Wage Inequality, Technology, and Trade

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Abstract

Recent widening of the wage gap between skilled and unskilled workers has been attributed mainly to skill-biased-technical-change and to trade liberalization. This paper examines the effects of the two in a unified model, in which trade and technology adoption are endogenous. The paper has two main results. First, technical progress increases the wage gap in developed and in less developed countries, while trade liberalization increases the wage gap in developed countries but reduces it in less developed countries. The second result is that while trade liberalization increases trade in all countries, technical progress does not increase trade everywhere. These two results indicate that the recent increase in wage inequality is a combined result of both technical progress and trade liberalization, and cannot be attributed to one factor only.

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1. Introduction

In recent decades we have seen a dramatic increase in wage inequality in the US. A similar, though smaller, increase has been observed in other countries. This phenomenon has been documented in many studies, including Davis and Haltwinger (1991), Katz and Murphy (1992), Juhn, Murphy, and Pierce (1993), and Davis (1992) and recently in Goldin and Katz (1999). A number of explanations have been offered to this rise in wage inequality. The most popular explanations are skill-biased technical progress on the one hand and the liberalization of international trade on the other hand. This paper examines the two explanations together within a unified theoretical model, in which technical progress and trade liberalization are exogenous, while technology adoption, the pattern of trade and wages are endogenous. Our main result is that neither exogenous change alone can account for the stylized facts of the recent decades, while both can together. Hence, the paper suggests that the rise in wage inequality is a result of both skill-biased technical change and trade liberalization.

The paper presents a model in which the final good is produced by use of many intermediate goods. Technological innovations in this model enable producers to replace unskilled workers in production of some intermediate goods by fewer skilled workers. Hence, technical progress replaces one input by a second. This has two results. The first is that technology adoption increases demand for skilled workers

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2 There can be other explanations to the widening wage gap as well. Recently Goldin and Katz (1999) and Card and Lemieux (1999) have offered a third explanation: reduction in supply of skill. We examine this explanation in our model as well in Section 6.
and at the same time also reduces demand for unskilled workers. Hence, technology adoption increases the wage ratio between the two types of workers. The second result is that such innovations are not everywhere adopted by producers, and adoption depends on input prices, namely on the wage ratio between skilled and unskilled workers.\footnote{This second result appears also in Zeira (1998), where the two inputs are labor and capital.} This leads us to an endogenous determination of developed vs. less developed countries. Countries that adopt all (or most) new technologies are called developed, while countries that do not adopt all available technologies are called less developed. Hence, each country can specialize in a different set of intermediate goods, thus leading to international trade.

International trade is introduced to the model by assuming that some intermediate goods are tradable. Trade liberalization increases the set of these tradable intermediate goods. Technical progress and trade liberalization are independent in the model, as we assume that goods are tradable independently of whether they are produced by skilled or unskilled labor. Note that this independence is only with respect to the exogenous change in trade, namely to liberalization, but the endogenous reaction of trade is affected by technical progress.\footnote{One could further claim that trade liberalization itself is caused by technical progress in transportation and communication. But since this is only a first attempt to tackle the issue, we assume that the two processes are independent.}

We find that the results of the model are very different with respect to developed and less developed countries. In developed countries both technical progress and trade liberalization increase wage inequality. In less developed countries technical progress increases wage inequality, though by less, but trade liberalization reduces wage inequality rather than increases it. These results imply that recent developments cannot be attributed solely to trade liberalization, since wage inequality
has increased not only in developed countries but in less developed countries as well, as shown in Berman, Bound and (1998) and many other studies.

The model also enables us to examine the effect of exogenous changes not only on wages but on trade as well. We show that technical progress raises the relative amount of trade in one country but reduces it in the other country. This result is at odds with the stylized facts of recent decades. We have seen a rise in the share of trade in income in all countries, developed as well as less developed. Hence, the recent changes in wage inequality and in trade volume cannot be attributed only to skill-biased technical progress. We, therefore, conclude that both factors, technical progress and trade liberalization, must have played important roles in the widening of wage inequality in developed countries.

Finally the paper examines the effect of changes in labor supplies on the equilibrium wages and trade. This is interesting for two reasons. First, because labor supplies tend to react to changes in relative wages, which supply incentive to invest more or less in human capital, namely in skill acquisition. Second, recently Goldin and Katz (1999) and Card and Lemieux (1999) have presented a third possible explanation to the widening of the wage gap: decline in supply of skill. We examine this explanation within our model and show that even when it holds, trade liberalization still plays a role in increasing wage inequality.

The paper is organized as follows. Section 2 presents the model, while section 3 analyzes equilibrium in a closed economy and focuses on technology adoption and wage determination. Section 4 analyzes equilibrium in global trade model with two countries. Section 5 examines the effect of technical progress and trade liberalization on wage inequality. Section 6 examines the effects of changes in labor supplies and section 7 concludes.
2. The Model

Consider an economy with one final good, which is used for consumption only. The final good is produced by use of a continuum of intermediate goods \([0,1]\). Production of the final good is described by the following Cobb-Douglas production function:

\[
\log y = \int_0^1 \log x_i \, di ,
\]

where \(y\) is output of final good and \(x_i\) is input of intermediate good \(i\).

Intermediate goods are produced either by unskilled labor or by skilled labor in two different technologies, which are both fixed coefficients technologies. If intermediate good \(i\) is produced by the unskilled labor technology, production of one unit requires \(n_i\) units of unskilled labor. If \(i\) is produced by the skilled labor technology, a production of one unit requires \(s_i\) units of skilled labor, where: \(s_i < n_i\), namely the skilled labor technology enables reduction of labor input, but it requires a different labor input as well. Denote the relative gain in labor when unskilled workers are replaced by skilled workers by \(g(i)\):

\[
g(i) = \frac{n_i}{s_i} > 1 .
\]

We assume that the function \(g\) is decreasing, namely that the intermediate goods are ordered by decreasing relative labor gain in replacing unskilled by skilled workers.

While the unskilled labor technologies are known from time immemorial, the skilled labor technologies are not known for all intermediate goods and are invented over time. At period \(t\) these technologies are known for only some intermediate goods, i.e. for a set \(F_t\). Technical progress therefore means increasing \(F_t\), namely creating technologies which enable reducing labor input in production of some intermediate
goods, by using skilled instead of unskilled labor. The set $F_t$ is called the technology frontier. We do not model inventions in this paper and treat them as exogenous, as we concentrate on technology adoption rather than technology creation. Clearly $\{F_t\}_t$ is an increasing sequence of sets, i.e. $F_t \supseteq F_{t+1}$ for all $t$. Our measure of technology is the size of $F_t$:

$$f_t = \int_{\hat{r}_t} \hat{\beta} \, d\hat{r},$$

which is an increasing sequence in time. We further specify the technology frontier and assume that each $F_t$ is uniformly distributed on $[0, 1]$. Note, that this specification means that the innovations are not biased toward any type of intermediate goods.

While in this paper we concentrate on increases in $f$, the standard view of skilled biased technical progress is an increase of productivity of skilled workers in all their jobs. In this model it is equivalent to a reduction of $s_i$ for all $i$, namely an increase of $g$. We discuss such a change in Section 5.

We next turn to describe labor supply of both types of workers. We leave the full specification of individuals and of skill acquisition to a later stage in the analysis. For the meanwhile we only assume that in each period $t$ the supplies of skilled and unskilled workers are predetermined. There is a mass off size $S_t$ of skilled workers and a mass of size $N_t$ of unskilled workers. We also assume that each worker supplies one unit of labor in one period of time. Hence, the supplies of both types of labor are assumed to be perfectly inelastic in the short-run. This assumption is later relaxed in Section 6.

Markets are assumed to be perfectly competitive. We assume that the final good is not traded, but some of the intermediate goods are traded. More precisely, the
set of traded intermediate goods is \( M_t \), which is uniformly distributed over the interval 
[0, 1]. This set is determined by type of goods, by geography and by policy. The size 
of the set \( M_t \) is defined as a measure for trade openness:

\[
(4) \quad m_t = \int_{M_t} d\mu.
\]

Trade openness in this economy is therefore characterized by the amount of traded 
goods. This measure differs from standard ones, such as size of barriers to trade, but is 
employed here as it fits the model better and it yields similar results to the standard 
measures. We further assume that there are two countries in the world, A and B.

### 3. Equilibrium in a Closed Economy

We first consider an economy which is closed to international trade, namely the set \( M \) 
of tradable intermediate goods is empty.\(^6\) Let the price of intermediate good \( i \) be \( p_i \), the 
wage of skilled workers \( w_s \), and the wage of unskilled workers \( w_n \), where the final 
good serves as a numeraire. Since the economy is closed, all these prices are 
determined in domestic markets. Before we turn to determination of the various prices 
and wages, we describe technology choice in production of each intermediate good.

All intermediate goods are produced within the economy. If the skilled 
technology for an intermediate good \( i \) has not been invented yet, i.e. if \( i \not\in F_t \), then 
clearly the unskilled technology is used. If the skilled technology has already been 
invented and \( i \in F_t \), then producers can choose between both technologies. They will 
adopt the new technology, which uses skilled labor, if and only if

\[
(5) \quad s_i w_s \leq n_i w_n,
\]

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\(^5\) The model can be solved also for other specifications of technology frontiers, which are biased toward 
some intermediate goods. Most of the results are similar. An example can be sent upon request.

\(^6\) From here on we delete time subscripts wherever possible.
or if:

\[ g(i) \geq \frac{w_s}{w_n}. \]

Hence, the wage ratio between skilled and unskilled workers determines technology adoption. This variable, which describes wage inequality in the economy, is the main variable in our analysis and is called the wage ratio. It is easy to see that the set of adopted technologies is \([0, d] \cap F\), where:

\[ d = \min \left\{ g^{-1}\left( \frac{w_s}{w_n} \right), 1 \right\}. \]

We can, therefore, distinguish between two cases. In the first case \(d = 1\) and all the existing skilled technologies are adopted. In the second case \(d < 1\) and not all technologies are adopted. The first case prevails when \(w_s/w_n \leq g(1)\), and the second prevails when \(w_s/w_n > g(1)\). We say that the higher is \(d\) the more ‘developed’ the country is. We sometimes call a country that adopts all technologies ‘fully developed’.

We next turn to the goods markets to describe price determination. Due to perfect competition in input markets and due to the Cobb-Douglas technology we get the following first order condition:

\[ p_i = \frac{\partial y}{\partial x_i} = \frac{y}{x_i}. \]

Due to perfect competition in input markets and due to constant marginal productivity we get:

\[ p_i = \begin{cases} w_i s_i & \text{if } 0 \leq i \leq d \text{ and } i \in F, \\ w_n t_i & \text{otherwise}. \end{cases} \]

In order to describe wage determination we turn to the equilibrium conditions in the two labor markets in the economy, omitting time subscripts as the equilibrium
is temporal. Equilibrium in the market for skilled labor is reached when supply equals demand and due to (8) and (9) we get:

\begin{equation}
S = \int_{0,d} s_i x_i \, di = df \frac{y}{w_f}.
\end{equation}

Similarly, the equilibrium condition in the market for unskilled labor is:

\begin{equation}
N = \int_{0,d} n_i x_i \, di + \int_{d}^{1} n_i x_i \, di = (1 - df) \frac{y}{w_n}.
\end{equation}

From (10) and (11) we get:

\begin{equation}
\frac{w_f}{w_n} = \frac{N \, df}{S \, 1 - df}.
\end{equation}

The right hand side of equation (12), which describes the wage ratio and which we denote by \(WR\), is an increasing function of \(d\). Furthermore, \(WR\) depends positively on the state of technology \(f\) and on the relative supplies of skilled and unskilled workers.

[Insert Figure 1 here]

The equilibrium wage ratio and the level of technology adoption \(d\) in the closed economy are determined by equations (7) and (12). The equilibrium is described in Figure 1 at the intersection of the \(WR\) curve and the \(g\) curve. There are two possible equilibria. If the educational system is sufficiently large and there are many skilled workers, as described by point A in Figure 1, all new innovations are adopted and the economy is fully developed. If on the contrary the education system is small and there are few skilled workers and many unskilled workers, the equilibrium is described by point B in Figure 1. In this case some of the new technological innovations, those between \(d\) and 1, are not adopted, and the economy is what we call less developed.
To complete the description of equilibrium we derive the absolute wage levels of skilled and unskilled workers. From the first order condition (8) and from the production function (1) we get:

\[ \int_{0}^{1} \log p_i \, di = 0. \]  

By substituting (9) and the wage ratio (12) in equation (13) we can calculate the wage of skilled workers:

\[
\log w_s = (1 - df) \log \frac{df}{1 - df} + (1 - df) \log \frac{N}{S} \]
\[
+ f \int_{0}^{d} \log g(i) \, di - \int_{0}^{1} \log n_i \, di
\]

and the wage of unskilled workers:

\[
\log w_n = -df \log \frac{df}{1 - df} - df \log \frac{N}{S} \]
\[
+ f \int_{0}^{d} \log g(i) \, di - \int_{0}^{1} \log n_i \, di.
\]

We next turn to analyze the effect of technical progress on equilibrium in the closed economy. An increase in \( f \) shifts the \( WR \) curve upward and thus raises the wage ratio. Note that if the economy is fully developed, the effect of an increase in \( f \) is larger than in a less developed economy. In a fully developed country the wage ratio rises by the full amount of the increase in the \( WR \) curve. In a less developed economy it rises by less, due to the downward slope of \( g \). Note also, that although \( d \) decreases or remains unchanged when \( f \) rises, the amount of intermediate goods produced by skilled workers increases, since \( df \) increases as can be seen from (12). It can be shown that a rise in \( f \) increases skilled wage \( w_s \), while it has an ambiguous effect on the wage of unskilled.
4. World Trade Equilibrium

As assumed in Section 2 there are two large economies. Economy A has a large amount of skilled workers $S_A$ and a small amount of unskilled labor $N_A$. Economy A adopts all technologies up to an intermediate good $d_A$, which might also be equal to 1. Economy B on the contrary has a small amount of skilled labor $S_B$ and a large amount of unskilled labor $N_B$, due to a small educational sector. It adopts technologies only up to an intermediate good $d_B$. Assume that $d_B < d_A$. Since both economies face the same technological tradeoff function $g$, this assumption means, according to equation (7), that the wage ratio in A is lower than the wage ratio at B.

While the tradable intermediate goods in $M$ have the same price across countries, the final good, skilled and unskilled labor and the intermediate goods in $M^c$ have different prices across countries. In order to describe the pattern of international trade between the two countries we show first that wages of skilled workers are lower in country A, while wages of unskilled workers are lower in country B.

Lemma 1: Wages in the two countries satisfy: $w_{sA} \leq w_{sB}$ and $w_{nA} \geq w_{nB}$ and one of the inequalities is strict.

Proof: Note first, that it is impossible that both inequalities are violated, since then the wage ratio in A is higher than in B, which contradicts greater technology adoption in A. A similar argument can be used to show that the two equalities are impossible.

We next show that if only one inequality is violated, for example if $w_{sA} > w_{sB}$, we reach a contradiction as well. Consider two possible cases for unskilled wages. If
If $w_{nB} < w_{nA}$ then country A is importing all goods from country B, which is impossible. If $w_{nB} = w_{nA}$ the wage ratio in country A is higher than in country B, which contradicts the assumption. Hence, both wage inequalities hold.

QED.

From Lemma 1 we conclude that country A is exporting intermediate goods produced by skilled labor, while country B is exporting intermediate goods produced by unskilled labor. If an inequality is strict, the respective country produces all the global consumption of the intermediate goods it exports and there is complete specialization. If wage levels are equal in both countries, there is some domestic consumption of these goods in the importing country. There are therefore three possible cases: full specialization, equality of skilled wages in the two countries, or equality of unskilled wages in the two countries. We focus our attention on the first two cases, as the third seems to be less realistic, and it adds no new insight.

The international price of an intermediate good exported by country A is therefore:

$$p_i = w_{sA} s_i,$$

while the international price of an intermediate good imported by country A is:

$$p_i = w_{nB} n_i.$$

Country A exports intermediate goods in $M$ as long as $w_{sA} s_i \leq w_{nB} n_i$, namely as long as:

$$(18) \quad g(i) \geq \frac{w_{sA}}{w_{nB}}.$$

Hence, country A is exporting the set of intermediate goods $M \cap F \cap [0, k]$, where $k$ is determined by:
(19) \[ k = \min \left\{ g^{-1}\left(\frac{w_{aA}}{w_{aB}}\right), 1 \right\}. \]

Country B is exporting intermediate goods produced by non-skilled labor, which includes all traded goods except those exported by A, i.e. \( M \setminus M \cap F \cap [0, k] \). The pattern of international trade is graphically described in Figure 2, which shows the costs of production of the intermediate goods in the two countries. Note that due to Lemma 1, \( k \) is always between \( d_A \) and \( d_B \). In the case of full specialization \( k \) is strictly between them as shown in the figure. If skilled wages in the two countries are equal, then \( k \) coincides with \( d_B \), as can be shown by shifting the curves in Figure 2.

Before we turn to analyze the two cases we focus on, we derive the inputs of intermediate goods in each country from the first order conditions. The input of intermediate good \( i \) in country \( j \), where \( j \in \{A, B\} \) is:

(20) \[ x_{ij} = \frac{p_j y_j}{p_y}, \]

similarly to equation (8).

A. Equilibrium with Full Specialization

We first analyze the case of full specialization, where skilled wages in A are strictly lower than in B. In this case all the input of traded skilled goods in B is supplied by A. Since global trade must be balanced and we get:

(21) \[ \int_{F \cap M \cap (0, k]} p_i x_{sA} \, di = \int_{M \setminus M \cap F \cap (0, k]} p_i x_{sA} \, di. \]

From this condition and from (20) we can derive the ratio of incomes in the two countries:
Hence, the income ratio depends negatively on $k$.

We next present the four labor market equilibrium conditions. The equilibrium condition for skilled labor in A is:

$$S_A = \int_{\{0,k\} \cap F \cap M} s_i (x_{ia} + x_{ib}) \, di + \int_{\{0,d_a\} \cap F \cap M'} s_i x_{ia} \, di = [k \, f (p_A y_A + p_B y_B) + d_A f (1-m) + p_A y_A] \frac{1}{w_{nA}}.$$ 

The equilibrium condition in the market for non-skilled labor in A is:

$$N_A = \int_{\{0,d_a\} \cap F \cap M'} x_{ia} \, di + \int_{\{d_a,1\} \cap M'} x_{ia} \, di = (1-d_A f) (1-m) \frac{P_A y_A}{w_{nA}}.$$ 

Similarly, the equilibrium in the market for skilled labor in B is reached at:

$$S_B = \int_{\{0,d_a\} \cap F \cap M} s_i x_{ib} \, di = d_B f (1-m) \frac{P_B y_B}{w_{nB}},$$

while equilibrium condition for non-skilled labor in B is:

$$N_B = \int_{M' \cap F \cap \{0,k\}} n_j (x_{ib} + x_{ia}) \, di + \int_{M' \cap \{d_a,1\} \cap M'} n_i x_{ib} \, di = \{[m-k \, f (1-m) + d_B f] \} P_B y_B + [m - k \, f m] p_A y_A \frac{1}{w_{nB}}.$$ 

From the labor equilibrium conditions and from condition (22) on the income ratio in the two countries we can derive the wage ratios in the two countries. The wage ratio in country A is:

$$\frac{w_{sA}}{w_{nA}} = \frac{N_A}{S_A} \frac{m + d_A f (1-m)}{(1-m) (1-d_A f)},$$

while the wage ratio in country B is:

$$\frac{w_{sB}}{w_{nB}} = \frac{N_B}{S_B} \frac{d_B f (1-m)}{1-d_B f (1-m)}.$$
Equations (23) and (24) together with the condition on technology adoption (7) determine the equilibrium in each economy, i.e. the degrees of technology adoption and the wage ratio in each country. Note, that the right hand side of equation (23), which we denote by \(WR_A\), is an increasing function of \(d_A\) and hence there exists a unique intersection with \(g\), which is decreasing in \(d_A\). This intersection determines both \(d_A\) and the wage ratio in A, as shown in Figure 3. Similarly, the right hand side of (24), which is denoted \(WR_B\), is increasing in \(d_B\) and hence has a unique intersection with \(g\), which determines the equilibrium in B.

We next turn to determination of equilibrium \(k\) and the pattern of international trade. From the labor market conditions and from the income ratio we derive the ratio between skilled wage in the developed economy and non-skilled wage in the less developed economy:

\[
\frac{w_{wA}}{w_{wB}} = \frac{N_B}{S_A} \frac{m + d_A f (1-m)}{1 - d_B f (1-m)} \frac{k}{1-k}.
\]

This condition together with the trade condition (18) determines \(k\). Since the right hand side of (25) is an increasing function of \(k\) it has a unique intersection with \(g\). This intersection determines \(k\) and thus the pattern of trade. To ensure that this is a full specialization equilibrium, \(k\) needs to be strictly smaller than \(d_A\) and strictly larger than \(d_B\). The conditions for that can be found by a straightforward calculation.

**B. Equilibrium without Full Specialization in Skilled Goods**

When the wages of skilled workers are equal in the two countries county B also produces some of the traded skilled goods in \([0, d_b]\). Hence, the world trade equilibrium is:
The equilibrium conditions of the four labor markets are derived in a similar way to that under full specialization. From these conditions and from (26) we calculate the wage ratios in the two countries. It can be shown that the wage ratio in country A is the same as in full specialization and is given by (23). Hence, the wage ratio $W_A$ and $d_A$ are the same in the two cases. The wage ratio in country B is determined by the following condition:

\[
\frac{w_{AB}}{w_{mB}} = \frac{m + (1 - m) d_A f}{m + (1 - m) d_A f + m S_A / S_B f} 1 - d_B f,
\]

and by (7). We have therefore shown that in both cases (and in the third case as well) an equilibrium exists and is unique, and we have fully characterized it.

5. The Effects of Technical Progress and of Trade Liberalization

We next examine how technical progress and trade liberalization affect the equilibrium in the developed and the less developed countries. We model technical progress as increasing $f$, i.e. increasing the set of inventions which enable production by skilled workers. We model trade liberalization by increasing $m$, i.e. increasing the set of traded goods. We first examine the effect of these changes in the full specialization equilibrium and then turn to an economy without full specialization of skilled goods.

In the full specialization case an increase in $f$ increases $W_A$ and thus shifts upward the $W_A$ curve in figure 3. As a result $d_A$ is reduced if smaller than 1, or stays unchanged if equal to 1. The wage ratio increases in either case and by much more if
$d_A$ is equal to 1. Hence, technical progress increases the wage ratio by increasing the demand for skilled workers and reducing demand for unskilled. In the less developed economy the effect of technical progress is similar. An increase in $f$ increases $WR_B$ and thus reduces $dB$ and increases the wage ratio in country B as well. Note that although the effects are in the same direction, they differ quantitatively. Examine the relative effects of technology on $WR_A$ and in $WR_B$ by calculating $d[\log(WR_A)-\log(WR_B)]/df$. For simplification assume that the developed economy adopts all new technologies, i.e. $d_A = 1$. We get:

\[
(28) \quad \frac{d \log WR_A}{df} > \frac{d \log WR_B}{df} \quad \text{iff} \quad dB < 1 - \frac{m}{1 - m} \frac{1 - f}{f^2}.
\]

Hence, the effect of technical progress on the less developed country is smaller if it is less developed significantly. Note, that the higher the degree of technical progress $f$, the more likely it is that the effect on the less developed country is smaller, both due to the increase in $f$ and due to the decline in $dB$.

Technical progress also affects the volume of international trade. As shown above, an increase in $f$ increases both $d_A f$ and $d_B f$ as it increases the wage ratio in both countries. As can be seen from equation (25) an increase in $f$ raises the right hand side and as a result it reduces $k$. Hence, technical progress reduces the range of products exported from developed to less developed countries. Furthermore, we can examine how technical progress affects the share of trade in both countries. From equation (21) it follows that the share of trade in country A is equal to $m(1 - kf)$, while in country B it is equal to $mkf$. Hence, whether technical progress increases $kf$ or not, the share of trade in one of the countries, either in A or in B, declines as a result of skill-biased technical change. Note that this result does not fit the stylized facts of the recent decades. We know from many sources, such as Maddison (1995) and others, that the
share of trade increased both in developed and in less developed countries. This result therefore means that the recent global increase in wage inequality cannot be explained only by skill-biased technical change.

We next turn to examine the effect of trade liberalization on wage inequality. Here the difference between the two countries is dramatic. An increase in $m$ shifts the $WR_A$ curve upwards in Figure 3 and thus reduces $d_A$ and increases the wage ratio. Namely, trade liberalization increases wage inequality in the developed country, since it increases global demand for skilled workers in this country. In the less developed country the effect is opposite. A rise in $m$ shifts the $WR_B$ curve downward and thus increases $d_B$ and reduces the wage ratio in B. Hence, trade liberalization increases global demand for unskilled workers in less developed countries and it therefore reduces wage inequality in such countries. Hence, the recent rise in wage inequality cannot be accounted for by trade liberalization only, as we observe an increase in wage inequality in less developed countries as well, as shown in Berman, Bound and Machin (1998). Our model therefore implies that no single factor can account for the stylized facts of the last decades. Only a combined effect of both skill-biased technical progress and trade liberalization can fully account for the changes in wage inequality across the world and in the global trade patterns.

The above analysis of the effect of trade liberalization also shows, that such a liberalization leads to convergence of economies to one another. As shown above the increase in $m$ leads to lower $d_A$ in the developed country and to a higher $d_B$ in the less developed country. Hence, trade liberalization leads to more technology adoption in the less developed country and to less technology adoption in the developed country. Therefore, the two countries become closer to one another as a result of more international trade.
As shown above, both skilled-biased technical progress and trade liberalization increase wage inequality. We next use the model to quantitatively compare these two effects. We compare the elasticities of $WR_A$ with respect to $f$ and to $m$ and get that:

$\frac{\partial \log WR_A}{\partial \log f} = \frac{1}{m + d_A f (1 - m)} \frac{d_A f}{1 - d_A f},$

and

$\frac{\partial \log WR_A}{\partial \log m} = \frac{1}{m + d_A f (1 - m)} \frac{m}{1 - m}.$

Hence, the effect of technical progress is larger than the effect of trade liberalization if and only if

$$d_A f > m.$$ 

This condition is satisfied if country A is fully developed, i.e. if $d_A = 1$, and if $f > m$, namely if trade liberalization occurs when trade is quite limited and $m$ is rather small. From equations (29) and (30) we learn also that the wage ratio is highly sensitive both to technical progress and to trade liberalization as the above elasticities are quite high. If $d_A$ is equal to 1 and if $f$ is higher than 1/2, then the elasticity of $WR_A$ with respect to $f$ is higher than 1. A similar result holds with respect to $m$.

We next turn to examine the effects of technical progress and trade liberalization in the case of no specialization. We show that the results are similar to those under full specialization. Consider first the effect of an increase in $f$ on the equilibrium in the two countries. Since the equilibrium in country A is the same as in full specialization, and is given by equations (7) and (23), the effect of technical progress is the same. Hence, as $f$ increases, $d_A$ decreases, the wage ratio increases, and $d_A f$ increases as well. Next examine equation (27), which describes the determination
of $d_B$. An increase in $f$ increases (27) and hence reduces $d_B$ and increases the wage ratio in country $B$ as well.

Consider next the effect of technical progress on international trade. The share of trade in output in country A is $m(1 - dBf)$, as can be seen from equation (26). Note that we cannot tell whether $dBf$ is increasing or decreasing. The share of trade in output in country B is equal to:

$$\frac{dBf (1-d_Bf)}{S_B \left(1 + d_Af \frac{m}{1-m} \right) + 1-d_Bf}.$$ 

It can be shown that this share is an increasing function of $dBf$ as long as $dBf < 0.5$, which is a reasonable assumption. Hence, whatever the change in $dBf$, whether it increases or declines, the share of trade in one country increases while in the other country it declines. Hence, the model yields a similar result to that in full specialization. Hence, in this case as well, technical progress alone cannot account for the stylized facts of the recent decades.

We next examine briefly the effect of trade liberalization on equilibrium when there is no full specialization. An increase in $m$ shifts (23) up and hence increases the wage ratio. From equation (27) it follows that if $m$ rises and $d_A$ falls, then $d_B$ increases and the wage ratio in country B falls. Hence, the effect of trade liberalization on the two economies is similar to that in full specialization. Hence, in this case as well trade liberalization alone cannot account for the stylized facts of the recent decades.

6. Changes in Labor Supplies

Until this section we have assumed that the supplies of the two types of workers are given and fixed. In this section we study two possible changes in labor supply. First
we study the effects of a reduction in the relative supply of skilled labor, in order to analyze the Card and Lemieux (1999) explanation within our framework. Second, we examine what happens in the long-run, when the supplies of labor adjust to changes in the wage ratio, since this ratio represents an incentive to acquire skill.

Consider next the following exogenous change in labor supplies: the ratio between unskilled and skilled labor increases in country A. If \( N_A/S_A \) increases the \( \text{WRA} \) curve in Figure 3 shifts upward and the wage ratio rises with it. In country B this change has no effect at all, as can be seen from equation (24). The effect of changes in labor supplies on \( k \) is not clear, but the effect on the shares of trade in output is similar to the effect of skill-biased technical change. The share rises in one country and falls in the other. Hence, changes in relative labor supplies cannot be the only explanation to the widening wage gap in recent decades.

Next we extend the model to allow for labor supply adjustment to changes in the wage ratio. As the wage ratio rises more people invest in human capital and become skilled, due to an incentive effect. In order to capture this mechanism in the simplest way we assume that training decisions are so flexible, that the long-run equilibrium is reached instantaneously. Consider a version of the model, where individuals live one period each in consecutive generations. There is no population growth and each generation consists of a mass of size 1. Individuals have utility from consumption and disutility from the effort of learning. An individual can either work as unskilled, or study and work as skilled worker. Utility is

\[
U = \log c - \delta \log e,
\]

where \( c \) is consumption, \( e > 1 \) measures effort, and \( \delta \) is equal to 1 if the individual invests in human capital and 0 if not. We assume that the effort needed to study and
invest in skills differs across countries, as it embodies the difficulty of education and of skill acquisition, access to education and similar issues. We assume that individuals are free to choose between the two alternatives and as a result utility from the two careers must equal. Hence the wage ratio is

\[
WR_j = \frac{w_{ij}}{w_{nj}} = e_j
\]

in each country \( j \in \{A, B\} \). The wage ratio reaches this level by a full adjustment of the supplies of skilled and unskilled workers.

Note, that if the education system has some frictions, and the amount of individuals who acquire skills depends on the existing amount of skilled workers in the economy, condition (32) is not reached instantaneously. Furthermore, the frictions in the education system can be such, that the economy might get stuck in a different equilibrium and never reach (32).\( \Box \) Our specification in this Section is, therefore, intended to present the steady state in an economy without traps and we do it by ignoring short-run dynamics and assuming that the economy moves to the steady state instantaneously.

[Insert Figure 4 here]

The equilibrium in each economy is presented in Figure 4, where the wage ratio is not determined by demand for the two types of labor, as in the former sections, but by the labor supply condition (32). The equilibrium wage ratio determines the degree of technology adoption in each country \( d_j \). It also determines the amounts of skilled and unskilled workers in each country \( j \) by equations (27) and (28) and by the

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7 This is the case for example if the capital markets are imperfect and individuals can finance education only by parental help, as in Galor and Zeira (1993).
constraint: \( S_j = 1 - N_j \). These variables also determine \( k \) and the volume of international trade by equation (29).

Hence, the long-run wage ratio between skilled and unskilled workers is not affected by technical progress or by international trade, but by the access of individuals to education and skill acquisition, namely by the labor supply conditions. The more costly education is, namely the higher \( e \) is, the higher the wage ratio in the country. Technical progress and international trade affect the amounts of workers of both types in the long-run, but not their relative wage. It can be shown that technical progress increases the amount of skilled workers in all countries, while trade liberalization increases the amount of skilled workers in the developed economy and reduces this amount in the less developed economy.

7. Conclusions
This paper constructs a theoretical model of skill-biased technical progress and of international trade in order to examine how the two processes together affect wage inequality in developed and less developed countries. The results of the model can shed some light on the recent debates on what has caused the rise in wage inequality in the US and in other western economies. Our model shows that the widening of the wage gap between skilled and unskilled workers cannot be attributed to one single factor, trade liberalization or skill-biased technical progress.

According to the model trade liberalization increases the wage gap in developed countries, but reduces it in less developed countries. Since the wage gap has increased in recent decades both in developed and less developed countries, we conclude that it cannot be the result of trade liberalization only. We therefore cannot ignore the effect of skill-biased technical progress, which according to the model
increases the wage gap both in developed and in less developed countries. But technical progress cannot be the only factor that explains the rise in the wage gap for the following reason. Our model shows that skill-biased technical progress does not increase trade in all countries. This is in contrast with stylized fact that trade increased in all groups of countries in recent decades. Hence, only a combination of the two changes, technical progress and trade liberalization, can accommodate between the theory and the stylized facts of recent decades.

One important final comment is that all the changes discussed above in wage inequality are due to changes in demand for labor and are therefore short-run in nature. As time passes younger agents react to changes in wages by acquiring skills and thus wages gaps tend to be reduced. Hence, the long-run determinants of wage inequality are neither technology nor trade, but rather the ability of young people to acquire education and skills. Namely, in the long-run wage gaps are determined by the supply of labor rather than by the demand for labor.
References


Figures

Figure 1
Figure 2
Figure 3
Figure 4