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Variety-skill complementarity: a simple resolution of the trade-wage inequality anomaly

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Abstract

The Stolper-Samuelson theorem predicts that the relative wage of high-skilled to low-skilled labor will increase in the high-skill abundant U.S. but decrease in low-skill abundant Mexico after trade liberalization, while it actually began to rise in both countries in the late 1980s. We present a simple resolution of this "trade-wage inequality anomaly" in a model of variety trade. Variety trade increases the variety of intermediate goods used by the final good. If the varieties and high-skilled labor are complements, the skill premium rises in both countries. This linking of imports of new foreign varieties—the extensive margin—to wage inequality is compatible with evidence. Our numerical examples illustrate that small amounts of variety trade can produce a significant increase in relative wage.

Keywords Trade, Wage inequality, Variety-skill complementarity, Extensive margin

JEL Classification F12, F16

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1 Introduction

One of the most well documented empirical facts in recent U.S. economic history is that, as Fig. 1 shows, the relative wage of high-skilled to low-skilled labor began to rise in manufacturing industries in the late 1980s, and this fact was observed in Mexico as well.¹ As can be seen, these two countries showed a surprisingly similar timing of the rise in relative wage in the late 1980s and early 1990s.² The data also show that, as in Fig. 2, U.S.-Mexican trade (as a percent of U.S. GDP) was dramatically increasing during the same period.³ Hence, this increased trade might have contributed to the recent increase in skill premium in these countries. However, there are a number of criticisms on this line of thought.

One criticism is based on a "trade-wage inequality anomaly." The standard Heckscher-Ohlin (H-O) model demonstrates a discrepancy between the model and data. The Stolper-Samuelson theorem of the H-O model predicts that the relative wage of high-skilled to low-skilled labor will increase in the high-skill abundant U.S. but decrease in low-skill abundant Mexico after trade liberalization. The H-O model thus generates a positive relationship between the trade and wage inequality in the U.S. but generates a negative relationship in Mexico. On the other hand, as we have seen in Fig. 1 and 2, the data generated a positive relationship between the trade and wage inequality in both countries in the late 1980s and early 1990s. This is a "trade-wage inequality anomaly."

A second criticism is based on price movements. The Stolper-Samuelson theorem predicts the same direction of movement of the relative price of high-skill to low-skill intensive goods and the relative wage of high-skilled to low-skilled labor since the rise in the relative wage of high skill should be driven by the rise in the relative price of high-skill intensive good in the high-skill abundant U.S. However, data show that the relative prices of high-skill intensive goods were declining or constant during the 1980s while the relative wage of high skill was increasing in the U.S. (Lawrence and Slaughter 1993).

A third criticism is based on the volume of trade. Trade-based explanations have often

¹Here, we use non-production and production workers as an index for high-skilled and low-skilled workers in the U.S. and Mexican manufacturing industries (Berman et al. 1994; Robertson 2004). We calculate the U.S. relative wage during the period 1980-2000 on the basis of the U.S. Annual Survey of Manufactures (ASM). On the other hand, we calculate the Mexican relative wage on the basis of the Mexican Monthly Industrial Survey (*Encuesta Industrial Mensual*, or EIM) by first calculating the average monthly wage of non-production relative to production labor. The annual average is then produced by averaging this monthly relative wage.

²As shown in Fig. 1, the non-production/production wage ratio in Mexico reached a plateau after the North American Free Trade Agreement (NAFTA) was enacted in 1994. Esquivel and Rodríguez-López (2003) also show the same movements of Mexican wages. Robertson (2004) argues, using the Mexican Industrial Census, that the Mexican skill premium declined from 1994 to 1998. We also note that the U.S. and Mexican relative wages are shown on different scales in Fig. 1, for here we want to emphasize the qualitative movements of these series. In Section 4, we will emphasize the quantitative difference of the same series during the period 1987-1994.

³Here, U.S.-Mexican trade is defined by the sum of U.S. exports to and U.S. imports from Mexico. The data for trade and GDP are from the International Trade Administration and the Bureau of Economic Analysis.

been criticized due to the small volume of trade as has been shown in Fig. 2. Krugman (1995) provides a theoretical argument to explain why the small volume of trade in the U.S. makes it unlikely that trade can account for the change in wages.⁴

Thus, mainly due to these criticisms, trade-based explanations for rising wage inequality have been minor in economic academia.⁵ Rather, major explanations have been based on technological change. A sharp decline in equipment prices in the 1980s led to an increase in the demand for high-skilled workers, who were complements for this equipment, and a decline in the demand for low-skilled workers, who were substitutes (Krusell et al. 2000).⁶ This technology-based explanation is consistent with the decline in the price of high-tech goods and the increase in the wage inequality both in the U.S. and in Mexico.

We now propose a simple theoretical framework to illustrate the possibility of an increase in wage inequality in each of the trading countries as a result of even small amounts of trade, and this can happen without a rise in the relative price of high-skill intensive good.

We first present a simple resolution of the trade-wage inequality anomaly. Our resolution is based on a straightforward application of the well-known model of variety trade in intermediate goods due to Ethier (1982).⁷ Ethier's model demonstrates that the variety of intermediate goods, which final goods producers can use, increases in both countries after trade and, therefore, their production increases through the higher productivity caused by increased number of inputs. Let us emphasize again that Ethier says something increases in both countries after trade.

Upon application of this logic, we show that the variety trade in differentiated intermediate goods increases the variety of intermediate goods used by the final good in both countries. The increased variety of inputs then can mean the increased variety of tasks to be handled and thus corresponds to higher demand for high-skilled labor. Through this variety-skill complementarity, the relative wage of high skill—the skill premium—rises in both countries. Thus our model provides a resolution of the trade-wage inequality anomaly.⁸ Moreover, our model manages to capture an interesting difference in U.S. and Mexican

⁴It should be noted that Krugman (2008) argues that, due to the increase in U.S. trade with poor countries and the growing fragmentation of production, it is no longer safe to assume that the effect of trade on wage inequality is very minor, although he admits that it is hard to prove the actual effect.

⁵Many papers relate trade to wage inequality in the U.S. and Mexico. For example, Borjas and Ramey (1994) show how trade volumes can be linked to U.S. inequality, and Harrigan and Balaban (1999) estimate an econometric general equilibrium model of U.S. wages as a function of prices, technology, and factor supplies. Revenga (1997) and Hanson and Harrison (1999) link changes in Mexican inequality to changes in trade policy, and Verhoogen (2008) links quality upgrading for export to Mexican inequality. See Feenstra and Hanson (2003) for a survey on trade and inequality.

⁶Berman et al. (1994), Karni and Zilcha (1995), Berman et al. (1998), and Katz and Autor (1999) also relate technological change to wage/income inequality. Kremer and Maskin (1996) link technological change or skill-distribution to both wage inequality and segregation by skill, and their model is extended by McCann and Trokhimtchouk (2010).

⁷Ethier's (1982) model is an intermediate-good version of Krugman's (1979) variety-trade model.

⁸Dinopoulos et al. (2009) also link variety trade to wage inequality. Their model, however, modifies the standard one-sector variety-trade model by introducing quasi-homothetic preferences for varieties and non-homothetic technology in the production of each variety, thus relating an increase in the output of each variety—not an increase in the number of variety—to an increase in the relative demand for high-skilled

wages: the smaller country Mexico shows a much larger increase in the skill premium than the larger country U.S. does as shown in Fig. 1.

We next argue that our model, though simple, has the capability of being applied to real world data, although a definitive answer must wait for more serious empirical work. In fact, the linking of imports of new foreign varieties—the extensive margin—to wage inequality is compatible with available empirical evidence. The correlation between the growth in the extensive margin and the growth in the relative wage of high-skilled labor was high, over 0.93, in both U.S. and Mexican manufacturing industries during the period 1980-2000. The variety-skill complementarity appears to be a plausible assumption as shown by the facts in regards to U.S. production organization. The movements of the relative price of high-skill to low-skill intensive goods and the relative wage of high-skilled to low-skilled labor are also consistent with the observations in the U.S., so our model does not require the Stolper-Samuelson price-wage mechanism.

We finally show several numerical examples with plausible parameters to see if we can obtain a significant increase in skill premium with relatively small amounts of trade. In fact, our numerical examples illustrate the possibility that increased U.S.-Mexican manufacturing variety trade, which is a small fraction of U.S. manufacturing GDP, is capable of significantly contributing to the increase in skill premium in both U.S. and Mexican manufacturing industries from 1987 to 1994. We also show that trade and technological change are complementary in that they both can contribute to increased skill premium in both countries.

Of course, other economists have also been successful in resolving the anomaly on the basis of trade models. One major explanation is based on foreign direct investment. Feenstra and Hanson (1996) show that foreign direct investment shifts production activities from the North to the South—an endogenous transfer of technology—and thus increases the North's outsourcing the low-skill intensive goods to the South, and these goods are high-skill intensive goods by the South standards.⁹

A second major explanation is based on the Schumpeterian mechanism. Dinopoulos and Segerstrom (1999) show that trade increases the relative price of innovation (the reward for innovation relative to the current level of R&D difficulty), thus encouraging high-skill intensive R&D investment in each country.¹⁰ Acemoglu (2003) shows that trade "induces" skill-biased technological change in the U.S., and this improved technology can be trans-

labor by each variety.

⁹Zhu and Treffer (2005) also show a mechanism closely related to this mechanism by Feenstra and Hanson (1996). We note that Feenstra and Hanson (1996) resolve the trade-wage inequality anomaly observed during the 1980s on the basis of a skill intensity reversal: intermediate goods—previously produced in the North but now produced in the South—are relatively high-skill intensive in the South but relatively low-skill intensive in the North. This assumption, however, poses an empirical challenge since past research has found little evidence for the so-called "factor intensity reversal" over the period. We, however, resolve the anomaly without assuming this skill intensity reversal.

¹⁰Dinopoulos and Segerstrom (1999) show that a contemporaneous correlation between an index of the relative price of innovation and an index of the U.S. skill premium was 0.80 during the period 1963-1989.

ferred to other countries by spillover effects. Thus these explanations also demonstrate the rise in the relative wage of high-skilled labor in each of the trading countries.¹¹

Compared to these past studies, without introducing any foreign direct investment or dynamic Schumpeterian mechanism, this paper is successful in formulating a simpler trade model in which trade between two countries can cause an increase in wage inequality in both countries. Moreover, this paper is the first to quantitatively show the possibility that trade, even small in volume, significantly contributes to the increase in skill premium both in the U.S. and in Mexico.

The rest of this paper is organized as follows: in Section 2, we formulate a very simple model of variety trade, and we provide a resolution of the trade-wage inequality anomaly. Section 3 shows that our model is compatible with available empirical evidence. In Section 4, we present our numerical examples. Finally, we summarize main results and mention future research in Section 5.

2 The Model

In this section, we first formulate our model. Second, we explicitly solve the model and show that variety trade can increase the skill premium in both countries. Finally, we discuss some economic implications of the derived results.

2.1 Ingredients of the Model

Consider an economy with a final good sector and an intermediate goods sector. There are two types of skills: high-skilled and low-skilled labor. Their endowments are given by \bar{H} and \bar{L} , respectively. These skills differ in that the high-skilled labor can do both high-skill and low-skill tasks while the low-skilled labor can do only a low-skill task. As will be shown later, this excludes the possibility that the relative wage of high-skilled to low-skilled labor is less than one in equilibrium.

The production side is as follows. The final good sector is perfectly competitive and non-traded. It uses a continuum $[0, n]$ of differentiated intermediate goods and the high skill. The technology is given by the following constant returns to scale production function:

$$y = \left[\left(\int_0^n x(j)^\rho dj \right)^{\epsilon/\rho} + H^\epsilon \right]^{1/\epsilon},$$

where y is the output of final good, $x(j)$ and H are the demand for differentiated intermediate good j and high skill, and $0 < \rho < 1$. In our model, handling a variety of inputs is

¹¹Acemoglu (2003) might not be successful in explaining the fact that the U.S. and Mexico showed the surprisingly similar timing of the rise in skill premium. This is because the rise in skill premium in Mexico should be driven by the spillover effects in his model but this spillover process usually takes many years.

represented as handling a variety of tasks and thus corresponds to a high-skill task.¹² We thus assume that $\epsilon < 0$, that is, the elasticity of substitution between the varieties and high skill is given by $\sigma = 1/(1 - \epsilon) < 1$. We define this case $\epsilon < 0$ ($\sigma < 1$) as the case where the varieties and the high skill are complements.¹³

On the other hand, the differentiated intermediate goods sector is monopolistically competitive. Firms are symmetric and follow Cournot pricing rules.¹⁴ There is also free entry and exit. The intermediate goods can be traded. Each variety does not require handling a variety of inputs and thus can use the low-skill. The technology of each variety is given by the following increasing returns to scale production function:

$$x(j) = \left(\frac{1}{b}\right) \max[l(j) - f, 0], \forall j,$$

where $l(j)$ is the demand for low skill to produce each variety j , f is the fixed cost in terms of low skill, and b is the unit low-skill requirement. We note that the high skill can also do this low-skill task.

The demand side is as follows. For simplicity, we focus on a representative consumer who has the endowments of high skill and low skill: \bar{H} and \bar{L} . He or she consumes the final good. His or her utility function is given by

$$u(c) = c,$$

where c is the quantity of the final good he or she consumes. His or her budget constraint is given by

$$p_y c = w_H H^S + w_L L^S,$$

where p_y is the price of the final good, w_H is the wage for the high skill, and w_L is the wage for the low skill. H^S is the supply of high skill for the final sector, and L^S is the supply of low skill for the intermediate sector, which can include the high skill. We assume $0 \leq H^S \leq \bar{H}$, $\bar{L} \leq L^S \leq \bar{L} + \bar{H}$, and $H^S + L^S = \bar{H} + \bar{L}$.

The feasibility conditions for high-skilled labor and low-skilled labor are

$$H = H^S,$$

¹²In some papers, the number of inputs plays a role in a related way. Blanchard and Kremer (1997) define the index of complexity which relates the increased number of inputs to more complexity in production processes. Kremer (1993) shows that higher skill workers will use more complex technologies that incorporate more tasks.

¹³We note that we can generalize the production function of the final good by assuming that the final good uses three factors: varieties, high-skilled labor, and low-skilled labor. The results, however, are unchanged as long as we assume that the varieties are more complementary to the high-skilled labor than to the low-skilled labor. We also note that, as will be noted in footnote 15, switching the role of high-skilled and low-skilled labor but assuming $\epsilon > 0$ (the varieties and the low skill are substitutes) gives the same results in this model.

¹⁴In this model with a continuum $[0, n]$ of differentiated intermediate goods, Bertrand pricing rules give the same results as the Cournot pricing rules do.

$$\int_0^n l(j) dj = L^S.$$

2.2 Explicit Solutions and the Autarky Equilibrium

We explicitly solve our model. First, we derive the solutions in the intermediate goods sector.

Given an arbitrary n , each producer of a variety facing the indirect demand by the final good sector maximizes the profit $p(j)x(j) - w_L b x(j) - w_L f$ where $p(j)$ is the price of intermediate good j . By using the symmetry $x(j) = \bar{x}$, each variety's output \bar{x} and price \bar{p} corresponding to this n can be given by

$$\bar{x} = \left[\left(\frac{w_L b}{p_y n^{(\epsilon/\rho)-1} \rho} \right)^{\epsilon/(1-\epsilon)} - n^{\epsilon/\rho} \right]^{-1/\epsilon} H, \forall j,$$

$$\bar{p} = \frac{w_L b}{\rho}, \forall j.$$

Since the price does not depend on the number of varieties n , the price when the profit of each variety becomes zero by the free entry and exit is also given by $\bar{p} = w_L b/\rho$, and the zero profit condition $\bar{p}\bar{x} - b\bar{x} - f = 0$ gives the output \bar{x} of each variety. The equality of labor demand and supply in intermediate goods sector, $\bar{n}(b\bar{x} + f) = L^S$, gives the number of varieties \bar{n} . Thus the price \bar{p} and output \bar{x} of each variety and the number of varieties \bar{n} are given by

$$\bar{p} = \frac{w_L b}{\rho}, \forall j,$$

$$\bar{x} = \frac{f\rho}{b(1-\rho)}, \forall j,$$

$$\bar{n} = \frac{L^S(1-\rho)}{f}.$$

We next derive the solutions in the final good sector.

In our model with the CES production function, it is not difficult to obtain an explicit solution for the demand for each variety by the final good sector, but we solve the maximization problem for the final good sector by means of the following short-cut method. Define a new good

$$X = \left(\int_0^n x(j)^\rho dj \right)^{1/\rho}$$

and its price p_X , and we can show desired results more easily.

The profit of the final good sector now becomes

$$p_y (X^\epsilon + H^\epsilon)^{1/\epsilon} - p_X X - w_H H.$$

First, by solving the cost minimization problem for the good X , we find that the price

of X is:

$$p_X = \left(\int_0^n p(j)^{\rho/(\rho-1)} dj \right)^{(\rho-1)/\rho}.$$

By symmetry $p(j) = \bar{p}$, this becomes

$$p_X = n^{(\rho-1)/\rho} \bar{p},$$

where $\bar{p} = w_L b / \rho$.

Dividing both sides by w_L gives:

$$\frac{p_X}{w_L} = n^{(\rho-1)/\rho} \frac{b}{\rho}. \quad (1)$$

Second, we solve for X . Since the technology of the final good shows the constant returns to scale with X and H , we have the following equality:

$$y = \frac{p_X X + w_H H}{p_y}.$$

On the other hand, the demand for the final good is given by

$$c = \frac{w_H H^S + w_L L^S}{p_y}.$$

The final good market clearing $y = c$ and the feasible condition for the high skill $H = H^S$ then give

$$X = \frac{w_L L^S}{p_X}. \quad (2)$$

Third, we solve for the relative wage of high-skilled to low-skilled labor w_H/w_L . The first-order conditions with respect to X and H for the final sector give

$$\left(\frac{X}{H} \right)^{\epsilon-1} = \frac{p_X}{w_H}.$$

By using (2) and $H = H^S$, in autarky equilibrium the relative wage of high-skilled labor w_H/w_L is given by

$$\frac{w_H}{w_L} = \left(\frac{p_X}{w_L} \right)^\epsilon \left(\frac{L^S}{H^S} \right)^{1-\epsilon}. \quad (3)$$

This autarky equilibrium is represented in Fig. 3-a and 3-b. The demand for high skill and low skill by the production side, H and L , is represented by the isoquant curve of the final good: $y = [(w_L L/p_X)^\epsilon + H^\epsilon]^{1/\epsilon}$ which is given by $y = (X^\epsilon + H^\epsilon)^{1/\epsilon}$ and (2). On the other hand, the supply of labor for each sector, H^S and L^S , is represented by AB . The autarky equilibrium is then achieved at A in Fig. 3-a or C in Fig. 3-b, and thus the relative wage of high skill w_H/w_L , given by the slope of the isoquant curve, is greater than or equal

to one before trade.

Since the focus of this paper is on the skill premium, in the following main text we concentrate on the interesting case as shown in Fig. 3-a, in which the relative wage of high skill given by (3) is greater than one. Thus the high skill and low skill each do their own task, letting $H^S = \bar{H}$ and $L^S = \bar{L}$. In Appendix A.1, we briefly analyze the case as shown Fig. 3-b, in which the relative wage of high skill given by (3) is one and the high skill is doing both high-skill and low-skill tasks.

2.3 Trade Equilibrium and a Resolution of the Trade-Wage Inequality Anomaly

Consider two countries: country 1 and country 2. They have identical technologies and preferences. They can be different in their endowments of high-skilled and low-skilled labor. We assume that the relative wage of high-skilled to low-skilled labor is greater than one in both countries before trade as shown in Fig. 3-a. Thus the high skill and low skill each do their own task, letting $H_i^S = \bar{H}_i$ and $L_i^S = \bar{L}_i$ in each country i , $i = 1, 2$. The number of varieties is thus given by $\bar{n}_i = \bar{L}_i(1 - \rho)/f$ in each country i before trade.

Let these two countries trade with each other. Then, from the derived solutions in the intermediate goods, we easily get the following information. The supply of labor for the intermediate goods sector, which is given by $L_i^S = \bar{L}_i$ before trade, cannot fall below this \bar{L}_i after trade. This implies that the number of varieties produced within each country i , which is given by $\bar{n}_i = \bar{L}_i(1 - \rho)/f$ before trade, cannot fall below this autarky level \bar{n}_i after trade. Thus the total number of varieties which is available to the final good sector after trade, $n_1 + n_2$, is greater than the autarky level \bar{n}_i in each country i .

Given this information, we show the following results. Here, let us focus only on country 1:

First, p_{X1} now becomes

$$p_{X1} = \left(\int_0^{n_1} p(j)^{\rho/(\rho-1)} dj + \int_{n_1}^{n_1+n_2} p(j)^{\rho/(\rho-1)} dj \right)^{(\rho-1)/\rho}.$$

By the symmetry $p(j) = \bar{p}_1$ for $j \in [0, n_1]$ and $p(j) = \bar{p}_2$ for $j \in [n_1, n_1 + n_2]$, this becomes

$$p_{X1} = \left(n_1 \bar{p}_1^{\rho/(\rho-1)} + n_2 \bar{p}_2^{\rho/(\rho-1)} \right)^{(\rho-1)/\rho},$$

where $\bar{p}_1 = w_{L1}b/\rho$ and $\bar{p}_2 = w_{L2}b/\rho$.

Dividing both sides by w_{L1} gives:

$$\frac{p_{X1}}{w_{L1}} = \left(n_1 + n_2 \left(\frac{w_{L2}}{w_{L1}} \right)^{\rho/(\rho-1)} \right)^{(\rho-1)/\rho} \frac{b}{\rho}. \quad (1')$$

Thus we see that the trading level of p_{X1}/w_{L1} given by (1') becomes lower than the

autarky level $p_{X1}/w_{L1} = \bar{n}_1^{(\rho-1)/\rho} b/\rho$ given by (1) since the coefficient of b/ρ becomes smaller due to $n_1 + n_2 (w_{L2}/w_{L1})^{\rho/(\rho-1)} > \bar{n}_1$ and $(\rho - 1)/\rho < 0$.

Second, from (2) we see that X_1 increases after trade since p_{X1}/w_{L1} decreases and L_1^S , which is \bar{L}_1 before trade, does not decrease. This implies that the marginal product of high-skilled labor given by $MPH_1 = (X_1^\epsilon + H_1^\epsilon)^{(1/\epsilon)-1} H_1^{\epsilon-1}$ increases for any H_1 . That is, the demand for high skill by the final good shifts upward. Since the supply of high skill for the final good, which is \bar{H}_1 before trade, does not increase, this implies that the real wage of high skill w_{H1}/p_{y1} increases.

Finally, from (3) we see that since $\epsilon < 0$ ($\sigma < 1$), that is, since the varieties and high skill are complements, the relative wage of high skill w_{H1}/w_{L1} —the skill premium—increases after trade. This is because $(p_{X1}/w_{L1})^\epsilon$ increases and $(L_1^S/H_1^S)^{1-\epsilon}$, which is $(\bar{L}_1/\bar{H}_1)^{1-\epsilon}$ before trade, does not decrease.¹⁵

Thus it follows that the high skill and low skill each do their own task after trade as well as before trade. That is, the supply of labor for the final and intermediate sectors remains at $H_1^S = \bar{H}_1$ and $L_1^S = \bar{L}_1$, respectively. Hence, the number of varieties produced within country 1 after trade remains at the autarky level $\bar{n}_1 = \bar{L}_1(1 - \rho)/f$.

We note that the above results are also obtained in country 2. Hence, we get the following results:

The variety trade in intermediate goods causes the total number of varieties available to the final good sector to simply increase from \bar{n}_i to $\bar{n}_1 + \bar{n}_2$, the sum of the autarky levels, in each country i . This causes p_{Xi}/w_{Li} to decline and thus causes X_i to increase in both countries. Consequently, the demand for high skill shifts upward, thus increasing the real wage of high skill w_{Hi}/p_{yi} in both countries. Moreover, since the varieties and high skill are complements, the decrease in p_{Xi}/w_{Li} also increases the relative wage of high skill w_{Hi}/w_{Li} —the skill premium—in both countries. Thus our model has provided a resolution of the trade-wage inequality anomaly.

We can derive more results from the above discussion. First, since the number of varieties before trade is given by $\bar{n}_i = \bar{L}_i(1-\rho)/f$ in each country i , the ratio of the number of varieties produced within each country before trade is given by $\bar{n}_1/\bar{n}_2 = \bar{L}_1/\bar{L}_2$. This implies that the rate of increase in \bar{n}_i is smaller in a country with the larger size of \bar{L}_i , and, therefore, the rate of decrease in p_{Xi}/w_{Li} is also smaller as can be seen in (1'). Hence, the rise in the relative wage of high skill w_{Hi}/w_{Li} is smaller in a country with the larger size of \bar{L}_i as can be seen in (3).¹⁶

Second, if $\epsilon = 0$ ($\sigma = 1$), that is, if the production function of the final good is given by the Cobb-Douglas function, from (3) we see that the relative wage of high skill w_{Hi}/w_{Li} is

¹⁵We note that switching the role of high-skilled and low-skilled labor but assuming $\epsilon > 0$ (the varieties and the low skill are substitutes) gives the same results in this model.

¹⁶In fact, this prediction is compatible with the following observations: the number of production workers in manufacturing industries was much greater in the U.S. than in Mexico during the period 1980-1994. As shown in Fig. 1, the U.S. skill premium increased by 12.5 percent from 1980 to 1994, while the Mexican skill premium increased by 48.9 percent.

not affected by the decrease in p_{Xi}/w_{Li} and therefore does not change after trade in either country.

2.4 Economic Implications of the Results

Before moving on to Section 3, we need to consider economic implications of some of the results which have been shown in Section 2.3 on the basis of the explicit solutions to the model. First, we explain the economic reason why the good X increases after trade, that is, why the MPH increases after trade.

As we have seen, the activities in the intermediate goods sector never change at all in each country after trade. Some changes, however, do occur after trade. The number of varieties used by the final good sector increases, while the input quantity of each variety used by the final good sector decreases in each country since each variety is shared by two countries.

Can the effect of increase in the number of varieties be canceled by the effect of decrease in the input quantity of each variety? The answer is no. This is because the effect of increase in the number of varieties is greater than the effect of decrease in the input quantity of each variety. This is the crucial effect in the variety-trade models which Ethier (1982) called the "international returns to scale." That is, the increased number of inputs translates into higher productivity. Thus the good X increases after trade, that is, the MPH increases after trade.

We next explain the economic reason why the relative wage of high skill can rise after trade. Now the final good market clearings $y_i = c_i$ in each country i , $i = 1, 2$, before trade are given by

$$y_i = \frac{w_{Hi}\bar{H}_i + w_{Li}\bar{L}_i}{p_{yi}}.$$

Since $w_{Hi}/p_{yi} = MPH_i$, this becomes the following:

$$y_i = MPH_i \cdot \bar{H}_i + \frac{w_{Li}}{p_{yi}} \bar{L}_i.$$

As we have seen, the marginal product of high skill increases in each country after trade. For the same reason, the output of final good also increases in each country after trade.

Since $MPH_i = (X_i^\epsilon + \bar{H}_i^\epsilon)^{(1/\epsilon)-1} \bar{H}_i^{\epsilon-1}$ and $y_i = (X_i^\epsilon + \bar{H}_i^\epsilon)^{1/\epsilon}$, it can be shown that the rate of increase in MPH_i is greater than the rate of increase in y_i since $\epsilon < 0$, that is, since the varieties and high skill are complements. This relationship and the final good market clearing condition $y_i = MPH_i \cdot \bar{H}_i + w_{Li}/p_{yi} \cdot \bar{L}_i$ imply that the rate of increase in MPH_i should be greater than the rate of change in w_{Li}/p_{yi} . In other words, the rate of increase in the real wage of high skill w_{Hi}/p_{yi} is greater than the rate of change in the real wage of low skill w_{Li}/p_{yi} . Thus the relative wage of high skill w_{Hi}/w_{Li} can increase in each country i .

3 Indirect Evidence for Mechanism

In this section, we first show that the linking of imports of new foreign varieties—the extensive margin—to wage inequality is compatible with available empirical evidence. Second, we claim that variety-skill complementarity appears to be a plausible assumption. We finally show that our model demonstrates price movement consistent with observed facts.

3.1 Extensive Margin and the Relative Wage of High-Skilled Labor

Fig. 4-a plots the 1980-2000 data on the growth in what Kehoe and Ruhl (2009) call the "least traded goods" in U.S. manufacturing imports from Mexico and on the relative wage of high-skilled to low-skilled labor in U.S. manufacturing industries. Fig. 4-b, on the other hand, plots the growth in the least traded goods in Mexican manufacturing imports from the U.S and the relative wage in Mexican manufacturing industries during the same period.

Kehoe and Ruhl classify the set of goods which accounts for only 10 percent of trade as the least traded goods. Here, we use the least traded goods for measuring the extensive margin. The data for the least traded goods growth are the Standard International Trade Classification (SITC) (revision 2) 3-digit manufacturing data from the OECD International Trade by Commodities Statistics (ITCS).¹⁷ The source of data for the U.S. and Mexican relative wages is the same as for Fig. 1.

As can be seen in Fig. 4-a and 4-b, the least traded goods that account for 10 percent of U.S. manufacturing imports from Mexico in 1980 account for 42.5 percent in 2000, and the least traded goods that account for 10 percent of Mexican manufacturing imports from the U.S. in 1980 account for 17.5 percent in 2000, respectively. This indicates that each country started importing goods that it had not imported before or had imported only in small quantities. Moreover, these figures reveal that this growth in the least traded goods was highly correlated with the growth in the relative wage in each country over 1980-2000. In fact, the correlation between these two series was high in each country: it was 0.932 and 0.947 in the U.S. and Mexico, respectively. Thus the linking of the extensive margin to the skill premium is compatible with this evidence in both countries.

It is worth noting that the method by Kehoe and Ruhl (2009) used in this paper for measuring the extensive margin is different from methods used in the few previous studies of the extensive margin. Broda and Weinstein (2006), for example, classify a good as not traded if the value of trade is zero, and Evenett and Venables (2002) classify a good as not traded if its yearly value of trade is less than or equal to 50,000 1985 U.S. dollars, regardless of the country to be studied. In Kehoe and Ruhl's definition of a non-traded good, on the other hand, goods with very small but non-zero amounts of trade can also be considered, and the actual dollar value of the cutoff can differ across countries.

¹⁷See Kehoe and Ruhl (2009) for the detailed procedure used to construct Fig. 4-a and 4-b. We note that the manufacturing imports in these figures include imports of both final and intermediate goods. Fortunately, however, much of the increase in trade has been in intermediate goods (Feenstra 1998).

3.2 Variety-Skill Complementarity

In our model, we have represented the variety of inputs as the variety of tasks which workers need to handle. Thus it is plausible to assume that the increased variety of inputs—the increased variety of tasks to be handled—translates into higher demand for high-skilled workers. In fact, this variety-skill complementarity appears to be a plausible assumption as shown by the historical facts in regards to U.S. production organization emphasized by Mitchell (2005).

During the first half of the 20th century, the spread of mass production, which is characterized by Ford’s factories, led to the larger size of manufacturing plants. On the other hand, during the second half of the century, flexible machine tools have allowed plants to operate at a smaller scale. The organization of production has changed from mass production with a traditional assembly line to smaller customized batches, thus making the size of plants smaller.¹⁸

Workers on the assembly line have a single routine task to perform; however, workers in each batch are no longer as highly specialized in a single routine task. Each batch is highly customizable and requires a worker who can handle a wide variety of tasks depending on the custom features of the batch. The change in the production organization therefore affected the number of tasks and therefore affected the importance of skills. As the tasks shifted from a single routine task to a wide variety of tasks, the required skill shifted from low skill to high skill.

Our assumption of the variety-skill complementarity is thus compatible with these historical facts in regards to U.S. production organization, although a definitive answer must wait for serious empirical work.¹⁹

3.3 Relative Price of High-Skill Intensive Goods

The standard H-O model predicts the same direction of movement of the relative price of high-skill to low-skill intensive goods and the relative wage of high-skilled to low-skilled labor since the rise in the relative wage of high skill should be driven by the rise in the relative price of high-skill intensive good in the high-skill abundant U.S. However, data show that the relative prices of high-skill intensive goods were declining or constant during the 1980s while the relative wage of high skill was increasing in the U.S. (Lawrence and Slaughter 1993).

Our model demonstrates price movement consistent with this observed fact whereas the H-O model cannot. In Section 2.4, it has been shown that the rate of change in w_{Li}/p_{yi} should be smaller than the rate of increase in MPH_i since $\epsilon < 0$. This implies that w_{Li}/p_{yi}

¹⁸Milgrom and Roberts (1990) present the empirical facts on a change in the size of U.S. manufacturing plants.

¹⁹The above historical observation is compatible with the theoretical result obtained by Kremer (1993) referred to in footnote 12.

can rise (but it should rise less than MPH_i), and therefore, the price of high-skill intensive final good relative to the low-skill wage, p_{yi}/w_{Li} , can decline. Here, let us recall that the price of the low-skill intensive variety relative to the low-skill wage, \bar{p}_i/w_{Li} , is constant at b/ρ before and after trade. Hence, the relative price of high-skill to low-skill intensive goods, $(p_{yi}/w_{Li})/(\bar{p}_i/w_{Li})$, can decline while the relative wage of high skill rises, letting $\epsilon < 0$. Thus the rise in the relative wage of high skill can happen without the rise in the relative price of high-skill intensive good.²⁰

4 Numerical Examples

We have shown that trade—in particular, variety trade—can theoretically cause the increase in skill premium in two countries and that our model is compatible with available empirical evidence. This section shows several numerical examples with plausible parameters to see if relatively small amounts of variety trade can produce a significant increase in skill premium without technological change.²¹

An increase in variety trade is here represented as a tariff reduction, for a tariff reduction in each country can mean that each country can use more foreign varieties.²² Technological change, on the other hand, is here represented as a decrease in fixed cost f . A decrease in f can cause an increase in the number of varieties, $n = \bar{L}(1 - \rho)/f$, without an increase in variety trade and thus can cause an increase in the demand for the high skill.²³

4.1 Model with Tariffs

We introduce tariffs into our simple model and assume that each country i , $i = us, mex$, imposes *iceberg* tariffs τ_i on imports from the other country, that is, the import quantity of a foreign variety is equal to the sum of the input quantity of the foreign variety used by the final good and the *iceberg* tariffs. We also introduce the share parameter α , $0 < \alpha < 1$, into the production function of the final good:

$$y_i = \left[\alpha \left(\int_0^{n_{us} + n_{mex}} x(j)_i^\rho dj \right)^{\epsilon/\rho} + (1 - \alpha) H_i^\epsilon \right]^{1/\epsilon}, \quad i = us, mex.$$

We note that the definition of an equilibrium with tariffs and all the derivations of

²⁰We note that the price of final good can be constant or increase if $\epsilon < 0$.

²¹Our model is very simple and thus cannot perform full-scale calibrations capturing many facts. Here, we just want to show several numerical examples with plausible parameters.

²²In Section 2, we have looked at the movement from autarky to trade in order to show our idea in the simplest way. However, here we begin with a trade equilibrium in order to compare our model with actual trade data. Thus variety trade can increase due to the increased import volumes of existing foreign varieties as well as the imports of new foreign varieties.

²³We note that in our model "technological change" refers to non-trade-based technological change which can occur without trade, although it is possible to interpret the increased number of inputs due to trade as trade-based technological change.

equations below are shown in Appendix A.2. We also note that our focus is on $w_{Hi}/w_{Li} > 1$, thus $H_i^S = \bar{H}_i$ and $L_i^S = \bar{L}_i$, $i = us, mex$.

The relative wages of high skill are now given by

$$\frac{w_{Hus}}{w_{Lus}} = \frac{1 - \alpha}{\alpha} \left(\frac{(1 - \rho)}{f} \left(\frac{b}{\rho} \right)^{\rho/(\rho-1)} \left(\bar{L}_{us} + \bar{L}_{mex} \left((1 + \tau_{us}) \frac{w_{Lmex}}{w_{Lus}} \right)^{\rho/(\rho-1)} \right) \right)^{\epsilon(\rho-1)/\rho} \left(\frac{\bar{L}_{us}}{\bar{H}_{us}} \right)^{1-\epsilon}, \quad (4)$$

$$\frac{w_{Hmex}}{w_{Lmex}} = \frac{1 - \alpha}{\alpha} \left(\frac{(1 - \rho)}{f} \left(\frac{b}{\rho} \right)^{\rho/(\rho-1)} \left(\bar{L}_{us} \left((1 + \tau_{mex}) \frac{w_{Lus}}{w_{Lmex}} \right)^{\rho/(\rho-1)} + \bar{L}_{mex} \right) \right)^{\epsilon(\rho-1)/\rho} \left(\frac{\bar{L}_{mex}}{\bar{H}_{mex}} \right)^{1-\epsilon}. \quad (5)$$

The volume of U.S.-Mexican variety trade relative to U.S. GDP is given by

$$2 \frac{\bar{L}_{us} \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} (w_{Lus}/w_{Lmex}) + \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}} / (w_{Hus}/w_{Lus}) \bar{H}_{us} + \bar{L}_{us}, \quad (6)$$

where w_{Hus}/w_{Lus} is given by (4).

4.2 Numerical Examples: Variety Trade and the Skill Premium

We simulate our model, "backcasting" from 1994 to 1987, to see what changes in U.S. and Mexican skill premium between 1987 and 1994 are predicted by the model.²⁴

We first give plausible values to some parameters. The value of $\rho = 0.83$ ($= 1/1.2$) is chosen so that the markup charged by each variety is 1.2. Norrbin (1993) and Basu (1996) both obtained empirical estimates of 1.05-1.4 for markups for intermediate goods, indicating that our choice is plausible. We normalize $b = 10$ and $f = 100$, the choice of which leaves our results (percent changes in skill premium) unchanged. We note that by keeping f constant from 1987 to 1994, we assume that no technological change occurs. The labor endowments \bar{L}_i and \bar{H}_i , $i = us, mex$, are constructed from the OECD Structural Analysis (STAN), the ASM, and the EIM data. U.S. endowments are first chosen from the data. We then calculate \bar{L}_{mex} so that the ratio $\bar{L}_{us}/\bar{L}_{mex}$ matches with the observed ratio $w_{Lus}\bar{L}_{us}/w_{Lmex}\bar{L}_{mex}$ in each year (effective labor units). This is because, as will be shown later, the balance of trade holds at $w_{Lus}/w_{Lmex} = 1$ in each year under our choice of parameters. We also calculate \bar{H}_{mex} so that the ratio $\bar{H}_{mex}/\bar{L}_{mex}$ matches with the observed ratio.²⁵

²⁴Bergoing and Kehoe (2003) quantitatively test the "new trade theory" by "backcasting" from 1990 to 1961. Due to data constraint, here we use data from 1987 to 1994. Fortunately, however, Mexico acceded to the General Agreement on Tariffs and Trade (GATT) in 1986 and agreed to a major liberalization of bilateral trade relations with the U.S. in 1987. Though the time-series movements of the inequality over 1987-1994 are outside the scope of this paper, it is worth noting that recent studies on the dynamics and persistence of inequality are, for example, Ray (2006) and Alexopoulos and Cavalcanti (2009).

²⁵U.S. endowments are: $\bar{H}_{us,1987} = 6707.6$, $\bar{L}_{us,1987} = 12242.7$, $\bar{H}_{us,1994} = 6274.3$, $\bar{L}_{us,1994} = 11845.3$ (in thousands of workers). Mexican endowments are: $\bar{H}_{mex,1987} = 94.6$, $\bar{L}_{mex,1987} = 222.5$, $\bar{H}_{mex,1994} = 210.0$, $\bar{L}_{mex,1994} = 481.2$, which satisfy: $\bar{L}_{us,1987}/\bar{L}_{mex,1987} = 55.03$, $\bar{L}_{us,1994}/\bar{L}_{mex,1994} = 24.61$, $\bar{H}_{mex,1987}/\bar{L}_{mex,1987} = 0.425$, $\bar{H}_{mex,1994}/\bar{L}_{mex,1994} = 0.436$.

We then perform our simulations using the following method:

Step 1: We choose the value of ϵ .

Step 2: We simulate our model to 1994 data. We normalize $\tau_{us,1994} = 0.01$ and then calculate the values of α and $\tau_{mex,1994}$ so that the U.S. relative wage in 1994 given by (4) matches with the corresponding data, satisfying the balance of trade in 1994 at $w_{Lus}/w_{Lmex} = 1$.

Step 3: We "backcast" to 1987. We calculate the values of tariffs $\tau_{us,1987}$ and $\tau_{mex,1987}$ so that the change in (6) between 1987 and 1994 is the same as the observed change in the volume of U.S.-Mexican manufacturing variety trade relative to U.S. manufacturing GDP, satisfying the balance of trade in 1987 at $w_{Lus}/w_{Lmex} = 1$ as well.

Step 4: We calculate how much the U.S. and Mexican relative wages (4) and (5) increase from 1987 to 1994.

Table 1-a reports the results of our benchmark numerical example in which $\epsilon = -1$ ($\sigma = 0.5$). Here, the volume of U.S.-Mexican manufacturing variety trade is measured by multiplying the Grubel-Lloyd (1975) index (a measurement of the variety-trade share) and the volume of U.S.-Mexican total manufacturing trade. The index for a country is a weighted average over SITC (revision 2) 3-digit manufacturing industries as follows:

$$1 - \frac{\sum_k |EX_k - IM_k|}{\sum_k (EX_k + IM_k)},$$

where EX_k and IM_k represent exports and imports of industry k . These data are obtained from the OECD ITCS and the OECD STAN.²⁶ The data for the U.S. and Mexican relative wages are extracts from Fig. 1. The parameters in the model are listed separately: free parameters in (a) and calculated parameters in (b).

As can be seen, the U.S. relative wage in 1994 is the same as the observed data, 1.780, and the volume of U.S.-Mexican manufacturing variety trade relative to U.S. manufacturing GDP increases by 158.2 percent as do the corresponding data. As a result, the U.S. relative wage increases by 6.8 percent from 1987 to 1994 while the data show a 9.2 percent increase, and the Mexican relative wage increases by 34.2 percent while the data show a 43.6 percent increase.

Thus the results indicate that increased variety trade accounts for 73.8 percent of the change in U.S. skill premium and accounts for 78.5 percent of the change in Mexican skill premium in the manufacturing industries during the period 1987-1994. We have here illustrated the possibility that U.S.-Mexican manufacturing variety trade, which is a small

²⁶We note that the manufacturing variety trade includes variety trade in both final and intermediate goods. Fortunately, however, variety trade between the U.S. and Mexico primarily involves intermediate goods (Ray 1991).

fraction of U.S. manufacturing GDP, can significantly contribute to the increase in wage inequality.²⁷

We note, however, that U.S.-Mexican manufacturing variety trade is not small from the Mexican viewpoint. In fact, U.S.-Mexican manufacturing variety trade as a fraction of Mexican manufacturing GDP was 50.2 percent in 1987 and 75.5 percent in 1994 as shown in the table. The table also shows the corresponding results in the model, but the results are far from the data in terms of the percent change. This is because much of the fluctuations in the trade to GDP ratio in Mexico were caused by fluctuations in GDP and in the real exchange rate. Our model cannot capture these fluctuations.

Table 1-b reports the results of the numerical example in which the reduction in f —technological change—occurs together with the tariff reduction from 1987 to 1994. The results indicate that if f decreases by 10.6 percent together with the same tariff reduction as in the previous benchmark example, then this can cause U.S. skill premium to increase by the same as data and can account for 85.4 percent of the increase in Mexican skill premium.²⁸

Thus the results indicate that trade and technological change are complementary in that they both can contribute to increased skill premium in both countries.

4.3 Sensitivity Analysis

The results obviously depend on the values of ϵ and ρ . We present some calculations for a variety of ϵ and ρ .

Table 2 reports the results of the numerical examples in which $\rho = 0.83$ remains unchanged but $\epsilon = -0.5$ ($\sigma = 0.66$) and $\epsilon = -1.5$ ($\sigma = 0.4$), respectively. The results indicate that a more negative value of ϵ —a smaller elasticity of substitution between the varieties and high skill, σ —is accompanied by a larger change in skill premium in both countries.

Table 2 also reports the results of the numerical examples in which $\epsilon = -1$ remains unchanged but $\rho = 0.7$ and $\rho = 0.9$, respectively. The results indicate that a change in the value of ρ —the elasticity of substitution between varieties—has larger effects on skill premium in the smaller country, Mexico.

5 Conclusion and Future Research

The main purpose of this paper has been to provide a simple resolution of the trade-wage inequality anomaly in a model of variety trade compatible with available empirical evidence.

²⁷It should be noted that even if we use data on trade in intermediate goods instead of data on variety trade, the numerical results would be little changed. This is because evidence suggests that a considerable amount of trade in intermediate goods is variety trade (Turkcan 2005).

²⁸We note that the 10.6 percent decrease in f is equivalent to the 10.6 percent increase in the number of firms, $n = \bar{L}(1 - \rho)/f$, in each country.

Section 2 has presented a simple resolution of the anomaly. We have shown that the variety trade increases the variety of intermediate goods used by the final good in both countries; as a result, if the varieties and high skill are complements, the skill premium rises in both countries after trade. Thus variety trade can stimulate variety-skill complementarity.

Section 3 has shown that our model is compatible with available empirical evidence. The correlation between the growth in the extensive margin and the growth in the relative wage of high-skilled labor was high, over 0.93, in both U.S. and Mexican manufacturing industries during the period 1980-2000. The variety-skill complementarity appears to be a plausible assumption as shown by the facts in regards to U.S. production organization, and the rise in the relative wage of high-skilled to low-skilled labor can happen without the rise in the relative price of high-skill to low-skill intensive goods, which is also consistent with the observed fact in the U.S.

Section 4 has shown that our model can produce a significant increase in relative wage with relatively small amounts of trade. In fact, our numerical examples have illustrated the possibility that increased U.S.-Mexican manufacturing variety trade, which is a small fraction of U.S. manufacturing GDP, is capable of significantly contributing to the increase in skill premium in both U.S. and Mexican manufacturing industries from 1987 to 1994.

It is true that the standard H-O model is incompatible with data which show a rising wage inequality in each of the trading countries. However, we can now show, using an elementary model, that trade—in particular, variety trade—can be a possible source of the increased wage inequality in each country. We note that the result that trade can theoretically increase wage inequality is not necessarily negative, for our model shows that the real wage of both high skill and low skill can rise despite the increase in inequality.²⁹

Of course, room for future research still exists. First, this paper has made a theoretical contribution in formulating a simple trade model to illustrate the possibility of an increase in skill premium as a result of variety trade. It, however, has not yet provided a compelling empirical analysis, although it has shown several numerical examples. This is because (a) trade in final goods is ignored in this paper, (b) much of output is services, which are largely non-traded but ignored in this paper, and (c) trade is not balanced in data.

Thus, in another paper, we formulate a more general version of our variety-trade model which can resolve problems (a)-(c) and allow us to perform a full-scale calibration.³⁰ In the model calibrated to the Mexican input-output data for 1987, our numerical experiments show that the increase in U.S.-Mexican manufacturing variety trade can account for approximately 12 percent of the actual increase in Mexican skill premium over 1987-2000. The result indicates that our mechanism is an important factor contributing to the increase in skill premium in its own right, but it seems to be quantitatively less important than

²⁹In fact, the real wage of non-production labor has increased, and, further, the real wage of production workers have slightly increased since the 1980s.

³⁰See Atolia and Kurokawa (2009).

other mechanisms such as technological change.³¹

Second, intermediate goods are horizontal in nature in our model, but it would be interesting to modify the model to consider vertical integration as in Yi (2003). Third, we can analyze the relationship between competition policies and wage inequality. In our model, the change in the number of varieties is related to wage inequality. This implies that government can affect wage inequality by entry policies which adjust the number of firms (see Kurokawa 2010). Finally, our model has been applied to the problems of trade between the U.S. and Mexico, but we can also directly apply it to the problems of intra-trade among EU nations.

Appendix

A.1 The Movement of High-Skilled Labor

In Section 2, we have focused on the interesting case in which the relative wage w_H/w_L given by (3) is greater than one before trade. Thus the high skill and low skill each do their own task, letting $H^S = \bar{H}$ and $L^S = \bar{L}$. In this appendix, we briefly analyze the other case in which the relative wage w_H/w_L given by (3) is one and the high skill is doing both high-skill and low-skill tasks before trade.

In the autarky equilibrium as shown in Fig. 3-b, the relative wage w_H/w_L given by (3) is one at C , and part of high skill is doing the low-skill task in the intermediate goods sector. This movement of high skill from A to C maximizes the output of final good, that is, the consumer's utility.

As we have seen in Section 2.3, the case as shown in Fig. 3-a let us conclude that the skill premium rises after trade. On the other hand, if it is one before trade as shown in Fig. 3-b, it can be shown that the relative wage w_H/w_L rises or remains after trade, and, in any case, the number of varieties used by the final good surely increases.

A.2 Model with Tariffs

A.2.1 Equilibrium

Definition 1 *An equilibrium is prices $p_{yus}, p_{ymex}, p(j), j \in [0, n_{us} + n_{mex}]$, $w_{Hus}, w_{Hmex}, w_{Lus}, w_{Lmex}$, and quantities $c_{us}, c_{mex}, y_{us}, y_{mex}, x(j)_{us}, x(j)_{mex}, x(j), j \in [0, n_{us} + n_{mex}]$, $H_{us}, H_{mex}, l(j), j \in [0, n_{us} + n_{mex}]$, $H_{us}^S, H_{mex}^S, L_{us}^S, L_{mex}^S$, and the number of firms in the intermediate sectors n_{us}, n_{mex} , given iceberg tariffs τ_{us} and τ_{mex} , such that*

1. *Final good: Given prices $p_{yi}, p(j)$, and w_{Hi} , quantities $y_i, x(j)_i$, and H_i solve*

³¹Berman et al. (1994) argue, using a regression, that skill-biased technological change can account for 40 percent of the shift in demand away from low-skilled and toward high-skilled labor in U.S. manufacturing during the 1980s. Krusell et al. (2000) find, using a calibrated model, that most of the wage inequality shift of the last 30 years in the U.S. can be explained by the capital-skill complementarity hypothesis.

(a) U.S.

$$\max p_{yus} y_{us} - \int_0^{n_{us}} p(j) x(j)_{us} dj - \int_{n_{us}}^{n_{us}+n_{mex}} p(j) (1 + \tau_{us}) x(j)_{us} dj - w_{Hus} H_{us}$$

$s, t,$

$$y_{us} = \left[\alpha \left(\int_0^{n_{us}+n_{mex}} x(j)_{us}^\rho dj \right)^{\epsilon/\rho} + (1 - \alpha) H_{us}^\epsilon \right]^{1/\epsilon},$$

(b) Mexico

$$\max p_{ymex} y_{mex} - \int_0^{n_{us}} p(j) (1 + \tau_{mex}) x(j)_{mex} dj - \int_{n_{us}}^{n_{us}+n_{mex}} p(j) x(j)_{mex} dj - w_{Hmex} H_{mex}$$

$s, t,$

$$y_{mex} = \left[\alpha \left(\int_0^{n_{us}+n_{mex}} x(j)_{mex}^\rho dj \right)^{\epsilon/\rho} + (1 - \alpha) H_{mex}^\epsilon \right]^{1/\epsilon};$$

2. Intermediate goods: Given price w_{Li} , quantity $x(j)$ solves

(a) U.S. $j \in [0, n_{us}]$

$$\max p(j) x(j) - w_{Lus} b x(j) - w_{Lus} f, \text{ where } x(j) = x(j)_{us} + (1 + \tau_{mex}) x(j)_{mex},$$

(b) Mexican $j \in [n_{us}, n_{us} + n_{mex}]$

$$\max p(j) x(j) - w_{Lmex} b x(j) - w_{Lmex} f, \text{ where } x(j) = (1 + \tau_{us}) x(j)_{us} + x(j)_{mex};$$

3. Consumer: Given prices p_{yi} , w_{Hi} , and w_{Li} , quantities c_i , H_i^S , L_i^S solve

(a) U.S.

$$\max c_{us} \quad s, t, \quad p_{yus} c_{us} = w_{Hus} H_{us}^S + w_{Lus} L_{us}^S,$$

(b) Mexico

$$\max c_{mex} \quad s, t, \quad p_{ymex} c_{mex} = w_{Hmex} H_{mex}^S + w_{Lmex} L_{mex}^S;$$

4. Market clearing:

$$c_{us} = y_{us}, \quad c_{mex} = y_{mex},$$

$$x(j)_{us} + (1 + \tau_{mex}) x(j)_{mex} = x(j), \quad j \in [0, n_{us}],$$

$$(1 + \tau_{us}) x(j)_{us} + x(j)_{mex} = x(j), \quad j \in [n_{us}, n_{us} + n_{mex}],$$

$$H_{us} = H_{us}^S, \quad H_{mex} = H_{mex}^S,$$

$$\int_0^{n_{us}} l(j) dj = L_{us}^S, \quad j \in [0, n_{us}], \quad \int_{n_{us}}^{n_{us}+n_{mex}} l(j) dj = L_{mex}^S, \quad j \in [n_{us}, n_{us} + n_{mex}].$$

Note : $(1 + \tau_{mex}) x(j)_{mex}$, $j \in [0, n_{us}]$, means that the imports of a U.S. variety by Mexico, and $(1 + \tau_{us}) x(j)_{us}$, $j \in [n_{us}, n_{us} + n_{mex}]$, means that the imports of a Mexican variety by the U.S. We note that the U.S. and Mexican final good can use only $x(j)_{us}$ and $x(j)_{mex}$ as input, respectively.

A.2.2 Solutions

Intermediate Goods

Introducing tariffs does not change the solutions in the intermediate goods sector.

By the symmetry $p(j) = \bar{p}_{us}$ for $j \in [0, n_{us}]$ and $p(j) = \bar{p}_{mex}$ for $j \in [n_{us}, n_{us} + n_{mex}]$, the price and output of each variety and the number of varieties in each country are now given by

$$\begin{aligned}\bar{p}_{us} &= \frac{w_{Lus}b}{\rho}, \quad j \in [0, n_{us}], \quad \bar{p}_{mex} = \frac{w_{Lmex}b}{\rho}, \quad j \in [n_{us}, n_{us} + n_{mex}], \\ \bar{x}_{us} &= \frac{f\rho}{b(1-\rho)}, \quad j \in [0, n_{us}], \quad \bar{x}_{mex} = \frac{f\rho}{b(1-\rho)}, \quad j \in [n_{us}, n_{us} + n_{mex}], \\ \bar{n}_{us} &= \frac{\bar{L}_{us}(1-\rho)}{f}, \quad \bar{n}_{mex} = \frac{\bar{L}_{mex}(1-\rho)}{f}.\end{aligned}$$

Final Good

The profit of the final good sector now becomes

$$p_{yi}(\alpha X_i^\epsilon + (1-\alpha)H_i^\epsilon)^{1/\epsilon} - p_{Xi}X_i - w_{Hi}H_i, \quad i = us, mex.$$

By solving the cost minimization problem for the good X , we can find that the price of X in each country is:

$$\begin{aligned}p_{Xus} &= \left(\int_0^{n_{us}} p(j)^{\rho/(\rho-1)} dj + \int_{n_{us}}^{n_{us}+n_{mex}} ((1+\tau_{us})p(j))^{\rho/(\rho-1)} dj \right)^{(\rho-1)/\rho}, \\ p_{Xmex} &= \left(\int_0^{n_{us}} ((1+\tau_{mex})p(j))^{\rho/(\rho-1)} dj + \int_{n_{us}}^{n_{us}+n_{mex}} p(j)^{\rho/(\rho-1)} dj \right)^{(\rho-1)/\rho}.\end{aligned}$$

By the symmetry $p(j) = \bar{p}_{us}$ for $j \in [0, n_{us}]$ and $p(j) = \bar{p}_{mex}$ for $j \in [n_{us}, n_{us} + n_{mex}]$,

$$\begin{aligned}p_{Xus} &= \left(n_{us}\bar{p}_{us}^{\rho/(\rho-1)} + n_{mex}((1+\tau_{us})\bar{p}_{mex})^{\rho/(\rho-1)} \right)^{(\rho-1)/\rho}, \\ p_{Xmex} &= \left(n_{us}((1+\tau_{mex})\bar{p}_{us})^{\rho/(\rho-1)} + n_{mex}\bar{p}_{mex}^{\rho/(\rho-1)} \right)^{(\rho-1)/\rho}.\end{aligned}$$

The good X in each country is now given by

$$X_{us} = \frac{w_{Lus}\bar{L}_{us}}{p_{Xus}}, \quad X_{mex} = \frac{w_{Lmex}\bar{L}_{mex}}{p_{Xmex}}.$$

The relative wage of high-skilled to low-skilled labor in each country is now given by

$$\frac{w_{Hus}}{w_{Lus}} = \frac{1 - \alpha}{\alpha} \left(\frac{p_{Xus}}{w_{Lus}} \right)^\epsilon \left(\frac{\bar{L}_{us}}{\bar{H}_{us}} \right)^{1-\epsilon}, \quad \frac{w_{Hmex}}{w_{Lmex}} = \frac{1 - \alpha}{\alpha} \left(\frac{p_{Xmex}}{w_{Lmex}} \right)^\epsilon \left(\frac{\bar{L}_{mex}}{\bar{H}_{mex}} \right)^{1-\epsilon}.$$

By substituting p_{Xi} , \bar{n}_i , and \bar{p}_i , $i = us, mex$, into the above formula, the equilibrium relative wages are rewritten as follows:

$$\frac{w_{Hus}}{w_{Lus}} = \frac{1 - \alpha}{\alpha} \left(\frac{(1 - \rho)}{f} \left(\frac{b}{\rho} \right)^{\rho/(\rho-1)} \left(\bar{L}_{us} + \bar{L}_{mex} \left((1 + \tau_{us}) \frac{w_{Lmex}}{w_{Lus}} \right)^{\rho/(\rho-1)} \right) \right)^{\epsilon(\rho-1)/\rho} \left(\frac{\bar{L}_{us}}{\bar{H}_{us}} \right)^{1-\epsilon},$$

$$\frac{w_{Hmex}}{w_{Lmex}} = \frac{1 - \alpha}{\alpha} \left(\frac{(1 - \rho)}{f} \left(\frac{b}{\rho} \right)^{\rho/(\rho-1)} \left(\bar{L}_{us} \left((1 + \tau_{mex}) \frac{w_{Lus}}{w_{Lmex}} \right)^{\rho/(\rho-1)} + \bar{L}_{mex} \right) \right)^{\epsilon(\rho-1)/\rho} \left(\frac{\bar{L}_{mex}}{\bar{H}_{mex}} \right)^{1-\epsilon}.$$

(4)
(5)

A.2.3 Trade

Step 1: Balance of trade.

The balance of trade (U.S. exports = U.S. imports) is given by the following:

$$\bar{n}_{us} \bar{p}_{us} (1 + \tau_{mex}) \bar{x}_{us,mex} = \bar{n}_{mex} \bar{p}_{mex} (1 + \tau_{us}) \bar{x}_{mex,us},$$

where $(1 + \tau_{mex}) \bar{x}_{us,mex}$ means that the imports of a U.S. variety by Mexico, and $(1 + \tau_{us}) \bar{x}_{mex,us}$ means that the imports of a Mexican variety by the U.S.

Step 2: The first-order conditions for each variety by the final good.

The first-order conditions for each variety by the final good give

$$\bar{x}_{mex,us} = (1 + \tau_{us})^{1/(\rho-1)} \bar{x}_{us,us}, \quad \bar{x}_{us,mex} = (1 + \tau_{mex})^{1/(\rho-1)} \bar{x}_{mex,mex}.$$

Step 3: The ratio of each country's share in each variety.

From Steps 1 and 2, we obtain the following:

$$\frac{(1 + \tau_{us}) (1 + \tau_{us})^{1/(\rho-1)} \bar{x}_{us,us}}{(1 + \tau_{mex}) \bar{x}_{us,mex}} = \frac{\bar{n}_{us} \bar{p}_{us}}{\bar{n}_{mex} \bar{p}_{mex}},$$

$$\frac{(1 + \tau_{us}) \bar{x}_{mex,us}}{(1 + \tau_{mex}) (1 + \tau_{mex})^{1/(\rho-1)} \bar{x}_{mex,mex}} = \frac{\bar{n}_{us} \bar{p}_{us}}{\bar{n}_{mex} \bar{p}_{mex}}.$$

Thus, by substituting \bar{n}_i and \bar{p}_i , $i = us, mex$, into the above formula, the ratio of the demand for a U.S. variety by the U.S. to the demand for a U.S. variety by Mexico becomes

$$\bar{x}_{us,us} / (1 + \tau_{mex}) \bar{x}_{us,mex} = \bar{L}_{us} w_{Lus} / \bar{L}_{mex} w_{Lmex} (1 + \tau_{us})^{\rho/(\rho-1)}.$$

The ratio of the demand for a Mexican variety by the U.S. to the demand for a Mexican variety by Mexico also becomes

$$(1 + \tau_{us}) \bar{x}_{mex,us} / \bar{x}_{mex,mex} = \bar{L}_{us} w_{Lus} (1 + \tau_{mex})^{\rho/(\rho-1)} / \bar{L}_{mex} w_{Lmex}.$$

Step 4: Trade.

The volume of U.S.-Mexican variety trade is represented as the sum of U.S. exports and imports:

$$\bar{n}_{us} \bar{p}_{us} (1 + \tau_{mex}) \bar{x}_{us,mex} + \bar{n}_{mex} \bar{p}_{mex} (1 + \tau_{us}) \bar{x}_{mex,us}.$$

From Step 3, this becomes

$$\bar{n}_{us} \bar{p}_{us} \frac{\bar{L}_{mex} w_{Lmex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} w_{Lus} + \bar{L}_{mex} w_{Lmex} (1 + \tau_{us})^{\rho/(\rho-1)}} \bar{x}_{us} + \bar{n}_{mex} \bar{p}_{mex} \frac{\bar{L}_{us} w_{Lus} (1 + \tau_{mex})^{\rho/(\rho-1)}}{\bar{L}_{us} w_{Lus} (1 + \tau_{mex})^{\rho/(\rho-1)} + \bar{L}_{mex} w_{Lmex}} \bar{x}_{mex}.$$

By substituting \bar{n}_i , \bar{p}_i and \bar{x}_i , $i = us, mex$, into the above formula, the volume of U.S.-Mexican variety trade is given by

$$\frac{\bar{L}_{us} w_{Lus} \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} (w_{Lus}/w_{Lmex}) + \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}} + \frac{\bar{L}_{mex} w_{Lmex} \bar{L}_{us} (1 + \tau_{mex})^{\rho/(\rho-1)}}{\bar{L}_{us} (1 + \tau_{mex})^{\rho/(\rho-1)} + \bar{L}_{mex} (w_{Lmex}/w_{Lus})},$$

where the balance of trade requires the following equality:

$$\frac{\bar{L}_{us} w_{Lus} \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} (w_{Lus}/w_{Lmex}) + \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}} = \frac{\bar{L}_{mex} w_{Lmex} \bar{L}_{us} (1 + \tau_{mex})^{\rho/(\rho-1)}}{\bar{L}_{us} (1 + \tau_{mex})^{\rho/(\rho-1)} + \bar{L}_{mex} (w_{Lmex}/w_{Lus})}.$$

Accordingly, the volume of U.S.-Mexican variety trade is simply given by

$$2 \frac{\bar{L}_{us} w_{Lus} \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} (w_{Lus}/w_{Lmex}) + \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}.$$

Thus the volume of U.S.-Mexican variety trade relative to U.S. GDP is given by

$$2 \frac{\bar{L}_{us} \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}}{\bar{L}_{us} (w_{Lus}/w_{Lmex}) + \bar{L}_{mex} (1 + \tau_{us})^{\rho/(\rho-1)}} / (w_{Hus}/w_{Lus}) \bar{H}_{us} + \bar{L}_{us}. \quad (6)$$

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Table 1-a Results for benchmark numerical example

	1987	1994	Change
Data			
Manuf. Variety Trade/U.S. Manuf. GDP	0.018	0.046	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.502	0.755	50.4%
U.S. Skill Premium	1.630	1.780	9.2%
Mex. Skill Premium	2.020	2.900	43.6%
Model			
(a) $\varepsilon = -1, \rho = 0.83, f = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.55, \tau_{mex,1994} = 0.18, \tau_{us,1987} = 0.05, \tau_{mex,1987} = 0.73$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.015	0.038	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.912	0.924	1.4%
U.S. Skill Premium	1.667	1.780	6.8%
Mex. Skill Premium	1.678	2.252	34.2%

Table 1-b Results for benchmark numerical example with technological change

	1987	1994	Change
Data			
Manuf. Variety Trade/U.S. Manuf. GDP	0.018	0.046	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.502	0.755	50.4%
U.S. Skill Premium	1.630	1.780	9.2%
Mex. Skill Premium	2.020	2.900	43.6%
Model			
(a) $\varepsilon = -1, \rho = 0.83, f_{1994} = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.55, \tau_{mex,1994} = 0.18, \tau_{us,1987} = 0.05, \tau_{mex,1987} = 0.73, f_{1987} = 111.82$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.015	0.038	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.920	0.924	0.4%
U.S. Skill Premium	1.630	1.780	9.2%
Mex. Skill Premium	1.641	2.252	37.2%

Table 2 Results for numerical examples with different ϵ and ρ

	1987	1994	Change
Data			
Manuf. Variety Trade/U.S. Manuf. GDP	0.018	0.046	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.502	0.755	50.4%
U.S. Skill Premium	1.630	1.780	9.2%
Mex. Skill Premium	2.020	2.900	43.6%
Model			
(a) $\epsilon = -0.5, \rho = 0.83, f = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.53, \tau_{mex,1994} = 0.18, \tau_{us,1987} = 0.05, \tau_{mex,1987} = 0.72$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.015	0.038	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.864	0.934	8.1%
U.S. Skill Premium	1.694	1.780	5.1%
Mex. Skill Premium	1.935	2.206	14.0%
(a) $\epsilon = -1.5, \rho = 0.83, f = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.57, \tau_{mex,1994} = 0.18, \tau_{us,1987} = 0.05, \tau_{mex,1987} = 0.74$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.015	0.038	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.960	0.915	-4.7%
U.S. Skill Premium	1.640	1.780	8.5%
Mex. Skill Premium	1.448	2.299	58.7%
(a) $\epsilon = -1, \rho = 0.7, f = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.93, \tau_{mex,1994} = 0.22, \tau_{us,1987} = 0.09, \tau_{mex,1987} = 2.06$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.015	0.039	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	1.129	0.963	-14.6%
U.S. Skill Premium	1.670	1.780	6.6%
Mex. Skill Premium	0.990	2.179	120.0%
(a) $\epsilon = -1, \rho = 0.9, f = 100, \tau_{us,1994} = 0.01$			
(b) $\alpha = 0.34, \tau_{mex,1994} = 0.14, \tau_{us,1987} = 0.03, \tau_{mex,1987} = 0.38$			
Manuf. Variety Trade/U.S. Manuf. GDP	0.014	0.037	158.2%
Manuf. Variety Trade/Mex. Manuf. GDP	0.800	0.876	9.5%
U.S. Skill Premium	1.666	1.780	6.9%
Mex. Skill Premium	2.066	2.320	12.3%

Fig. 1 Relative wage of high-skilled to low-skilled labor in U.S. and Mexican manufacturing industries, 1980-2000

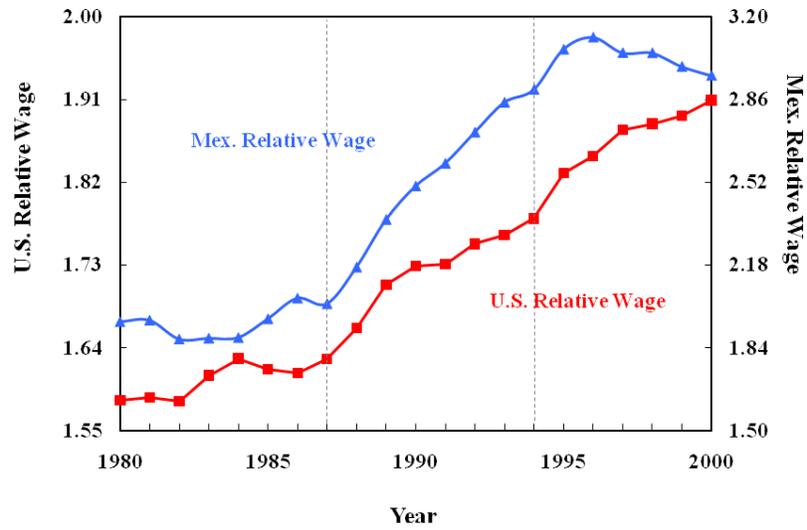


Fig. 2 U.S.-Mexican trade as percent of U.S. GDP, 1980-2000

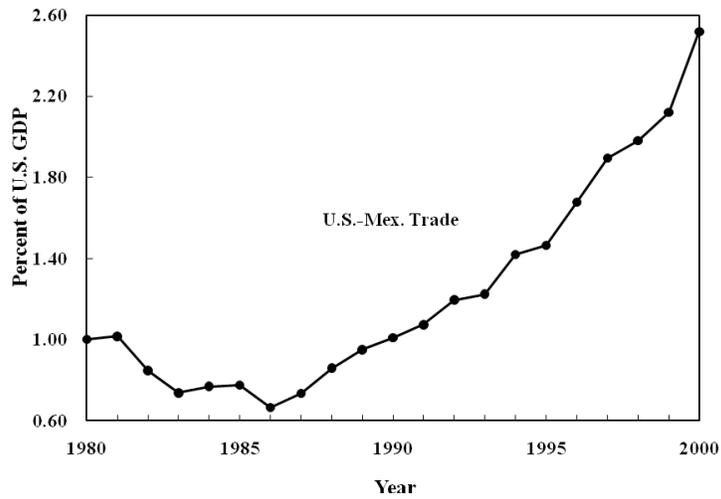


Fig. 3-a Autarky equilibrium with $w_H/w_L > 1$

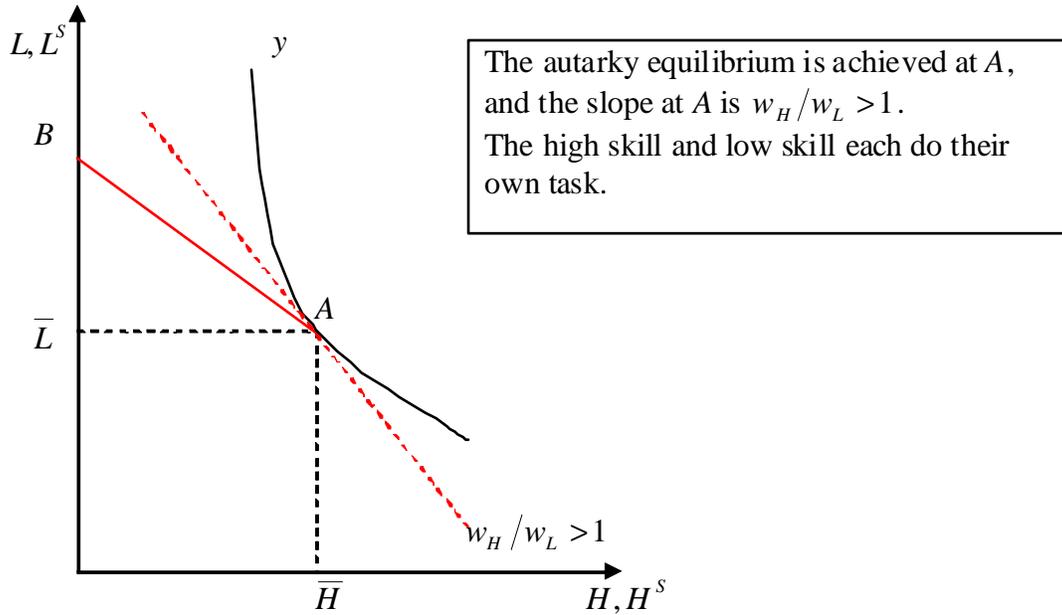


Fig. 3-b Autarky equilibrium with $w_H/w_L = 1$

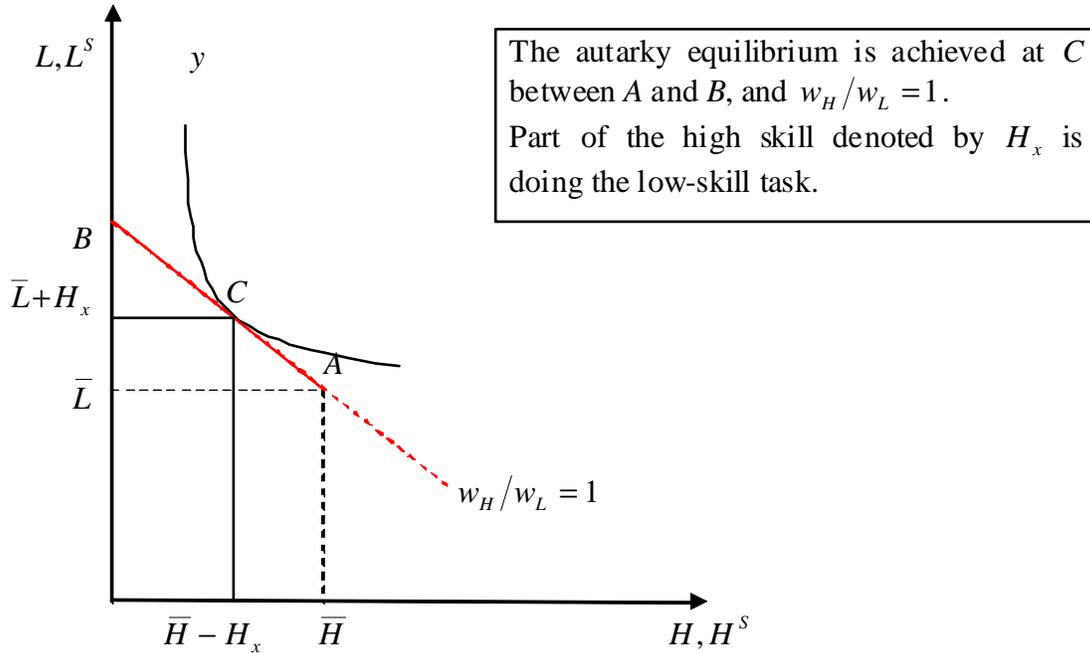


Fig. 4-a Least traded goods growth: U.S. manufacturing imports from Mexico, 1980-2000

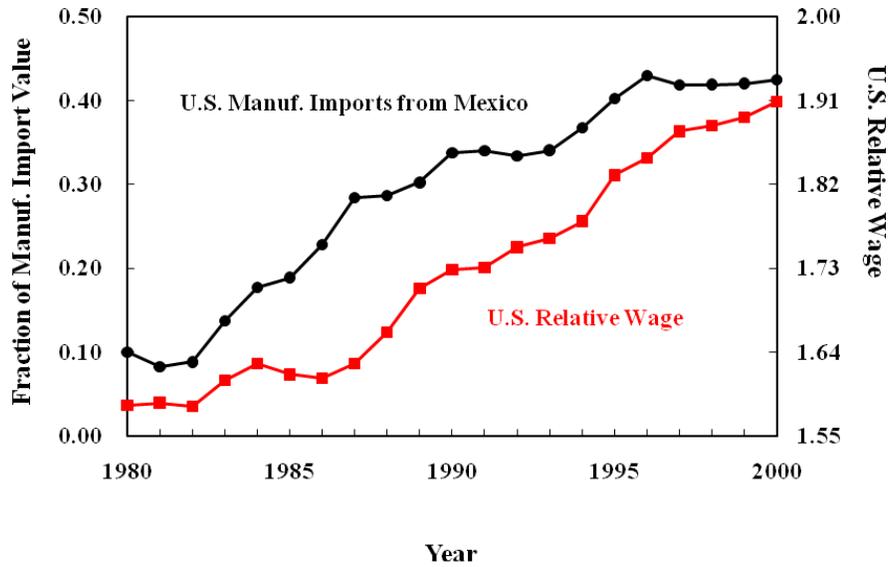


Fig. 4-b Least traded goods growth: Mexican manufacturing imports from U.S., 1980-2000

