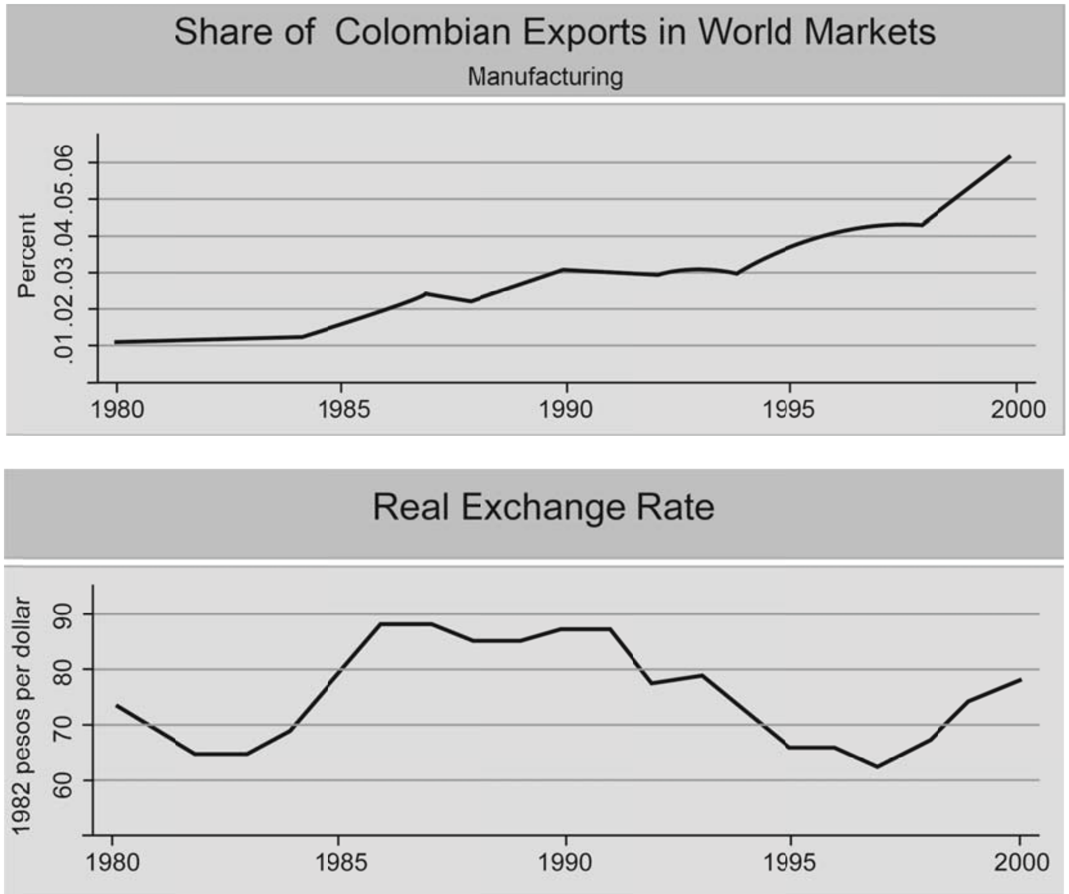
Figure 1



[7] The most important being the free trade agreement G-3 with Venezuela and Mexico signed in 1990 and fully effective in 1995. Others included trade agreements with Chile (1994), Argentina (1993), and Panama (1993).

[8] Mainly telecommunications and distribution of energy.

(Continued)

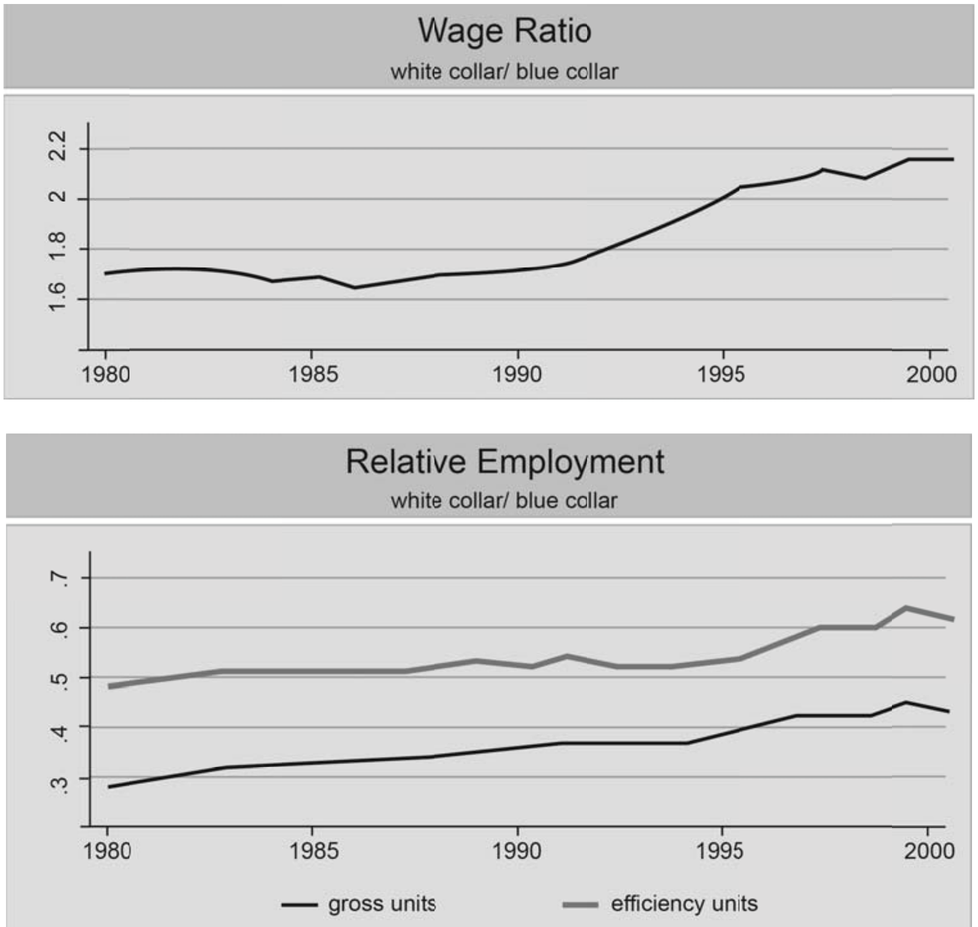


Source: Own calculations with data from Robert C. Feenstra et al. (1997), World Bank, OECD, National Planning Department, and Colombian Central Bank.

3.2. Manufacturing wages, investment, and employment

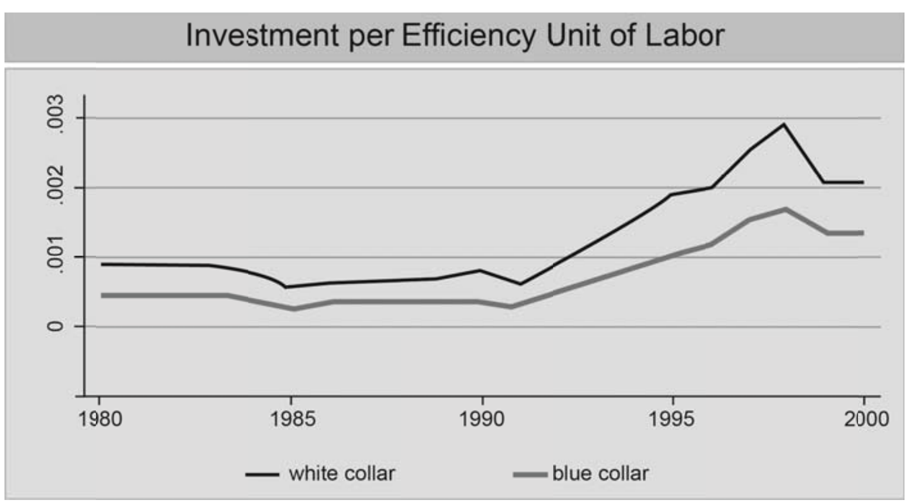
Figure 2 illustrates the evolution of the wage ratio and relative employment between white collar and blue-collar workers. The period after the trade liberalization was characterized by a rapid increase of the wage ratio, which rose 30% after 1986, with the steepest rise in the first half of the 90's. Relative employment, however, started rising only after 1995, and at a much lower pace. The bottom plot of the graph shows the evolution of relative employment both in number of workers and in efficiency units. This last variable takes into account the level of education of the labor force by multiplying the number of blue and white collar workers by their average years of education. Average years of education were obtained from Household Surveys, while the number of workers in each category comes directly from the Annual Manufacturing Census. It is apparent that not only did relative employment increase but also the relative level of education of white and blue collar workers.

Figure 2



Source: Own calculations with data from Monthly Manufacturing Survey and Household Survey - DANE.

Figure 3



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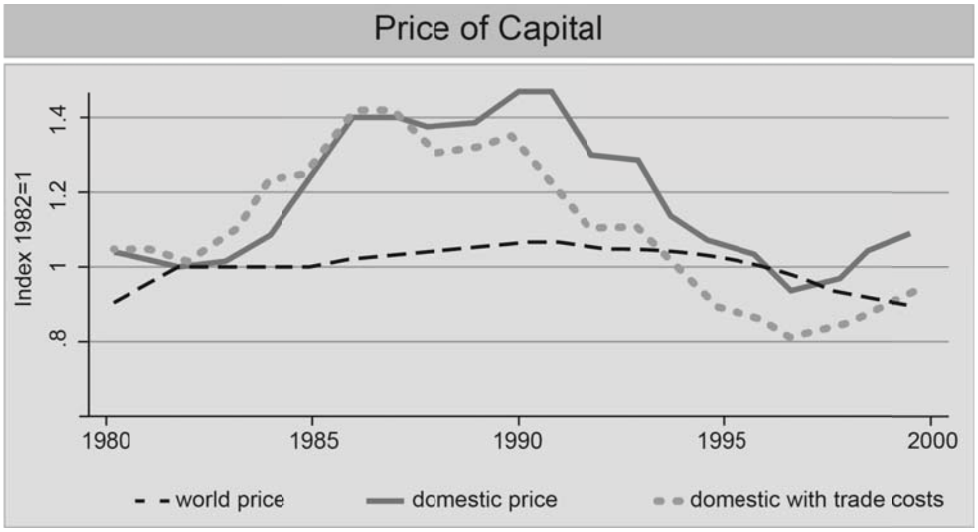

Source: Own calculations with data from Monthly Manufacturing Survey, NIPA and Colombian Central Bank.

Finally, figure 3 shows imports of machinery and equipment per worker as well as the estimated price of capital and its components[9]. Imports of machinery and equipment accounted for 73% to 83% of total investment (excluding structures) during the period analyzed[10]. As can bee seen, investment per worker tripled after 1990. The lower panel illustrates the behavior of the price index of capital. The dashed line represents the price of capital in US dollars, which is a measure of technical change. It corresponds to the price of private investment in machinery and equipment reported by the US National Income and Product Accounts (NIPA). After a steady but small increase between 1980 and 1990, this price saw a decrease of 15%. The solid line corresponds to the price in domestic currency of capital before tariffs, thus taking into account exchange rate effects, which were significant. Finally the dotted line presents the price index in domestic currency including trade costs. The decrease in the price of capital in the US coincided with the second period of trade liberalization. This fact together with the appreciation of the exchange rate, meant that between 1986 and 1998 the total cost of imported capital had fallen 42%.

Perhaps the most prominent phenomenon during the reform was the sharp increase of imported capital goods (and with it in total investment), during a time when domestic demand was being displaced by imports while exports were increasing more modestly. This suggests that the rise in capital investments was very much related to the decrease in its price due to technological change (viewed as reduction in the US price of capital), lowering of trade barriers and exogenous exchange rate appreciation. The behavior of imports of capital goods is surprisingly matched by the behavior of the wage ratio. In what

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[9] Imports of machinery and equipment include transport equipment. Capital structures are excluded.

[10] With a standard deviation of 5 percentual points.

follows I present a general equilibrium model that allows me to decompose the rise in the wage ratio in its trade-induced and exogenous technology sources.

4. The Model

In formalizing the mechanisms by which trade and technology might induce a rise in the skill premium within industries and firms in developing countries, I draw on two elements of the existing literature. As mentioned before the traditional Heckscher-Ohlin model relies on homogeneous products with different skill intensities for trade to affect the wage ratio. This implies that it is shifts between industries of different skill-intensities that ultimately lead to changes in the wage ratio, a feature that has been consistently rejected empirically. A model that can account for within industry shifts thus requires producer heterogeneity with either differing or fixed skill intensities. I opt by extending the Bernard, Eaton, Jensen, and Kortum (2003) model of imperfect competition (henceforth BEJK) to allow for multiple factors of production: skilled labor, unskilled labor, and capital, but I set-up the model in a north-south framework, so that each individual firm in the south has a negligible effect on input prices or demand in the north[11]. I believe this to be more in line with the reality of small developing countries such as Colombia. To allow for capital-skill complementarity and exogenous embodied technological change I combine inputs through a CES production function as in Krusell et al. (2000). Two other features are worth noting. Capital is imported from the north, a feature that, as explained in the previous section, is empirically more adequate. Second, to preserve tractability I assume full depreciation so that it is investment rather than the stock of capital that will determine the change in the wage ratio, which differs from Krusell et al (2000). This formulation allows for a realistic yet very tractable way to decompose the rise in the skill premium. The next section borrows heavily from BEJK (2003).

4.1. The Economy and Technology

There are 2 goods, y is a differentiated manufacturing good and x is a homogenous agricultural good, such as food[12]. Both goods are traded. There are two geographical areas, the north N, which will be empirically matched to rest of the world, and the south S, which will be empirically matched to Colombia. I will refer to the south also as the domestic economy. Although this is admittedly a crude

[11] I could have also opted by extending the Eaton and Kortum (2002) perfect competition model or the Melitz (2003) monopolistic competition model. But as shown by Eaton and Kortum (2004), the three can be seen as as special cases of a more general version of the model, with differences mainly determined by the functional form of constant parameters. I opt for the Bertrand competition version of the model as I consider it more realistic than perfect competition, yet simpler to implement empirically than the monopolistic competition version, which has fixed trade costs and endogenous available varieties.

[12] Small x (small y) denotes one unit of agricultural (manufacturing) output, whereas capital X (capital Y) denotes total agricultutal (manufacturing) output.

approximation, OECD or 'northern countries' account for 64% of Colombian exports, and the 5 main northern trading partners alone account for 55% of imports.

Manufactured goods can be transported between countries at a cost. Trade costs are of the iceberg type. Delivering one unit of a good to country n from country i, requires shipping $d_{n1} \geq 1$ units. This includes all tariff and non tariff barriers to trade as well as transport costs due to geographic distance. For simplicity I will assume that there are no costs for trading agricultural goods.

Production of manufactures takes place using unskilled labor u, with wage w_u; skilled labor s, with wage w_s; capital k, with price w_k; and intermediates v, which are a representative bundle of final goods, with price index P. The variables will be stared whenever they refer to the corresponding prices in the North (*e.g.* $w_s^*, w_u^*, w_k^*, Pw^*$). There is a continuum of manufactured goods $j \in [0, 1]$.

Each country has multiple potential producer of each good with varying degrees of efficiency. More efficient producers will convert a bundle of inputs into larger output at constant returns to scale. Except for this heterogeneity in efficiency, manufacturing producers in a country face the same production function and input prices. Firms compete in prices, so that each good is produced only by the lowest cost supplier.

I will consider embodied technological change, which will be defined as a reduction in the price of capital per efficiency unit[13]. Capital is produced only in the north. Southern firms import capital. This implies that capital will be cheaper in the north, since firms do not incur in trade costs. Instead, the price of capital in the south will be composed of two elements: p^k, which will be the price of capital in the north, and d^k, which will be the cost of transporting capital to the south; that is, $\mathrm{w}_k = p^k d^k$. In the north the price of capital will be $\mathrm{w}_k^* = p^k$.

This means we need to consider three different trade costs: The first is the cost of importing capital d^K. Only southern firms are subject to this cost. The second is the cost of transporting manufactured goods to the south from the north d_{SN}, which will affect the price of southern imports of manufactures. The third will be the cost of transporting manufactured goods to the north from the south d_{SN}, which will affect the price of southern exports. I allow trade costs of goods and machinery to differ so that $d^K \neq d_{SN}$

Finally, food is produced using only land L, with rental rate w_L. Total available units of factors are denoted by capital letter (U, S, L).

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[13] In this setting research and technology can be understood as discoveries that reduce the price of capital. The model allows also for disembodied technological change. This would correspond to discoveries that increase the overall efficiency in the production of goods. In other words, for the same cost of a bundle of inputs (including the price of capital per efficiency unit), more overall efficiency translates into more output.

4.2. Households

There is a single household with S skilled members which earn wage w_S and U unskilled members that earn wage w_U. The household owns a fixed amount of land L, for which it gets a per unit rental rate w_L. The household also receives remittances from abroad R, which I consider exogenous and the profits from the manufacturing firms Π. The household's total income is given by $I = Sw_s + Uw_u + \Pi + Lw_s + R$.

Household utility is log linear in food and the composite commodity of manufactures:

$$U\left(X, Y^d\right) = (1-\mu)\log X + \mu \log Y^d$$

with the composite community of manufactures given by: $Y^d = \left(\int_0^1 y^d\ (j)\frac{\sigma-1}{\sigma}\ dj\right)^{\frac{\sigma-1}{\sigma}}$ and $\sigma > 1$. This implies that the household spends a constant fraction $1-\mu$ of its income on food and a fraction μ, on manufactures. The price elasticity of demand perceived by the manufacturing firms is σ. As in the Dixit-Stiglitz formulation, this implies that demand for each manufactured good is:

$$y^d(j) = \frac{p(j)^{-\sigma}}{\int_0^1 p^{j^{1-\sigma}}}\ \mu I$$

and the price index and hence the price for the composite commodity Y will be:

$$P = \left(\int_0^1 p(j)^{1-\sigma} dj\right)^{\frac{1}{1-\sigma}}$$

Total spending in manufactures PY^d will be given by:

$$PY^d = \mu I \qquad (1)$$

4.3. The Manufacturing Sector: Market Structure and Technology

Each country has many potential producers of each good, with varying levels of technical efficiency. The k^{th} most efficient producer of good j, in country n can convert one bundle of inputs (factors of production and intermediates) into a quantity $Z_{kni}(j)$ of good j at constant returns to scale.

Production of manufactures requires capital, skilled labor, unskilled labor and intermediates. Intermediates are a representative bundle of manufactured goods with price equal to the price index P. The k^{th} most efficient producer of good j, in country i can thus deliver one unit of good j, to country n at a cost:

$$C_{kni}(j) = \frac{W_i}{Z_{ki}(j)}\ d_{ni} \qquad (2)$$

with upper case C denoting the total cost n and $Z_{ki}(j)$ the level of efficiency of the producer in country i. W_i corresponds to the cost of a bundle of inputs, faced by all firms in country i. I consider two types of inputs: Intermediates v, which, as mentioned above are a representative bundle of goods and hence have price P, and factors of production, labor and capital. The production function is Cobb-Douglas over intermediate and a CES function of the remaining inputs. The two different types of labor and capital are combined through a nested CES specification as in Krusell et al. (2000).

The cost of a bundle of inputs is in the south will thus be:

$$W_S = P^{1-\delta} c(\omega_s)^{\delta} \qquad (3)$$

with $c(\omega_s)$ being the cost of a bundle of factors $\omega_s = (w_s, w_u, w_k)$ and given by:

$$c(\omega_s) = \left[a_1 \, (w_u)^{\frac{\gamma}{\gamma-1}} + a_2 \left[b_1 (w_k)^{\frac{\rho}{\rho-1}} + b_2 (w_s)^{\frac{\rho}{\rho-1}} \right]^{\frac{\rho}{\rho-1} \frac{\gamma}{\gamma-1}} \right]^{\frac{\gamma}{\gamma-1}} \qquad (4)$$

The elasticity of substitution between skilled labor and unskilled labor, which is the same as the elasticity of substitution between unskilled labor and capital, will determined by γ[14]. The elasticity of substitution between capital and skilled labor will be determined by ϱ. Both should be smaller than one. Capital skill complementarity requires $\varrho < \gamma$. If either γ or ϱ is zero then the corresponding nesting is a Cobb-Douglas.

The cost of a bundle of inputs in the north W_N will have the same functional forms, but will be denoted by stared variables: P^*, for the price index in the north and $\omega^* = (w_s^*, \, w_u^*, w_k^*)$ for the factor price vector in the north.

Firms compete under Bertrand, so that each market is captured by the lowest cost supplier of each good, and the supplier is constrained not to charge a price higher than the second lowest cost. However, the low cost supplier will not want to charge more than the mark-up over his marginal cost $\bar{m}$, so that the price chosen by each monopolist in market $n = N, S$ will be: $P_n(j) = \min\{C_{1n}(j)\bar{m}, C_{2n}(j)\}$, where $\bar{m} = \frac{\sigma}{\sigma-1}$ is the Dixit-Stiglitz mark-up.

4.3.1. Probabilistic Formulation of the Distribution of Efficiencies

BEJK treat the efficiency parameter $Z_{kin}(j)$ as realizations of random variables, and given Bertrand competition they need to concern themselves only with the highest and second highest efficiencies in each country. Assuming that the number of ideas flow freely and arrive at any location following a

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14 In this expression $a_1 \beta^{\frac{-1}{\gamma-1}}$, $a_2 (1-\beta)^{\frac{-1}{\gamma-1}}$, $b_1 \lambda^{\frac{-1}{\rho-1}}$ and $b_2 (1-\lambda)^{\frac{-1}{\rho-1}}$, where λ are weighting factors in the corresponding production function and should be elements of the set [0, 1].

Poisson distribution, they show that the two highest efficiencies in country $i, Z_{1i}(j)$ and $Z_{2i}(j)$ will have a Fréchet joint distribution:

$$F_1(Z_1, Z_2) = \left[1 - T_i\left(Z_1^{-\theta} - Z_2^{-\theta}\right)\right] e^{-T_i {z_2}^{-\theta}} \qquad (5)$$

For $0 \leq Z_1 \leq Z_2$ the parameter θ governs heterogeneity of efficiency, with higher values of θ implying less variability, and is assumed to be the same across countries and goods. T_i is a location parameter, it governs the average efficiency in country i. Hence it determines absolute advantage and the level of disembodied technological change. In this context, it seems natural that average efficiency in the north is higher than in the south, so that $T_N > T_S$ From the joint distribution of efficiencies they derive the joint distribution of costs of supplying good j to country n:

$$G_n\left(C_1^{'}, C_2^{'}\right) = \exp\left[-\Phi_n C_1^{'-\theta}\right] - \Phi_n C_1^{'-\theta} \exp\left[-\Phi_n C_2^{'-\theta}\right] \text{ for } C_1 < C_2$$

In the simple setting with only two trading regions, north and south $(n = N, S), \Phi_n$ is a cost parameter given by: $\Phi_n = T_N(W_N d_{NN})^{-\theta} + T_S(W_S d_{NS})^{-\theta}$, with $d_{NN} = d_{SS} = 1$. The cost parameter Φ_n captures the parameters of the distribution of efficiencies, the costs of input and trade costs in both regions into a single term governing the joint distribution of $\mathrm{C_{1n}}$ and $\mathrm{C_{2n}}$, and hence the distribution of prices and mark-ups in region n.

Although all goods will be consumed in both regions, not all goods need to be produced in each. Let j index goods with respect to their comparative advantage with respect to the north $C_{1N}(j)/C_{1S}(j)$, so that goods for which $C_{1N}(j)d_{SN}/C_{1S}(j) > 1$, will be produced in the north only, and goods for which $C_{1N}(j)/C_{1S}(j)d_{SN} < 1$, will be produced in the south only. The goods in between will be produced by both and will not be traded. Let J_S be the lowest j produced in the south.

Following BEJK, this setting implies the following 3 key results for $\sigma < 1 + \theta$:

1. The price index in the south will be given by:

$$P = \bar{\Gamma}(\sigma, \theta)\Phi_S^{-1/\theta} \qquad (6)$$

with the cost parameter being $\Phi_S = T_N(W_N d_{SN})^{-\theta} + T_S(W_S)^{-\theta}$ and $\bar{\Gamma}(\sigma, \theta)$ being a constant[15].

2. The share of expenditure of the southern households in domestic goods is:

$$\pi_{SS} = \frac{T_S {W_S}^{-\theta}}{\Phi_S} \qquad (7)$$

[15] Specifically, $\bar{\Gamma} = (\sigma, \theta) = \left(\frac{1+\theta-\sigma+(\sigma-1)\bar{\mathrm{m}}^{-\theta}}{1+\sigma-\theta}\,\Gamma\,\frac{2\theta-(\sigma-1)}{\sigma}\right)^{1/(1-\sigma)}$

and the share of northern expenditure devoted to imports from the south is:

$$\pi_{NS} = \frac{T_S(W_S d_{SN})^{-\theta}}{\Phi_N} \quad (8)$$

with $\Phi_N = T_N W_N^{-\theta} + T_S(W_S d_{SN})^{-\theta}$.

3. Aggregate profits Π in the south will be

$$\Pi = \frac{1}{1+\theta} YP \quad (9)$$

where YP is total sales of domestic firms, both abroad and at home.

These results allow for a very simple solution to the model, with the advantage that its calibration can be done with aggregate data, despite the fact that there is a distribution of efficiencies and a continuum of goods.

4.4. Traded Agricultural Sector

Empirically Colombia has been a net importer of manufactures and capital goods. Remittances from abroad or debt are one way to finance this trade deficit. However, for empirical purposes, I also introduce another traded sector: agriculture. It should, however, be more broadly understood as other traded sectors different to manufacturing which finance the trade deficit in manufactures. In the case of Colombia it will correspond to mining and agriculture.

Food x is produced only with land l in a competitive setting it is traded at the world price, which I will normalize to one. The production function for food is $f(l) = C$, so that 1 unit of land is needed to produce one unit of x, which is rented at a rate W_L, The zero profit condition for the food sector will imply that $W_L = 1$ pinning down the rental rate of land. Income from agricultural activities will then be constant and equal to L. The agricultural clearing condition implies that total output of food will be equal to the demand by the north X^{d*}, plus the domestic demand X^d, with domestic demand $X^d = (1-\mu)I$. Exported output will then be given by:

$$X^{d*} = X - X^d$$

$$= L - (1-\mu)I \quad (10)$$

and the expression for income can be simplified to:

$$I = Sw_s + Uw_u + \Pi + L + R \quad (11)$$

The south can thus be a net importer or exporter of food, however as mentioned before, in the case of Colombia, there should be a trade surplus in this sector. The numeraire will be the price of food.

4.5. Factor Market Clearing Conditions

The supply of labor, both skilled and unskilled, is exogenous, so that wages will be such that total demand for each type of labor equates with the exogenous supply. Using Shepard's lemma the demand for labor of each firm will be given by the derivative of the cost with respect to wages. Since J_s is the lowest j produced in the south, integrating over all active firms, the labor market clearing conditions for the south will be:

$$\frac{\partial W_S}{\partial w_s} \int_{J_s}^{1} \frac{y(j)}{Z(j)} dj = S \qquad (12)$$

$$\frac{\partial W_S}{\partial w_u} \int_{J_s}^{1} \frac{y(j)}{Z(j)} dj = U \qquad (13)$$

On the other hand, demand for capital and intermediates will be given by:

$$\frac{\partial W_S}{\partial w_k} \int_{J_s}^{1} \frac{y(j)}{Z(j)} dj = K \qquad (14)$$

$$\frac{\partial W_S}{\partial P} \int_{J_s}^{1} \frac{y(j)}{Z(j)} dj = V \qquad (15)$$

Here V denotes the total demand for intermediate goods and K denotes the total demand for capital. The price of capital here is exogenous, at the given price firms will import the amount of capital they need from the north[16].

4.6. Balance of payments equilibrium

Finally, total imports of manufactures $(1-\pi_{SS})(PY^d + PV)$ and capital $w_k K$, minus total exports of manufactures $\pi_{NS}P^*Y^*$ and food X^{d*}, has to equal remittances from abroad (or debt):

$$\text{R} = (1-\pi_{SS})\left(PY^d + PV\right) + w_k K - \pi_{NS}P^*Y^* - X^{d*} \qquad (16)$$

With $X^{d*} = L - (1-\mu)I$ as in (10). I will assume that the south is small relative to the north, that is the south has a negligible effect on the cost of a bundle of inputs in the north W_N and on total demand P^*Y^*, so that these two magnitudes can be taken to be exogenous. As mentioned before, for empirical purposes the north is the rest of the world, and the south is Colombia, so this is not a strong assumption[17].

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[16] Note that the model is static because I am assuming full depreciation (e.g. capital equals investment).

[17] Strictly speaking, a reduction in the southern cost of producing or in the cost of transporting intermediates to the north should decrease production costs there (via lower price of intermediates) and increase the demand for intermediates and final goods (and hence total demand). However, although intermediates constitute up to 80% of total costs, Colombia's share on foreign markets was on average 0.04% during the post reform period. A simple calaculation of the elasticity of the world price with respect to transport or production cost from Colombia suggests that, for the above values of the share of Colombian exports in world markets and share of intermediates in the cost, this eslasticity is 0.002. So that the elasticity of the cost in the north with respect to the cost of inputs or trade costs in Colombia is 0.0016.

4.7. Equilibrium Level of Capital and the Wage Ratio

The equilibrium for the southern economy will be given by the maximization conditions for the consumers (1) with income I given by (11), the four aggregate equilibrium conditions for the manufacturing sector (6) to (9), the 3 factor market clearing conditions (12) to (14) (one is redundant by Walras law), the market clearing condition for intermediates (15), and the balanced trade equation (16). The nine endogenous variables of the model (all corresponding to domestic values) are the price index P, total output Y, total domestic demand Y^d, the share of domestic production in the domestic market π_{SS}, the share in foreign markets π_{NS}, the skilled and unskilled wages w_S and w_U, the level of investment K, and total aggregate profits Π.

The price of capital w_K is determined in the north and is exogenous to the model. The supply of skills S and U are also exogenous, as well as remittances from abroad R and the three trade costs d^K, d_{SN} and d_{NS}.

Since all firms face the same factor prices, by using the factor market clearing conditions an expression for wages as a function of capital purchases can be found:

$$w_s = \frac{1-\lambda}{\lambda}\left(\frac{S}{K}\right)^{\rho-1} w_k \qquad (17)$$

$$w_u = \frac{\beta}{(1-\beta)\lambda}\left(\frac{U}{K}\right)^{\gamma-1}\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\rho-\gamma}{\rho}}\left(\frac{S}{K}\right)^{\rho-1} w_k \qquad (18)$$

By using this expressions to substitute for wages in (3), I can get the cost of a bundle of inputs as a function of capital, its price, and the price index $w_s\,(K, w_k, P)$, which I can substitute in the trade shares and the price index to get them as functions only of those variables:

$$\pi_{SS} = \frac{T_S W_S(K,w_k,P)^{-\theta}}{T_N(W_N d_{SN})^{-\theta} + T_S W_S(K,w_k,P)^{-\theta}} \qquad (19)$$

$$\pi_{NS} = \frac{T_S(W_S(K,w_k,P)d_{SN})^{-\theta}}{T_N(W_N)^{-\theta} + T_S(W_S(K,w_k,P)d_{SN})^{-\theta}} \qquad (20)$$

$$P = \bar{\Gamma}(\sigma,\theta)\left[T_N(W_N d_{SN})^{-\theta} + T_S W_S(K, w_k, P)^{-\theta}\right]^{\frac{-1}{\theta}} \qquad (21)$$

To get the equilibrium conditions for capital I use the fact that $\Pi = \frac{1}{1+\theta}\,PY$ (from 9), which together with the clearing condition for intermediates, gives:

$$\frac{\delta\theta}{1+\theta}PY = \left(w_s S + w_u U + w_k K\right) \qquad (22)$$

By using the expression for wages found above, the RHS of this equation can be expressed as a function of capital and its price, denoted by $H(K, w_k) \equiv (w_s(K, w_k)S + w_u(K, w_k)U + w_k K)$. Finally, by using the balance of payment condition (16) together with the maximization condition of the consumers (1) to substitute for PY in (22), I can find an implicit equation for the equilibrium purchases of capital:

$$H(K,w_k) = \varphi[\pi_{SS}\mu[L+R-w_kK] + \pi_{NS}P^*Y^*] \quad (23)$$

with $\phi = \frac{\delta\theta}{(1+\theta)-\pi_{SS}[\theta(1-\delta)+\mu(1+\delta\theta)]}$ and π_{SS} and π_{NS} given by (19) and (20). The above equation together with the price index (21) will constitute a system of two implicit equations in the price index P, and total capital investment K, over which comparative statics can be easily performed. I denote these equilibrium values by $\widetilde{K} = \widetilde{K}(\tau)$ and $\tilde{P} = \widetilde{KP}(\tau)$, with τ denoting the vector of exogenous variables and parameters of the model.

4.8. Comparative Statics

The equilibrium level of capital $\widetilde{K}$ can now be plugged in the expressions for wages, cost of a bundle of inputs, and payments to factors of production. Both wages are increasing in the equilibrium level of capital $\widetilde{K}$ and in its price w_k. The same holds true for the equilibrium cost of a bundle of factors $c\left(\widetilde{K}, w_k\right)$ and the total payments to factors of production $H\left(\widetilde{K}, w_k\right)$ (see appendix).

By plugging the equilibrium level of capital

$$\frac{w_S}{w_u} = \frac{(1-\lambda)(1-\beta)}{\beta}\left(\frac{U}{S}\right)^{1-\gamma}\left[\lambda\left(\frac{\widetilde{K}}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\gamma-\rho}{\rho}} \quad (24)$$

Capital-skill complementarity requires $\gamma > \varrho$. As in Krusell et al. (2000), if $\gamma > \varrho$, this expression is increasing in the total equilibrium amount of efficiency units of capital in the economy $\widetilde{K}$. Hence if trade increases total capital $\widetilde{K}$, the wage ratio will increase. On the other hand if technological change can be seen as a decrease in the price of capital per efficiency unit, then technological change will exert an upward pressure on the wage ratio by increasing capital intensity within firms. This provides a straightforward way of differentiating between trade induced changes in technology and exogenous embodied technological change, as well as an easy methodology for decomposing the rises in the wage ratio in these two components.

The comparative statics on the equilibrium level of capital $\widetilde{K}$ are formally proved in the appendix. I will state them here without proof:

a) A decrease in the cost of trading manufactures with the south d_{SN}, will have an ambiguous effect on the demand for capital. As domestic producers face stronger competition, the least efficient producers will be driven out of the market. This will reduce the total demand for capital[18]. On the other hand, lowering restrictions on imports will also reduce the price of intermediate goods, hence decreasing the price of domestic goods and making southern producers more competitive both abroad and at home. This should increase the demand for capital. If the former effect dominates the latter, then capital will decrease.

b) A decrease in the cost of trading manufactures with the north d_{SN} will increase the demand for capital. Lower barriers to exports will make domestic producers more competitive abroad, new producers will enter the export market and thus increase the demand for capital.

c) A decrease in the price of capital w_k will increase the demand for capital. The decrease in the price of capital has two effects. A direct effect will be to increase the demand for capital as firms substitute towards the cheaper factor. Indirectly, it will also reduce the cost of a bundle of factors making domestic firms more competitive both at home and in foreign markets, thus rising the demand for domestic products. This, in turn, will increase the demand for capital. Both effects act in the same direction.

Two things are worth noting. First, the price of capital can decrease for two different reasons, exogenous technological change, which corresponds to a decrease in the price of capital in the north, p^k, and reductions of barriers to imports of capital goods, d^k. While the later only affects the cost of capital in the south, the former affects both the cost of capital in the south and in the north. Hence when performing the counterfactual experiments, they have to be treated separately. Second, under capital-skill complementarity, a higher equilibrium level of capital will imply a bigger wage gap. The above results imply that unilaterally lowering trade barriers to imported goods in the south may increase or decrease the wage ratio. This is contrary to the traditional Heckscher-Ohlin result, where going from autarky to trade unambiguously reduces the wage ratio. It is also different from the results obtained by Yeaple (2005) and Eckholm and Midelfart (2001), where in a setting of symmetric countries, lowering trade barriers unambiguously increases technological adoption and skilled wages. An additional feature is present in this model, which I consider empirically relevant for developing countries, and that is that trade might have an additional effect on technology adoption via lowering the cost of imported capital. As will be seen bellow, in the case of Colombia this had a non-negligible effect on capital intensity and wages.

[18] Stronger competition from abroad will also reduce the mark-up of some firms. This reduction in price should spur demand for these goods. However, this effect is neutralized by the fact that the producers that exit are also the ones that were charging the lowest mark-ups. This is a particular feature of the Fréchet assumption.

5. Calibration

5.1. Calibration Strategy

There are 11 parameters in the model, those that govern preferences, production and the distribution of efficiencies. Table 1 summarizes them:

Table 1. Parameters that need to be calibrated

Preferences
σ – price elasticity of demand
μ – share of income spent in manufactures
Production
γ – governs elasticity of substitution between capital/skilled labor and unskilled labor
ρ – governs elasticity of substitution between capital and skilled labor
β –Weighting parameter of unskilled labor in output
λ –Weighting parameter of capital in the output
δ –The share of factors in the cost W_S
Distribution of Efficiencies
T_N – Absolute advantage of the north (average efficiency)
T_S – Absolute advantage of the south (average efficiency)
θ – Dispersion of efficiency
W_N – The cost of a bundle of inputs in the north

Additionally to the parameters of the model, I have the trade costs d^k, d_{SN}, and d_{NS}, which capture both the transport costs and the tariff and non tariffs policy barriers to trade. Although there is information on tariffs, and transport costs may be approximated by differences between FOB and CIF import prices, as mentioned before, Colombia had a host of other barriers to trade such as previous licences, quotas or prohibitions, which can have an important effect on imports of manufactured goods. For this reason, the strategy I pursue is to use the observed tariffs for imports of capital goods, and to back-out d_{NS} and d_{SN} year by year from the available data[19].

The calibration is broken in three stages. In the first stage I choose values for μ, σ, δ and θ from available data. Taking these as inputs for the second stage, I estimate the parameters of the cost function ϱ, β, λ and γ, using annual time series data from the manufacturing sector between 1980-2000. In the third stage I calibrate the parameters of the distribution of efficiencies T_N, T_S and W_N and trade costs d_{NS}, and d_{SN}, As inputs for this stage I use the parameters obtained in stages 1 and 2. All the estimation and calibration was done with the data relative to the numeraire (price of agricultural goods). Before describing each step of the calibration strategy in detail, I will describe the data sources.

5.2. Data

All the estimation and calculation was performed using annual national aggregate time series, between 1980 and 2000.

Data on wages and units of labor, both for blue and white collar workers, comes from the Monthly Manufacturing Survey (MMS), which provides index variables for a representative sub-sample of the Annual Manufacturing Census (AMC). I use the first year of the AMC to get all the variables in levels[20].

Efficiency units of labor for both blue and white collar workers were calculated by multiplying the number of workers by the average years of education. Average years of education for manufacturing blue and white collar workers was calculated using household surveys[21].

Imports of capital goods in current dollars are reported by the Colombian office of customs and taxes, DIAN, and the National Statistics Department, DANE. The series was deflated using the US price index of private investment in machinery and equipment reported by the US National Income and Product Accounts (NIPA)[22].

The price of imported capital goods w_k has three components: the price of capital in the US, p_k; the exchange rate r; and import tariffs d^K. Tariffs on capital goods d^K were obtained from the National

[19] Non-tariff barriers to imports of capital goods were substantially less than for other imported goods.

[20] Although the AMC contains this data in levels, several changes in the population of firms and in the definition of the employed personnel make using this series risky. In particular 1991-1992 data contain unexplained jumps in the variables. Instead the MMS, has maintained consistent sample and variable definition, and is specifically designed for time series comparisons.

[21] I used National Household Surveys (NHS) 1980-2000 for 7 main cities and their metropolitan areas. To classify workers between blue and white collar I matched these categories to the National Classification of Occupations, which is the item reported in the NHS.

[22] The behavior of investment that comes from using the data directly reported in the AMC has some unexplainable behavior between 1994-1996, with enormous negative investments. The MMS does not report investment or capital.

Planning Department (DNP). The price of capital goods in the north p^K corresponds to the price index of private investment in machinery and equipment reported by NIPA. The exchange rate (pesos per dollar) was obtained from the Colombian Central Bank. The total cost of imported capital goods was then constructed as $w_k = p_k * d^K * r$.

Total sales (PY) and consumption of intermediates (PV) come directly from the Annual Manufacturing Census.

Profits are not reported by either AMC or MMS. To construct profits for the manufacturing sector I use data from National Accounts, which has information on the Gross Production Surplus (GPS)[23]. I construct profits Π as GPS minus imports of capital goods at CIF prices.

The share of Colombian exports in world demand for manufactures (π_{NS}) was constructed using the Feenstra and Lipsey (2002) world import and export data, together with data from World Bank and OECD on total manufacturing output or value added. In the cases where only value added was available I used a conversion rate of 3.1, which is the average observed ratio of output to value added for the countries for which both value added and total production was available. Import penetration of manufactures in Colombian markets ($1 - \pi_{SS}$) comes directly from the National Planning Department.

5.3. Calibration Strategy:

5.3.1. Stage 1

The share of income spent in manufactures μ: This value is set to 0.25, which corresponds to the average share of expenditure in manufactures in total consumption between 1980 and 2000, calculated with data from the Colombian National Accounts.

The price elasticity of demand σ**:** I use the value estimated by Eslava et al. (2000). Using firm level data from the Annual Manufacturing Census (AMC), they find a price elasticity of demand of 2.28.

The share δ, *of factors K,S,U) in the total cost of a bundle of inputs* W_S: Given constant returns to scale this is equivalent to the share of total payments to factors in total production costs. I construct the total cost of production as $Kw_K + Sw_S + Uw_U + PV$ for every year, and calculate the average share for the period under study[24]. The average observed share of factors in total cost is 0.19. *Dispersion of Efficiencies* θ*:* Using the reported value of sales in the AMC, I back out θ using the fact that total profits are equal to

[23] The *GPS* is the value added minus payments to labors minus taxes (including import taxes).

[24] $\delta = \sum_{t=1980}^{2000} \frac{1}{20}\left[1 - \frac{PV_t}{S_t w_{st} + U_t w_{ut} + K_t(p_t^k * r_t * d_t^K) + PV_t}\right]$

$\frac{\theta}{1+\theta}PY$ (equation 9). The backed out value for the average period in the sample is 2.70 which is slightly smaller than the one used by BEJK of 3.60. This value of θ implies that the share of profits in total sales is 27%, which is slightly higher than the share implied by the BEJK value, of 21%.

5.3.2. Stage 2

To estimate the parameters of the cost function $\zeta = (\rho, \gamma, \lambda, \beta)$, I estimate equations (17) and (24) which I re-state here for clarity, using time series data between 1980 and 2000:

$$\frac{w_S}{w_u} = \frac{(1-\lambda)(1-\beta)}{\beta}\left(\frac{U}{S}\right)^{1-\gamma}\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\gamma-\rho}{\rho}} \quad (25)$$

$$\frac{w_S}{w_k} = \frac{(1-\lambda)}{\lambda}\left(\frac{S}{K}\right)^{\rho-1} \quad (26)$$

Using a minimum distance estimator I find the values of the parameters that minimize the distance between the empirical values of the moment conditions (25) and (26), with its theoretical counterpart:

$$\min_{\zeta} G(\zeta) = [W - W(\zeta)]'\Omega\,[W - W(\zeta)] \quad (27)$$

where W is a $2t \times 1$ vector of the empirical value of the variable (e.g. the left hand side of equations (25) and (26) for every period, stacked), with t denoting the number of periods (1980-2000). $W(\zeta)$ is the model counterpart (e.g. the right hand side of equations (25) and (26)). Ω is a $2t \times 2t$ weighting matrix, which I set equal to the identity[25].

Under relatively weak finite moment assumptions the minimum distance estimator is consistent. Mainly regularity conditions that guarantee that the minimization problem in (27) is well defined and that the true parameters of the model are identified (see Hayashi (2000), chapter 7; Wooldridge (2002), chapters 12 and 14; and Greene (2003), chapter 17)[26]. Additionally the model needs to be identified. The parameter

[25] By using the identity as the optimal weighting matrix I am assuming the moment conditions are uncorrelated and have homogenous variance. If the assumption is not true the parameters estimated may not be efficient. However, while I am not concerned with efficiency given that I am not making any specification tests, Altonji and Segal (1994) show that for small samples estimates of the variance covariance matrix used to construct the weighting matrix may be biased thus biasing the estimated coefficients. They show that for small samples equal weights outperform the usual weighting matrix constructed from the variance covariance matrix of the moment conditions.

[26] For consistency the usual requirement is that the parameter space is compact and that $m(\zeta) = W - W(\zeta)$ is continuous. Where ζ is the parameter vector. Here $\beta, \lambda \in [0, 1]$, but $\rho, \lambda \in (-\infty, 1)$, hence the parameter space is not compact. However, as noted by Wooldridge (2000), the parameter space can be defined to be such a large closed and bounded set as to always contain ζ. For the problem here it would suffice to set $\beta, \lambda \in [-z, 0.999]$, with $|z|$ sufficiently large. Alternatively the requirements for consistency can be relaxed to the parameter space being convex and the objective function $G(\zeta)$ being convex over the parameter space for all the data. Proving convexity for nonlinear problems however is generally not easy. As is the case for the problem considered here. Most applications thus assume that the objective function is convex in a neighborhood of the parameter space (Geene, 2003).

governing the elasticity of substitution between unskilled labor and skills/capital (γ) is identified through the exogenous variation in $\frac{U}{S}$. The parameter governing the elasticity of substitution between capital and skills (ρ) is identified through exogenous variation in w_k and S. Once γ and ρ are identified, identification of the weights β and λ come directly from the ratios $\frac{U}{S}$ and $\frac{S}{K}$. Both variables display sufficient variability and are not collinear.

Data on capital imports and tariffs comes from the sources explained in the previous section. The estimation was performed using both units of labor and efficiency units, with little impact on the results.

5.3.3. Stage 3

Finally, I need to calibrate the remaining parameters of the distribution of efficiencies and the three trade costs. To do so, I normalize the average value of efficiency in the north $T_N = 1$. This leaves four parameters to be estimated: The cost of a bundle of inputs in the north W_N, the trade costs d_{SN} and d_{NS} and the average level of efficiency in the south T_S. As mentioned before, the cost of a bundle of inputs in the north depends also on the price of capital in the north p^k. It is important to take this into account when performing the counterfactual experiments. Given constant returns to scale in the production function and the fact both wages are linear in p^k, I can define $W_N = p^k\,\overline{W}_N$ and calibrate $\overline{W}_N$, d_{SN}, d_{NS}, and T_S. These appear only in three equations: the trade shares and the price index. Hence I will be able to identify only three of them separately. I use the following equations:

The share of southern firms in the domestic market:

$$\frac{T_S(W_S)^{-\theta}}{\left(p^k\overline{W}_N/d_{SN}\right)^{-\theta}+T_S(W_S)^{-\theta}} \quad (28)$$

the share of the south in the northern market which I will re-write as (dividing by ${d_{NS}}^{\theta}$):

$$\pi_{NS}\frac{T_S(W_S)^{-\theta}}{\left(p^k\overline{W}_N/d_{NS}\right)^{-\theta}+T_S(W_S)^{-\theta}} \quad (29)$$

and the price index:

$$P = \lambda\,(\sigma,\theta)\left[(p^k\overline{W}_N/d_{SN})^{-\theta} + T_S(W_S)^{-\theta}\right]^{\frac{-1}{\theta}} \quad (30)$$

This makes a set of three equations in the unknowns $\overline{W}_N\, d_{SN}$, $\overline{W}_N/d_{NS}$, and T_S. The first one captures the exogenous factors affecting the competitiveness of the south in its own markets; that is, if the cost of producing goods in the rest of the world ($\overline{W}_N$) rises or the cost of trading goods with the south for northerns producers (d_{SN}) rises, domestic producers will gain share in the domestic market (π_{SS} will increase). The second one captures the exogenous factors that affect competitiveness of the south in northern markets. If $\overline{W}_N$ rises or the cost of transporting goods to the north from the south d_{NS} decreases the south will gain share abroad (π_{NS} will increase). I back out each of these 3 variables for each year.

Note that p^k has no effect on the trade shares, since the cost of a bundle of inputs in the south can also be expressed as $W_S = p^k \overline{W}_S$, and hence p^k will appear both in the denominator and numerator of (28) and (29).

5.4. Calibration Results

The parameter values obtained in the first stage are summarized bellow:

Table 2. Parameter values obtained in step 1

Preferences		
Elasticity of demand	σ	2.28
Share of income spent on manufactures	μ	0.25
Distribution of efficiencies		
Dispersion of efficiency	Θ	2.70
Production		
Share of factors in the cost of a bundle of inputs	δ	0.19

The estimated values of the production function are show bellow, with its standard errors in parenthesis[27].

Table 3. Estimated production function parameters

Parameter		value	std. error
Elasticity of subst. Skilled/Unskilled	γ	0.98	(0.293)
Elasticity of subst. Skilled/Capital	ϱ	0.13	(0.004)
Weighting parameter of unskilled labor in output	β	0.31	(0.005)
Weighting parameter of capital in output	λ	0.20	(0.0001)

[27] Reported values are from the estimation using efficiency units of labor.

The results support $\gamma > \rho$ and thus capital-skill complementarity. These values imply a partial Allen elasticity of substitution between skilled and unskilled labor of $\frac{1}{1-\gamma} = 50.0$. Although this value seems quite high, Duffy, Papageouriou, and Pérez-Sebastian (2004) find that this elasticity increases as one lowers the years of education used to define the skilled work force. For this particular data, the average years of education of the skilled workers is 7.3, which corresponds to only two years of secondary education. Klenow and Rodriguez-Clare (1997) find an elasticity of 65 using complete primary to define skilled labor. Hence the result is not unprecedented. The implied Hicks-Allen elasticity of substitution between skilled and unskilled labor is 2.52, which is higher than the one found by Cárdenas and Gutiérrez (1996) of 0.98, but uses a Generalized Leontief production function. The Implied partial Allen elasticity of substitution between skilled labor and capital is 21 and the Hicks-Allen elasticity of substitution between skilled labor and capital $\frac{1}{1-\rho} = 1.15$. Both are higher than previous empirical estimates[28]. This elasticities are not strictly comparable with previous estimates, since I am using investment instead of capital stock as a measure of capital.

Figure 4 (a)

[28] The partial Allen elasticity of substitution between capital and skilled labor is $\sigma_{k,s} = \frac{1}{1-\gamma} + \frac{1}{\zeta^{sk}}\left(\frac{1}{1-\rho} + \frac{1}{1-\gamma}\right)$.

Figure 4 (b)

Figure 4 (a) shows the fitted and observed values of the ratio between the average skilled wage and the cost of capital. Figure 4 (b) illustrates the fitted and observed values of the wage ratio. Except for the final years (1999 and 2000) the fit is very close. During these last years there was a significant drop in imports of capital goods; however, wages did not respond. The fact that wages are index to inflation may have slowed the adjustment.

Figure 5 (a)

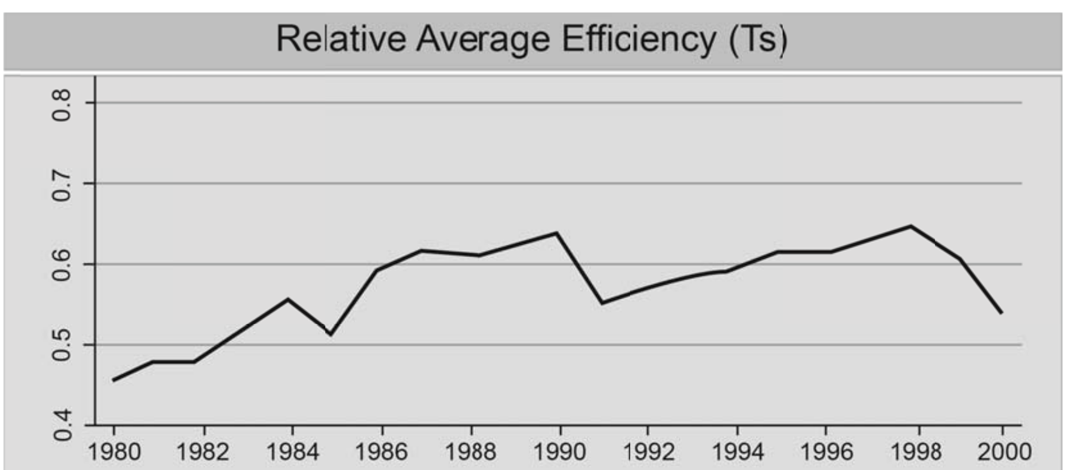


Figure 5 (b)

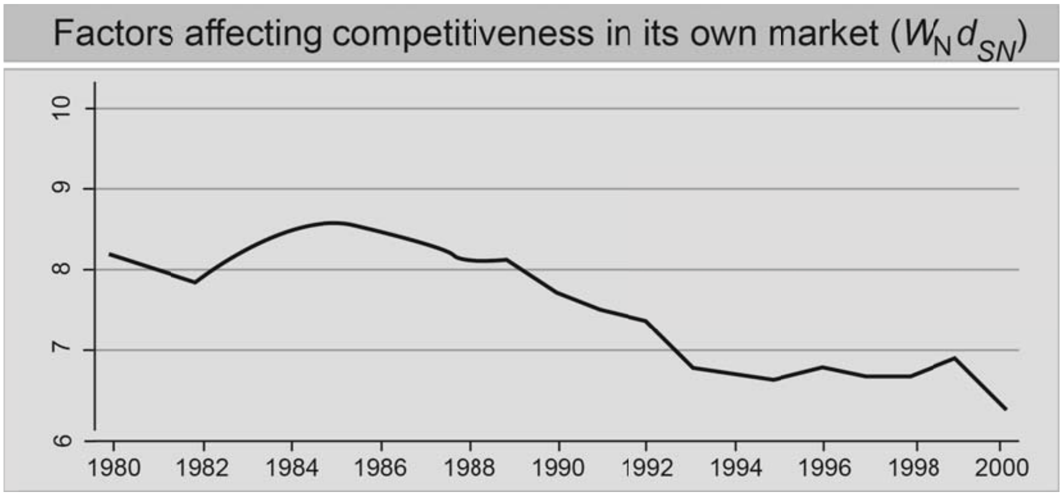
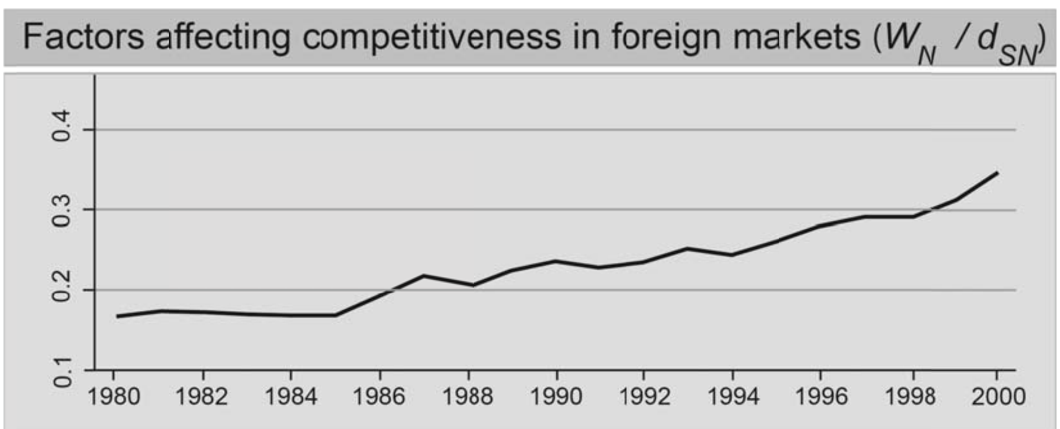


Figure 5 (c)



The three exogenous trade variables T_S, $\bar{W}_N d_{SN}$, and $\bar{W}_N / d_{NS}$ were calibrated for each year in the sample; results are shown on Figure 5 (a), (b), and (c), respectively. Relative average efficiency of the south with respect to the rest of the world has an increasing trend and is smaller than one, suggesting, as expected, that the rest of the world is more efficient than Colombia[29]. The exogenous factors affecting the competitiveness of the south in its own market, which are plotted relative to the price of manufactures, follow very closely the trade liberalization trends. It increases between 1982 and 1984 and then steadily decreases until 1992-1993, stabilizing after this period, when trade reforms had been fully implemented.

[29] The trade parameters were calibrated using the fitted values of wages. The decrease of average efficiency *Ts* in 1985 and 1991 is due to a decrease in the cost of a bundle of factors calculated using the fitted values of wages. The decrease of the cost is due to a reduction of the fitted skilled wage brought about by a reduction in the observed $\frac{U}{S}$ ratio and in $\frac{K}{S}$.

The exogenous factors affecting the competitiveness of Colombia in foreign markets (also plotted relative to the price of manufactures) follow an increasing pattern with a slight acceleration starting in 1986, which reflects the generalized trade liberalization in the world and the signing of trade agreements between Colombia and its trading partners during the period 1986-1993.

6. Counterfactuals

The calibrated results seem to match well the facts and data. Using the estimated parameters and the trade exogenous variables derived in the previous section, I perform three counterfactual experiments to determine the contribution of different factors to the rise in the wage gap.

The first one assumes that trade variables stayed at their pre-reform levels. That is, trade costs of capital d^K stayed at the 1984 level, and the exogenous factors affecting Colombian competitiveness in its own and in foreign markets ($\overline{W}_N d_{SN}$ and $\overline{W}_N / d_{NS}$) stayed at their 1989 level (in terms of the numeraire)[30]. In the second exercise I assume that the price of capital in US dollars p^k, which is my measure of technical change, continued to increase at the same rate as the one registered between 1980-1989. Finally, since the price of capital is calculated as the price in dollars times the real exchange rate, real exchange rate appreciations will make capital cheaper increasing its demand[31]. In the last exercise I assume the exchange rate stayed at the pre-reform average level. Figures 6 to 8 show the results. The upper plot shows the observed evolution of the variable over which the exercise is taking place versus the counterfactual assumed value. The lower plot shows the impact on the wage ratio.

Figure 6

[30] As mentioned before the first step in trade liberalization was to eliminate tariffs on capital goods, which took place between 1986-1990.

[31] Here the real exchange rate is the nominal exchange rate in terms of the price of agricultural goods.

Figure 7 (a)

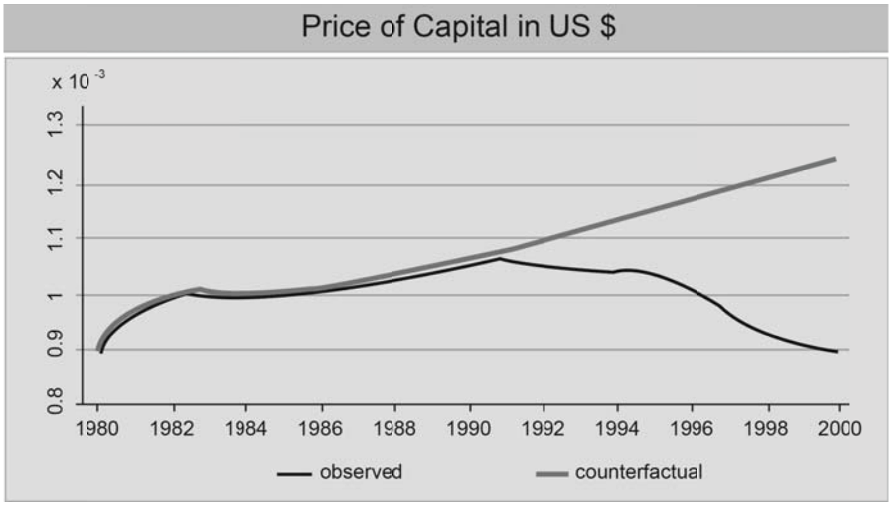


Figure 7 (b)

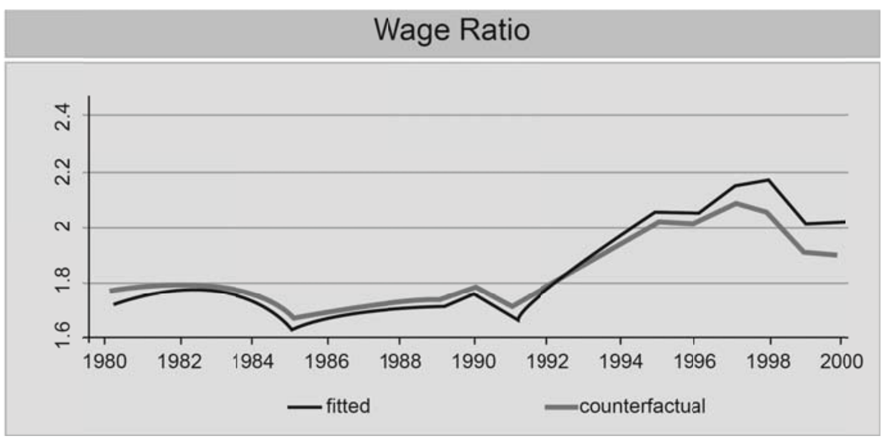


Figure 8 (a)

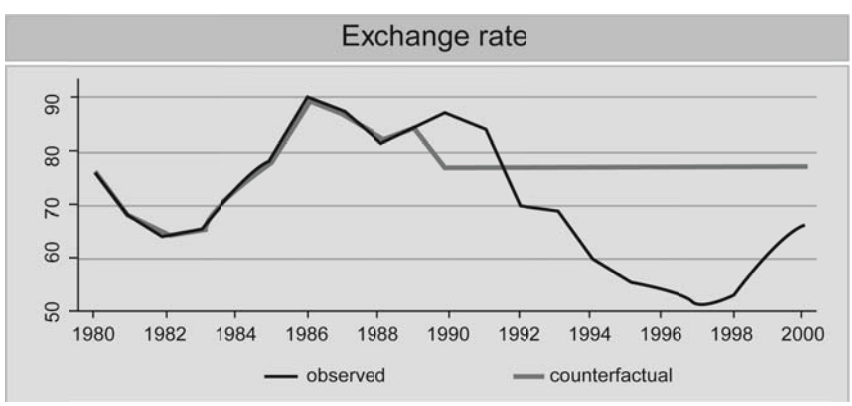
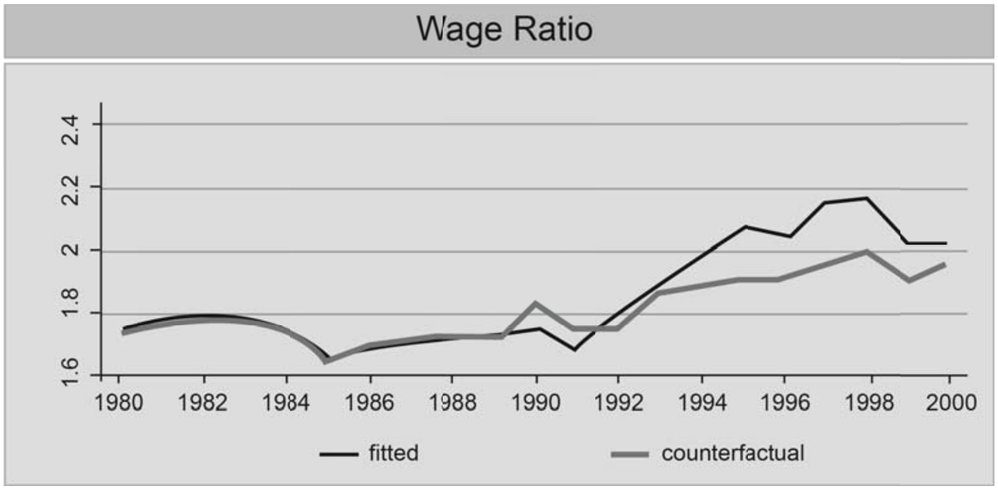


Figure 8 (b)



Finally, figure 9 shows the contribution of each factor (trade, technology and exchange rate) over the baseline wage ratio, which corresponds to the value of the wage ratio if all the variables had stayed at its pre-reform levels. The skilled and unskilled employment levels are the observed ones. The results suggest that the 30% appreciation of the exchange rate registered during the post-reform period played a mayor role in the increase of the demand for capital, and with it, in the rise of the wage ratio. This factor alone explains 51% of the difference between the baseline wage ratio in 1998 and the fitted value for this year. Embodied technological change defined as a decrease in the price of capital explains 32% of the difference and trade explains 17%. When disaggregating the trade effects into its three components, it is the trade costs of capital that has the highest impact. The decrease of the exogenous factors affecting competitiveness in its own markets (barriers to imports) has a negligible impact, slightly decreasing the wage ratio until 1998 and increasing after that. Exogenous factors affecting competitiveness in foreign markets (barriers to exports) also has a small effect. Even more, the two effects almost cancel each other, leaving only trade costs of capital as the main trade variable affecting the wage ratio[32]. Only after 1998 do both barriers to exports and barriers to imports act in the same direction, thus increasing the wage ratio. Figures 10 to 12 show the impact of each trade variable on its own.

[32] An additional exercise was performed keeping the value of exogenous factors affecting market competitiveness relative to the price of manufactures (as opposed to relative to the numeraire) in its pre-reform levels, results are very similar with trade having only a slightly lower contribution.

Figure 9

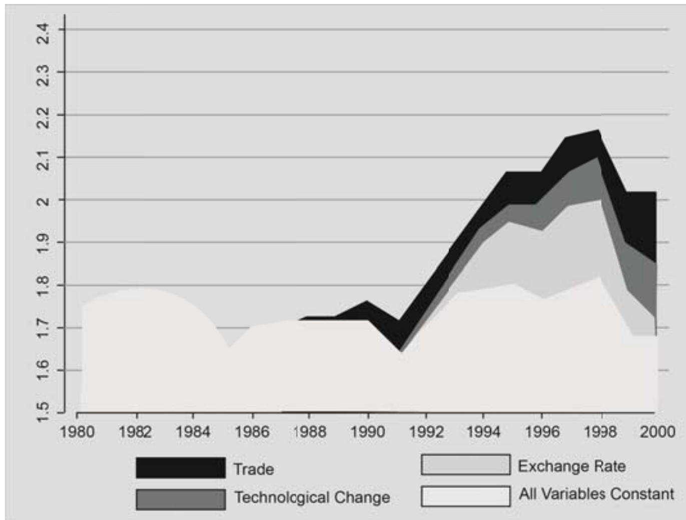


Figura 10 (a)

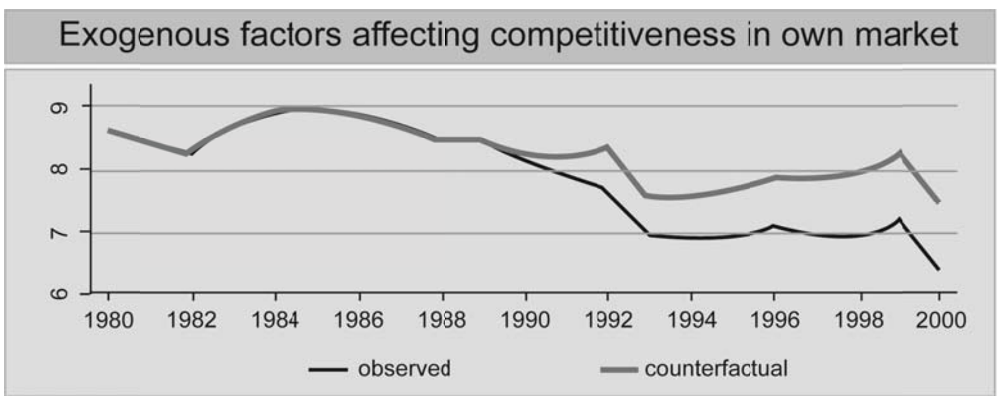


Figura 10 (b)

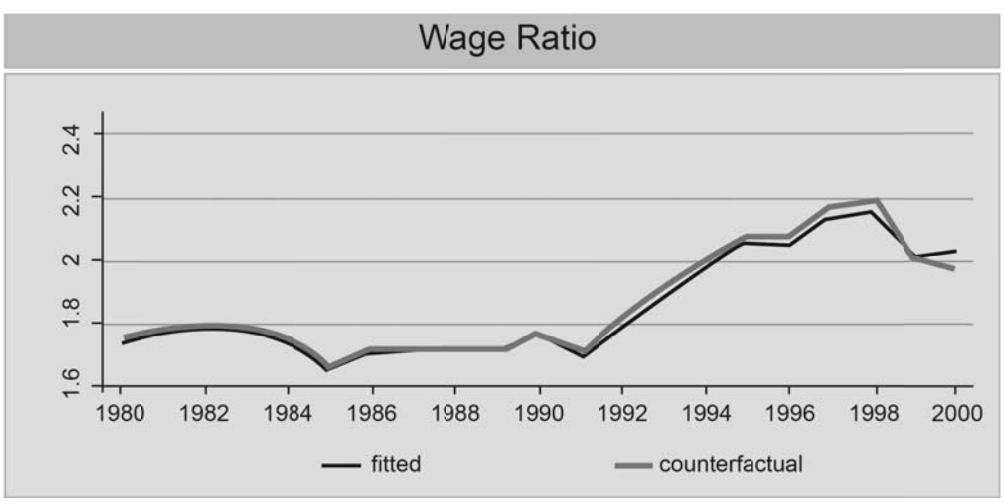


Figure 11 (a)

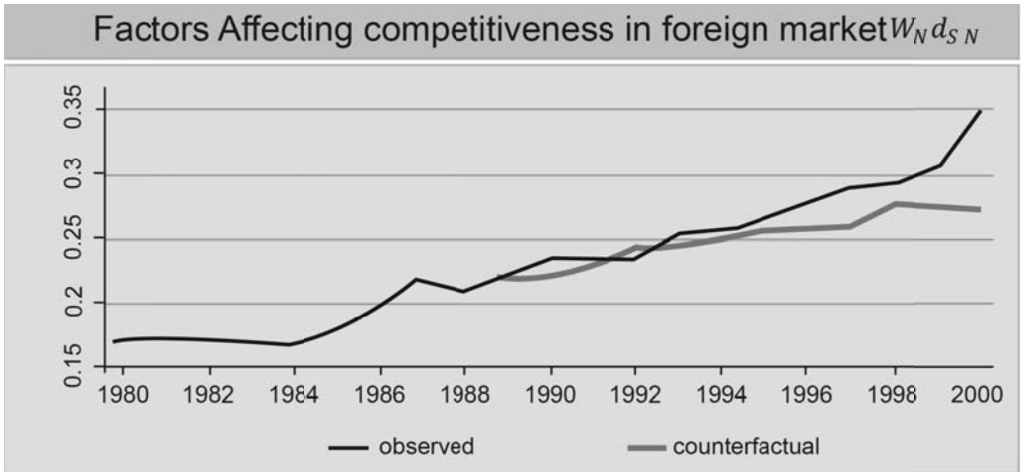


Figure 11 (b)

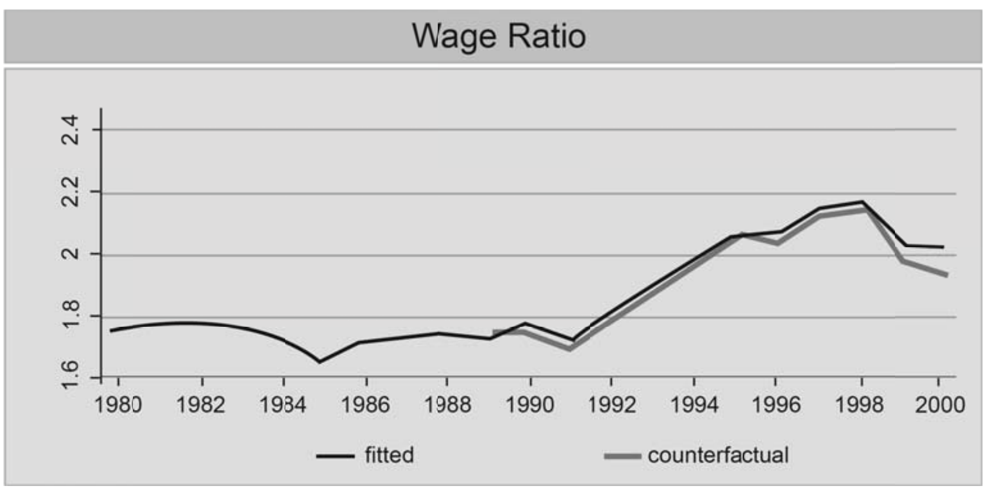


Figure 12 (a)

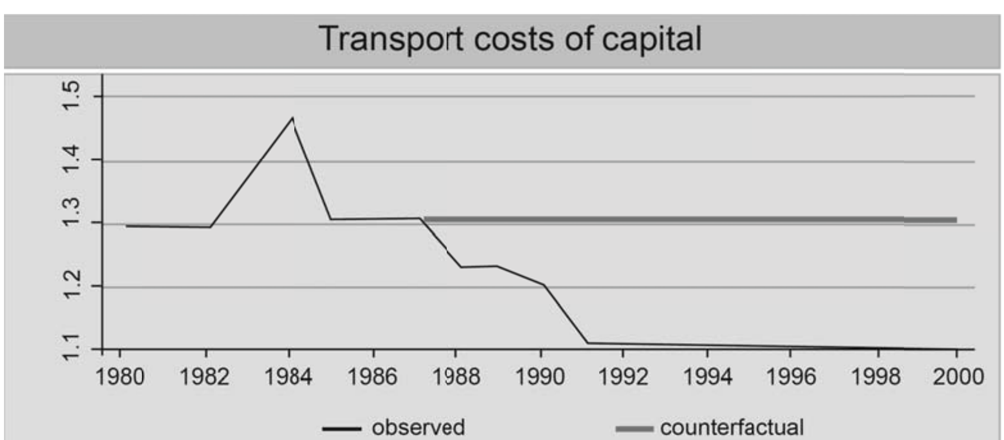
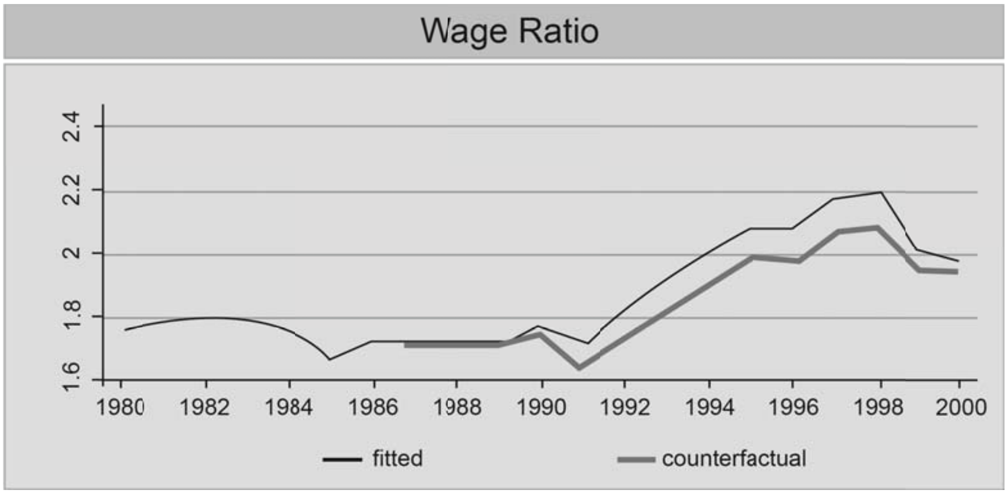


Figure 12 (b)



7. Conclusions

The impact of structural reforms on equity and efficiency in Latin America have generated widespread interest. While in general studies agree on the fact that structural reforms had a positive impact on efficiency, the conclusions about their impact (and in particular about the impact of trade on wage inequality) have been less clear. It is my view that this has been partly due to the fact that studies have based their analysis on the Heckscher-Ohlin model of trade and its implication that trade should shift production between traded and non-traded sectors or sectors with different skill intensities, something that did not occur in Latin America. However, studies recognize the puzzling coincidence between the rapid trade reforms undertook in countries like Colombia and the rise in the wage ratio. This had led to the generalized conclusion that, maybe trade played a role through trade induced changes in technology. By using the BEJK (2003) model of trade and combining it with capital-skill complementarity, as in Krusell et al. (2000), I am able to find new mechanisms by which trade might have affected the demand for capital might and impacted the wage ratio, and quantify them.

My results indicate that structural reforms did play an important role in rising wage inequality in the manufacturing sector. However, it was not trade liberalization in manufactured goods. Two other components of the structural reforms are to blame. The first one was the lifting of foreign investment restrictions, as well as the reform to the exchange rate regime, which coincided with a decrease in the profitability of investments in the US and led to massive inflows of capital to many Latin American countries. The second one was the elimination on the restrictions of imports of capital goods. This two factor explain 68% of the explained rise in the wage ratio. Finally, technological change accounts for a significant 32% of the rise.

Some limitations of the model are worth mentioning. There is some discussion of whether trade generated pro-competitive effects. Many analysts argue that trade reduced the monopolist power of domestic firms, lowered the price of output, and hence increased domestic demand and with it demand for capital. In the BEJK trade model used here, the rise in demand due to a decrease in prices via lower mark-ups is completely off-set by the loss of domestic market, via a lowering of the price index. This is a direct result of the Fréchet distribution assumption. Therefore in the model put forth in this paper, the pro-competitive effects of trade are completely offset by construction. A second concern is that the threat of trade might have promoted firms to overinvest in order to keep the competition outside of the market, as in Neary (2000). Anecdotal evidence from business administrators does support this idea. This again is a possibility not explored here. Finally and maybe more importantly, the structural reforms also included substantial changes in labor market regulation and labor costs. The data here refers only to wage earnings and does not include other costs to the firm such as severance payments, payroll taxation, and health and social security contributions that undoubtedly affected the relative demand for labor. Although these are not explored here, it is an extension to the model that would be worth exploring.

Despite the limitations mentioned above, the results do have some interesting implications for the design of structural reforms in other developing countries. The main lesson that can be extracted from the Colombian case is that it is the response of capital to the structural reforms that has raised the skill premium. Structural reforms have made capital cheaper. Under capital-skill complementarity this makes unskilled labor less 'competitive' and hence lowers its demand and its return. Additionally, protecting domestic markets from foreign competition may actually raise wage inequality if it results in higher output for domestic markets and more demand for capital. Moreover, the evidence shows that efficiency losses might be considerable. Increased exports will translate in higher demand for capital and skilled labor, and thus higher wage inequality. For the Colombian case, the effects of higher trade in manufactured goods are small, and tend to cancel out. Exogenous technological change is also playing an important role in earnings inequality. All of the above suggest that it is imperative to strengthen the efforts to increase the level of skills of the labor force. This would counteract the upward pressure exerted by technological change and by structural reform-driven changes in capital investment on the wage gap. Whether the mechanisms discussed in this paper can explain the raise in wage inequality elsewhere in Latin America remains to be seen, but the model developed here can be easily applied to other countries, with the advantage that only aggregate industry data is needed.

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Appendix: Proofs

To simplify notation I will refer to the equilibrium level of capital purchases as K instead of $\bar{K}$, which is only a function of the exogenous variables and parameters of the model.

Lemma 1: Both wages are increasing in the equilibrium level of capital purchases K and in its price W_k

Proof: the wages are given by:

$$w_S = \frac{1-\lambda}{\lambda}\left(\frac{S}{K}\right)^{\rho-1} w_k$$

$$w_u = \frac{\beta}{(1-\beta)\lambda}\left(\frac{U}{S}\right)^{\gamma-1}\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\rho-\gamma}{\rho}}\left(\frac{S}{K}\right)^{\rho-1} w_k$$

from which it is trivial that both are increasing in w_k and that w_S is also increasing in K, since $\rho - 1$. The derivative of the unskilled wage with respect to capital is will depend on the term

$$\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\rho-\gamma}{\rho}}\left(\frac{S}{K}\right)^{\rho-1}$$

that has derivative:

$$\frac{\lambda(\rho-\gamma)}{S}\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{-\gamma}{\rho}} - \frac{(\rho-1)}{K}\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{\rho-\gamma}{\rho}}\left(\frac{S}{K}\right)^{\rho-1}$$

Factoring out $\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{-\gamma}{\rho}}\frac{1}{S}$, it can be expressed as:

$$\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{-\gamma}{\rho}}\frac{1}{S}\left\{\lambda(\rho-\gamma) - (\rho-1)\left[\lambda + (1-\lambda)\left(\frac{S}{K}\right)^{\rho}\right]\right\}$$

Since $\left[\lambda\left(\frac{K}{S}\right)^{\rho} + (1-\lambda)\right]^{\frac{-\gamma}{\rho}}\frac{1}{S}$ is positive, the sign of the derivative will depend on the sign of the second term in brackets, which can be re-written as: $(1-\gamma)\lambda + (1-\rho)(1-\lambda)\left(\frac{S}{K}\right)^{\rho} > 0$, which is positive since $\rho < 1$ and $\gamma < 1$. *Q.E.D.*

Lemma 2: The equilibrium cost of a bundle of factors $c(K, w_k)$ and the equilibrium total payments to factors of production $H(K, w_k)$, are increasing K and w_k.

Proof: $H(w_S, w_u, K, w_k) \equiv (w_S S + w_u U + w_k K)$, by plugging the expressions for w_S and w_u, I get $H(K, w_k)$. By lemma 1 both wages are increasing in K and w_k, so trivially $H(K, w_k)$ will be increasing in this variables. In the same way $c(K, w_k)$ is derived by plugging w_S and w_u in (4), which is increasing in all factor prices. *Q.E.D*.

Lemma 3:

a) A decrease in the cost of transporting manufactures to the south from the north d_{SN}, has an ambiguous effect on capital.

b) A decrease in the cost of transporting goods to the north from the south d_{NS} will increase technology adoption.

c) As a decrease in the price of capital w_k will increase technology adoption.

Proof: Equilibrium level of prices and capital will be given implicitly by:

$H(K, w_k) = \phi[\pi_{SS}\mu[L + R - w_k K] + \pi_{NS}P^* Y^*]$ (A1)

$P = \bar{\Gamma}(\sigma, \theta)\left[T_N(W_N d_{SN})^{-\theta} + T_S(W_S)^{-\theta}\right]^{\frac{-1}{\theta}}$ (A2)

$= \bar{\Gamma}(\sigma, \theta)\Phi_S{}^{-\frac{1}{\theta}}$ (A3)

with $W_S = P^{1-\delta}c(K, w_k)^{\delta}, \phi = \frac{\delta\theta}{(1+\theta)-\pi_{SS}[\theta(1-\delta)+\mu(1+\delta\theta)]}$ and trade shares given by:

$$\pi_{SS} = \frac{T_S\big(W_S(K, w_k)\big)^{-\theta}}{(W_N d_{SN})^{-\theta} + T_S\big(W_S(K, w_k)\big)^{-\theta}}$$

$$\pi_{NS} = \frac{T_S\big(W_S(K, w_k)\big)^{-\theta}}{(W_N d_{NS})^{-\theta} + T_S\big(W_S(K, w_k)\big)^{-\theta}}$$

I will refer to equation A1 as the capital equilibrium condition and to equation A2 as the price equilibrium condition. To prove the proposition it will be useful to get first some results.

Result 1: The price equilibrium equation is increasing in the (*K*, *P*) plane. Applying implicit function theorem to 10, we find that:

$$\frac{dP}{dc(K, w_k)} = \frac{\bar{\Gamma}(\sigma, \theta)\Phi_S{}^{\frac{-1}{\theta}-1}\delta(W_S)^{-\theta}c(K, w_k)^{-1}}{1 - \bar{\Gamma}(\sigma, \theta)\Phi_S{}^{\frac{-1}{\theta}-1}(1-\delta)(W_S)^{-\theta}P^{-1}}$$

The numerator is clearly positive. To sign the denominator I can use the fact that in equilibrium, equation A2 holds so that the denominator can be written as:

$$1 - \Phi_s{}^{-1}(1-\delta)(W_s)^{-\theta}$$

$$= 1 - (1-\delta)\pi_{ss} > 0$$

Since $c(K, w_k)$ is increasing in K, the price equation is increasing in capita, by lemma 1.

Result 2: The partial derivatives (holding prices fixed) of the trade shares with respect to capital are negative. It is easy to see that both the share of domestic markets π_{SS} and the share of foreign markets π_{NS} are decreasing in the equilibrium cost of a bundle of factors $c(K, w_k)$, that is, $\frac{\partial \pi_{SS}}{\partial c(K,w_k)} < 0$ and $\frac{\partial \pi_{NS}}{\partial c(K,w_k)} < 0$. By lemma 2, the equilibrium cost of a bundle of factors is increasing in K, and in w_k so that the shares are decreasing in these arguments (holding prices fixed). In fact

$$\frac{\partial \pi_{SS}}{\partial K} = -\theta\delta \frac{\partial c(K, w_k)}{\partial K} \pi_{SS}[1 - \pi_{SS}]$$

$$\frac{\partial \pi_{NS}}{\partial K} = -\theta\delta \frac{\partial c(K, w_k)}{\partial K} \pi_{NS}[1 - \pi_{NS}]$$

Result 3: The partial derivative (holding K constant) of the trade shares with respect to the price are negative. As the cost of intermediates increases the share in both domestic and foreign markets diminishes.

Result 4: The equilibrium equation of capital (A1), is decreasing in the (*K*,*P*) plane: First let$g(\pi_{SS}, \pi_{SN}) \equiv \phi[\pi_{SS}\mu[L + R - w_k K] + \pi_{NS} P^* Y^*]$ denote the RHS of the capital equilibrium condition. Trivially $g(\pi_{SS}, \pi_{SN})$ is increasing in both shares. Applying implicit function theorem in A1, we find that:

$$\frac{dP}{dK} = -\frac{\left[\frac{\partial H(K,w_k)}{\partial K} - \frac{\partial g(\pi_{SS},\pi_{SN})}{\partial K}\right]}{-\frac{\partial g(\pi_{SS},\pi_{SN})}{\partial P}} < 0$$

This derivative is negative since from results 2 and 3 it follows that $\frac{\partial g(\pi_{SS},\pi_{SN})}{\partial K} < 0$ and $\frac{\partial g(\pi_{SS},\pi_{SN})}{\partial P} < 0$, and from lemma 2 it follows that $\frac{\partial H(K,w_k)}{\partial K} > 0$.

Result 5: The equilibrium pair (*P*,*K*) is a unique. This follows directly from results 1 and 4.

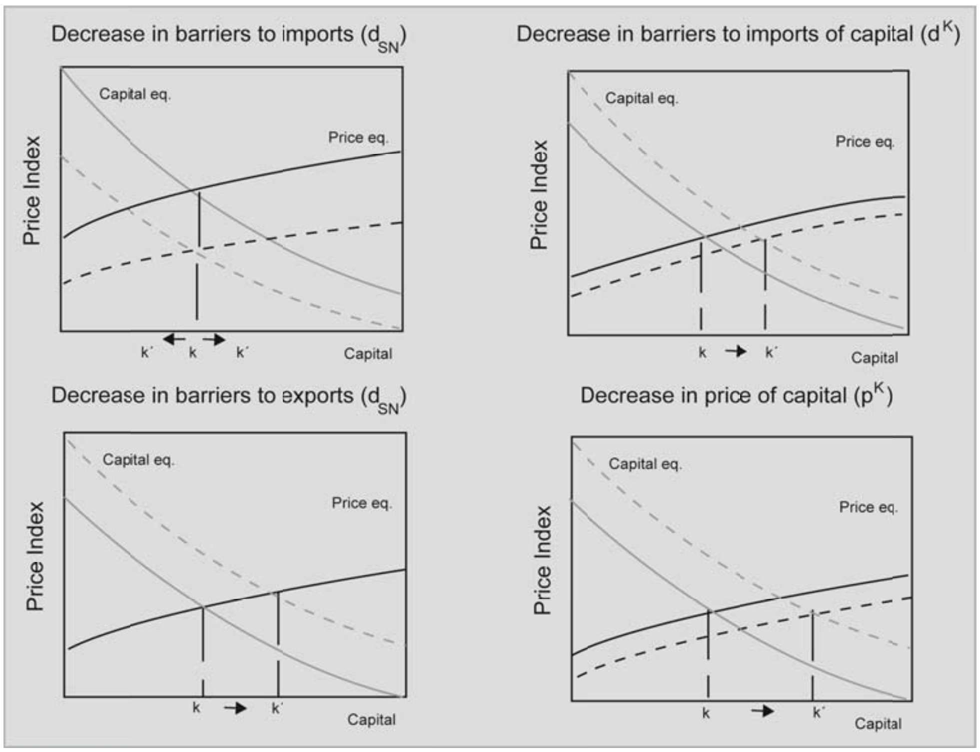
Result 6: Exogenous technological change, interpreted as a decrease in P^k, will have no effect on the trade shares. By plugging (17) and (18) in (4) an expression for the unit cost of a bundle of inputs, as a function of capital and the price of capital, can be found, denote it by $c(K, w_k)$:

$$\frac{w_k \left[\lambda + (1-\lambda)\left(\frac{S}{K}\right)^{\rho}\right]^{\frac{\rho-\gamma}{\rho}} \left[\beta\left(\frac{U}{K}\right)^{\gamma} + (1-\beta)\left[\lambda + (1-\lambda)\left(\frac{S}{K}\right)^{\rho}\right]^{\frac{\gamma}{\rho}}\right]^{\frac{\gamma-1}{\gamma}}}{(1-\beta)\lambda}$$

since it is linear in w_k, and $w_k = p^k d^k$ the term p^k will be canceled out from the trade shares, as it appears both in the denominator and numerator since both the cost of a bundle of inputs in the north and south have the same functional form and are subject to the same price of capital. The intuition behind this result is straight forward: Exogenous technological change will affect both regions equally in terms of lowering their cost of a *bundle* of factors.

With these results it is easy to prove Lemma 3. The proof can be sketched graphically. Figure A1 illustrates the result:

Figure A1



a) The cost of transporting manufactures to the south from the north (d_{SN}) has a direct effect on both the price and capital equilibrium conditions. A decrease in this cost will lower the RHS of A2 for a given price to restore the equilibrium the level of capital has to be higher so that the price equilibrium equation has to shift down. On the other hand, lower barriers to imports will directly reduce the market share of domestic producers at home, and hence the RHS of A1 will be lower. For a given price, the level of capital thus has to be lower. This means that the capital equilibrium equation shifts down. As it is clear from the graph, prices will unambiguously be lower, but capital can be higher or lower than before. The analytic solution does not yield any unambiguous solution.

b) The cost of shipping manufactures to the north from the south, d_{NS} only has an effect through the equilibrium condition for capital, directly through the share of domestic products in northern markets π_{NS}. The equilibrium condition of the price unaffected. For a fixed level of prices, a lowering of d_{NS} will increase the share of the domestic firms in the northern market. This implies that the RHS of A1 will increase. For a given price the equilibrium level of capital, K has to be higher than before, so that the equilibrium condition for capital must shift upwards. As a result the equilibrium level of capital purchases increases.

c) I will prove that a decrease in the two components of the price of capital $w_k = p^k d^k$ will increase technology adoption. From result 6 we have that p^k has no effect on the trade shares π_{SS} or π_{NS}. Hence it will affect the equilibrium condition of capital only through two channels. A direct effect which increases the resources available for consumption $[L + R - w_k K]$ and an indirect effect through total payments to factors of production $H(K, w_k)$, with a positive effect. Thus for a fixed price, a decrease in p^k, will lower the LHS of A1 and rise the RHS. For a given price, equilibrium requires a higher level of capital, thus shifting the capital equilibrium equation upwards. On the other hand, it will affect the price equilibrium condition through the cost $c(K, w_k)$ also with a positive effect. Hence lowering p^k will decrease the RHS of the price equation. For a given price the level of capital has to be higher, thus the price equation will have to shift downward. As can bee seen in the graph, the equilibrium level of capital will be higher.

The cost of importing capital d^k affects both the price and capital equilibrium conditions. Its has a direct effect on the equilibrium equation for capital, via the amount of income devoted for consumption $[L + R - w_k K]$, and it will have an indirect effect both through total payments to factors of production $H(K, w_k)$ and the cost of a bundle of factors $c(K, w_k)$. Analyzing first what happens to the price equilibrium condition, we see that for a fixed price, a decrease in d^k will decrease the RHS of A2. For a given price, to restore the e quilibrium, the level of capital must be higher than before. This means that the price equilibrium equation will shift downward. As for the capital equilibrium condition, a lowering of d^k will rise both market shares, through a lower cost $c(K, w_k)$ and will increase the amount of resources available for consumption $[L + R - w_k K]$ this will rise the RHS of A1. On the other hand, the total payments to factors of production $H(K, w_k)$ will go down, consequently the LHS of A1 will decrease. For a fixed price, the equilibrium will require a higher level of K, so that the capital equilibrium condition must shift upward. As a result the equilibrium level of capital will be higher. *Q.E.D.*