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GLOBAL PRODUCTION CHAINS[‡]

Global Supply Chains and Wage Inequality[†]

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A salient feature of globalization in recent decades is the emergence of "global supply chains" in which different countries specialize in different stages of a sequential production process. In Costinot, Vogel, and Wang (2011), CVW hereafter, we have developed a simple theory of trade with sequential production to shed light on how global supply chains affect the interdependence of nations. The goal of this paper is to develop a multifactor extension of CVW to explore how the emergence of global supply chains may affect wage inequality within countries.

We start from the same basic environment as in Costinot and Vogel (2010), CV hereafter. As in CV, we consider a world economy with two countries, North and South, each populated by a continuum of workers with different skills. Both countries have access to the same technology for producing a unique final good, but North is skill abundant relative to South. Crucially, as in CVW, production of the final good requires a continuum of stages to be performed sequentially. At each stage, producing new intermediate goods requires workers and intermediate goods produced in the previous stage. The more skilled are workers at a given stage, the higher is the output of the intermediate good at the next stage.

We focus on the following thought experiment. Suppose that North and South move from complete autarky to complete goods market integration, i.e., from a world with only local supply chains to a world with both local and global supply chains. What would be the implications for the assignment of workers to stages of production and for wage inequality? We demonstrate that global supply chains lead all Southern workers to move into earlier stages of production. As they do, wage inequality in South decreases among workers employed at the bottom of the chain, but increases at the top, an anti-Stolper-Samuelson effect. This does not arise because of market imperfections, but because of the sequential nature of production.

While there is large literature focusing on the relationship between trade and inequality, our paper is most closely related to Antràs, Garicano, and Rossi-Hansberg (2006) who use a perfectly competitive assignment model to study the consequences of offshoring on wage inequality in a "knowledge economy." Beside the fact that our analysis does not rely on strong functional form assumptions on the distribution of worker skills, our model of trade with sequential production has one clear and distinct prediction: the emergence of global supply chains should have opposite effects on wage inequality among workers employed at the bottom and the top of these chains. This new theoretical insight is the main contribution of our paper.

The rest of the paper is organized as follows. Section I describes the basic environment. Section II characterizes the free trade equilibrium. Section III discusses the consequences of global supply chains for matching and wage inequality. Section IV offers some concluding remarks.

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I. Basic Environment

We consider a world economy with two countries, North (N) and South (S). Each country is populated by a measure one of heterogeneous workers with skill $s \in [\underline{s}, \overline{s}] \subset (0, 1)$. We denote by $L_c(s) > 0$ the inelastic supply of workers with skill s in country $c = N, S$ and by $w_c(s)$ the wage of these workers in country c. As in CV, we conceptualize differences in skill abundance between North and South by assuming that the distribution of skills can be ranked in terms of the monotone likelihood ratio property

$$(1) \qquad \frac{L_N(s')}{L_N(s)} > \frac{L_S(s')}{L_S(s)}, \text{ for all } s' > s.$$

As in CVW, there is one final good. Production of the final good is sequential and identical around the world. To produce the final good, a continuum of stages $\sigma \in [0, 1]$ must be performed. At each stage, the production function is Leontief. Formally, consider two consecutive stages, σ and $\sigma + d\sigma$, with $d\sigma$ infinitesimal. If a firm combines $q(\sigma)$ units of intermediate good σ with $q(\sigma)d\sigma$ units of workers of skill s, its output of intermediate good $\sigma + d\sigma$ is given by

$$(2) \qquad q(\sigma + d\sigma) = (1 + \ln s d\sigma)\, q(\sigma).$$

According to equation (2), more skilled workers produce more output at any stage. Hence, s measures absolute productivity differences across workers. Since $s \in (0, 1)$, equation (2) implies that output falls along the production chain. This is consistent with a model in which a worker with skill s makes mistakes at a constant Poisson rate equal to $-\ln s$, as in the benchmark model of CVW. All markets are perfectly competitive and all goods are freely traded. $p(\sigma)$ denotes the world price of intermediate good σ. For expositional purposes, we assume that "intermediate good 0" is in infinite supply and has zero price, $p(0) = 0$. "Intermediate good 1" corresponds to the unique final good mentioned before, which we use as our numeraire, $p(1) = 1$.

II. Free Trade Equilibrium

In a free trade equilibrium, markets clear and firms maximize profits taking prices as given. Profit maximization requires that

$$(3) \qquad p(\sigma + d\sigma) \leq (1 - \ln s d\sigma)\, p(\sigma) + w_c(s)\, d\sigma,$$

with equality if total employment of workers of skill s in country c is strictly positive between stages σ and $\sigma + d\sigma$. Condition (3) states that the price of intermediate good $\sigma + d\sigma$ must be weakly less than its unit cost of production, with equality if intermediate good $\sigma + d\sigma$ is actually produced by a worker with skill s in country c.[1] Together with the labor market clearing conditions, condition (3) implies that factor price equalization must hold in a free trade equilibrium. Otherwise workers of a given skill would not be employed in at least one country. Accordingly, the free trade equilibrium must replicate the integrated equilibrium, i.e., the autarky equilibrium of a fictitious economy with endowments $L(s) \equiv L_N(s) + L_S(s)$. In the rest of this article, we denote by $w(\cdot)$ the common wage schedule in both countries under free trade.

The free trade equilibrium always exhibits positive assortative matching, as the next lemma demonstrates.

LEMMA 1: *In a free trade equilibrium there exists a strictly increasing matching function* $M: [\underline{s}, \overline{s}] \to [0, 1]$ *such that in both countries:* (i) *workers with skill* s *are employed in stage* σ *if and only if* $M(s) = \sigma$, (ii) $M(\underline{s}) = 0$, *and* (iii) $M(\overline{s}) = 1$.

SKETCH OF PROOF:

The key part of the proof consists of showing that if a worker of skill s is employed in stage σ then a worker of skill $s' > s$ cannot be employed in a stage $\sigma' < \sigma$. As in CVW, the wage and price schedules are strictly increasing. If the wage schedule were not strictly increasing, then no firm would hire the high-wage, low-skill workers, and the labor market would not clear. If the price schedule were not strictly increasing, then no firm could produce the stages at which prices were not rising without violating condition (3).

[1] To see this, note that the production of one unit of intermediate good $\sigma + d\sigma$ using a worker of skill s requires $1/(1 + \ln s d\sigma)$ units of intermediate good σ as well as workers for all intermediate stages in $(\sigma, \sigma + d\sigma]$. Thus the unit cost of production of intermediate good $\sigma + d\sigma$ is given by $[p(\sigma) + w_c(s)\, d\sigma]/(1 + \ln s d\sigma)$. Since $d\sigma$ is infinitesimal, this is equal to $(1 - \ln s d\sigma)p(\sigma) + w_c(s)\, d\sigma$.

Given these results, one can then proceed by contradiction. Suppose that there exist $s' > s$ and $\sigma' < \sigma$ such that $M(s') = \sigma'$ and $M(s) = \sigma$. Then condition (3) implies $w(s') - w(s) \leq (\ln s' - \ln s)\, p(\sigma')$ and $w(s') - w(s) \geq (\ln s' - \ln s)\, p(\sigma)$, which together imply $p(\sigma') \geq p(\sigma)$, contradicting $p(\cdot)$ strictly increasing.

The intuition is the same as in CVW: efficiency requires more skilled workers to leverage their higher productivities on larger amounts of inputs by operating higher up the chain. Since North is skill abundant and the matching function is the same in both countries, one can further show that North produces relatively more in later stages of production. This implies the existence of global supply chains with Southern workers at the bottom and Northern workers at the top under free trade.

Using Lemma 1, one can express the good and labor market clearing conditions in a compact way. Letting $Q(\sigma)$ denote world output at stage σ, good and labor market clearing imply

$$\frac{Q(M(s + ds))}{Q(M(s))} = 1 + \ln s M'(s)\, ds, \tag{4}$$

$$M'(s) Q(M(s)) = L(s). \tag{5}$$

In line with equation (2), equation (4) states that the percentage change in world output between two consecutive stages is determined by the skill of the worker assigned to this stage. Equation (5), in turn, equates the demand for workers over this set of stages with the supply of workers assigned to them. The rest of our analysis crucially relies on the following lemma.

LEMMA 2: *In a free trade equilibrium the matching function and wage schedule are given by the solution of two ordinary differential equations*

$$\frac{d \ln M'(s)}{ds} = -\ln s e^{\ln M'(s)} + \frac{d \ln L(s)}{ds}, \tag{6}$$

$$\frac{d^2 \ln w(s)}{ds^2} = -\frac{1 + sM'(s) \ln s}{s} \frac{d \ln w(s)}{ds} - \left(\frac{d \ln w(s)}{ds}\right)^2 + \frac{M'(s)}{s} \tag{7}$$

with boundary conditions such that:

$$\int_{\underline{s}}^{\overline{s}} \left[\frac{d \ln L(s)}{ds} - \frac{d \ln M'(s)}{ds}\right] \frac{ds}{\ln s} = 1, \tag{8}$$

$$w'(\underline{s}), w'(\overline{s}) = 0. \tag{9}$$

PROOF:

Let us first consider equation (6). By equation (4), we know that

$$\frac{Q'(M(s))}{Q(M(s))} = \ln s.$$

By differentiating equation (5), we also know that

$$Q'(M(s)) = \frac{L'(s)M'(s) - L(s)M''(s)}{[M'(s)]^3}.$$

Combining the two previous expressions with equation (5), we obtain

$$\frac{L'(s)M'(s) - L(s)M''(s)}{L(s)[M'(s)]^2} = \ln s,$$

which can be rearranged as equation (6). Note that integrating this equation, we get

$$M(s) = M(\underline{s}) + \int_{\underline{s}}^{\overline{s}} \frac{1}{\ln t} \left[\frac{d \ln L(t)}{dt} - \frac{d \ln M'(t)}{dt}\right] dt.$$

By Lemma 1, we know that $M(\underline{s}) = 0$ and $M(\overline{s}) = 1$. Combining this observation with the previous expression, $M'(0)$ must be such that equation (8) holds. Let us now turn to equation (7). The zero-profit condition implies

$$p'[M(s)] = -\ln s p[M(s)] + w(s). \tag{10}$$

In equilibrium firms must be indifferent between using workers of skill s and $s + ds$ in sector $M(s + ds)$, which implies, after simplifications,

$$w'(s) = \frac{p[M(s)]}{s}. \tag{11}$$

Differentiating the previous expression, we get

$$w''(s) = \frac{p'[M(s)]\, M'(s) s - p[M(s)]}{s^2}.$$

Combining this expression with equations (10) and (11), we obtain, after simplifications, equation (7) with $w'(\underline{s}) = 0$ and $w'(\overline{s}) = 0$ since $p(0) = 0$ and $p(1) = 1$, by choice of numeraire.

Note that the system of differential equations characterizing the free trade equilibrium is block-recursive. We now take advantage of this simple structure to explore the consequences of global supply chains.

III. Consequences of Global Supply Chains

We focus on the following thought experiment. Suppose that North and South move from complete autarky to complete goods market integration, i.e., from a world with only local supply chains to a world with both local and global supply chains. What would be the implications for the assignment of workers to stages of production and for wage inequality?

Since the free trade equilibrium replicates the integrated equilibrium, moving from the autarky equilibrium to the free trade equilibrium is isomorphic to changing the skill distribution from $L_i(\cdot)$, $i = N, S$, to $L(\cdot) \equiv L_N(\cdot) + L_S(\cdot)$. This means that the consequences of global supply chains can be studied by starting from the counterparts of equations (6) and (7) under autarky and doing comparative dynamics on this system of differential equations as the skill distribution goes from $L_i(\cdot)$ to $L(\cdot)$.

Let $M_i(\cdot)$ denote the matching function under autarky in country $i = N, S$. We can state the first of our two main results as follows.

PROPOSITION 1: *Starting from autarky, the emergence of global supply chains leads to stage downgrading for all Southern workers, $M(s) \leq M_S(s)$. The converse is true in North.*

PROOF:

We focus on South. The argument for North is similar. We proceed by contradiction. Suppose that there exists $s_0 \in (\underline{s}, \overline{s})$ such that $M(s_0) > M_S(s_0)$. Then there must exist $s_1 \in [\underline{s}, s_0)$ such that $M(s_1) = M_S(s_1)$ and $M'(s_1) = M'_S(s_1)$. By condition (1), we know that the world distribution is such that $L(s')/L(s) > L_S(s')/L_S(s)$, for all $s' > s$, which implies $L'(s)/L(s) > L'_S(s)/L_S(s)$. Combining this observation with equation (6), we must therefore have $d \ln M'(s)/ds > d \ln M'_S(s)/ds$ whenever $\ln M'(s) = \ln M'_S(s)$. Since $\ln M'(s_1) = \ln M'_S(s_1)$,

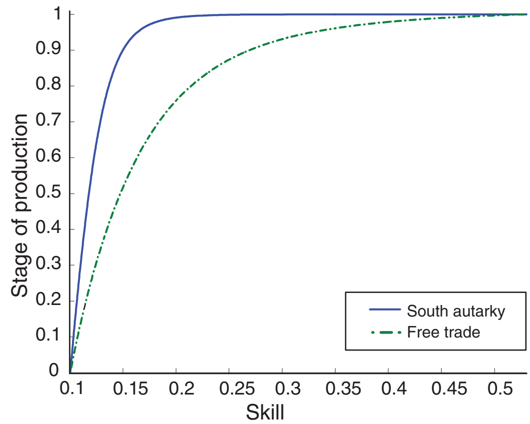

FIGURE 1. CHANGE IN SOUTHERN MATCHING

we must therefore have $\ln M'(s) \geq \ln M'_S(s)$, and, hence, $M'(s) \geq M'_S(s)$ for all $s \in [s_1, \overline{s}]$, with strict inequality for some s. Since $M(s_1) = M_S(s_1)$, this further implies $M(\overline{s}) > M_S(\overline{s})$, which contradicts $M(\overline{s}) = M_S(\overline{s}) = 1$.

The intuition is the same as in CV. Since North is skill abundant compared to South, the world skill distribution features relatively more high-skill workers than the Southern skill distribution. Accordingly, more stages should employ high-skill workers. This explains why $M^{-1}(\sigma) \geq M_S^{-1}(\sigma)$, and, in turn, why $M(s) \leq M_S(s)$. This is illustrated in Figure 1, in which we assume that the skill distribution is a truncated Pareto with the same support in both countries but, in line with condition (1), the Northern skill distribution has a fatter tail.

To conceptualize changes in wage inequality, we follow CV and focus on changes in $d \ln w(s)/ds$. To see why this is a natural metric for inequality, suppose that $d \ln w(s)/ds$ under free trade is higher than $d \ln w_S(s)/ds$ under autarky in South over some range of skills $[s_1, s_2]$. Then starting from autarky, the relative return to skill rises at all points within this range: $w(s'')/w(s') > w_S(s'')/w_S(s')$ for all $s_2 \geq s'' > s' \geq s_1$.

The second of our two main results can be stated as follows.

PROPOSITION 2: *Starting from autarky, the emergence of global supply chains decreases wage inequality among low-skill Southern* *workers, $d \ln w(s)/ds \leq d \ln w_S(s)/ds$ for $s \leq \hat{s}$, but increases wage inequality among high-skill Southern workers, $d \ln w(s)/ds \geq d \ln w_S(s)/ds$ for $s \geq \hat{s}$, with $\hat{s} \in [\underline{s}, \overline{s}]$. The converse is true in North.*

PROOF:

We focus on South. The argument for North is similar. First note that since $w'(\underline{s}) = w'_S(\underline{s}) = 0$, we have $d \ln w(\underline{s})/ds = d \ln w_S(\underline{s})/ds$. Now let

$$\hat{s} \equiv \sup\left\{s \in [\underline{s}, \overline{s}] \;\middle|\; \frac{d \ln w(s)}{ds} \leq \frac{d \ln w_S(s)}{ds} \text{ for all } s \in [\underline{s}, \hat{s}]\right\}.$$

If $\hat{s} = \overline{s}$, the proposition trivially holds. Now suppose that $\hat{s} < \overline{s}$. By definition, $\hat{s}$ must be such that $d \ln w(\hat{s})/ds = d \ln w_S(\hat{s})/ds$ and $d^2 \ln w(\hat{s})/ds^2 > d^2 \ln w_S(\hat{s})/ds^2$. Since $d \ln w(\hat{s})/ds = d \ln w_S(\hat{s})/ds$ and $d^2 \ln w(\hat{s})/ds^2 > d^2 \ln w_S(\hat{s})/ds^2$, equation (7)—which also holds in autarky in South with $w(s)$ and $M(s)$ replaced by $w_S(s)$ and $M_S(s)$—implies that $M'(\hat{s}) > M'_S(\hat{s})$. We must therefore also have $d \ln M'(\hat{s})/ds > d \ln M'_S(\hat{s})/ds$. And by the same argument as in the proof of Proposition 1, this implies $M'(s) \geq M'_S(s)$ for all $s > \hat{s}$, with strict inequality for some $s > \hat{s}$. Combining this observation with equation (7), we must have, for all $s > \hat{s}$, $d^2 \ln w(s)/ds^2 \geq d^2 \ln w_S(s)/ds^2$ whenever $d \ln w(s)/ds = d \ln w_S(s)/ds$. This implies $d \ln w(s)/ds \geq d \ln w_S(s)/ds$ for $s \geq \hat{s}$, which concludes our proof.

In words, global supply chains have opposite effects on wage inequality among workers employed at the bottom and the top of the chain. The impact on inequality at the bottom of the Southern income distribution is reminiscent of the well-known Stolper-Samuelson effect. Compared to the autarky equilibrium in South, high-skill workers are relatively more abundant in the integrated equilibrium, which tends to lower their relative wages. In a model without sequential production, such as the one studied in **CV**, this effect would lead to a pervasive decrease in inequality in South. Here instead the sequential nature of production leads to an increase in inequality at the top of the Southern income distribution. This is illustrated in Figure 2.[2]

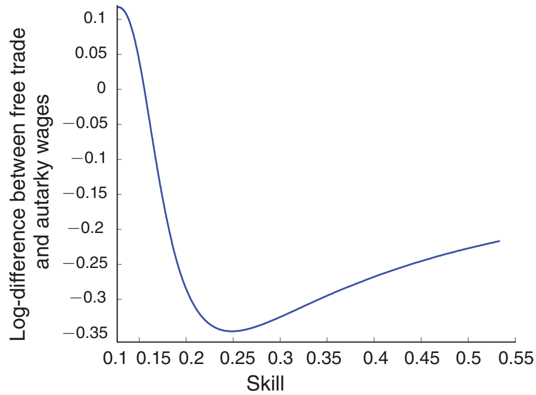

Figure 2. Change in Southern Wages

The logic of such nonmonotonic effects is discussed in detail in CVW, but the key reason why trade models with and without sequential production have very different implications for wage inequality can be understood as follows. In a perfectly competitive model without sequential production, changes in wages reflect changes in the prices of the goods produced by different workers. If free trade makes the prices of the goods produced by high-skill workers relatively cheaper in South compared to autarky, then inequality must go down in South. In a perfectly competitive model with sequential production, by contrast, changes in wages also reflect changes in the prices of the intermediate goods used by these workers. In this environment, if free trade makes the prices of the intermediate goods used by high-skill workers relatively cheaper in South compared to autarky, then this tends to increase inequality. This force dominates in the second portion of Figure 2.

IV. Concluding Remarks

In this paper we have developed a multi-factor extension of CVW to investigate the consequences of global supply chains on wage inequality within countries. Our model of trade

[2] Figure 2 focuses on an example in which inequality increases at the top. Proposition 2 allows for $[\hat{s}, \overline{s}]$ to be empty. In our simulations, we have encountered both situations.

with sequential production features a continuum of heterogeneous workers and allows for general skill distributions but remains highly tractable. A novel result that emerges from our analysis is that global supply chains have opposite effects on wage inequality among workers employed at the bottom and the top of these chains. This suggests that the consequences of globalization on wage inequality may be very different in primary sectors like agriculture or mining—which account for a large fraction of GDP in many developing countries—than in manufacturing sectors—which are the focus of most empirical studies on trade and inequality.

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