Global Supply Chains and Wage Inequality

By ARNAUD COSTINOT, JONATHAN VOGEL, AND SU WANG*

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 Arnaud Costinot, Jonathan Vogel and Su 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 multi-factor extension of **CVW** to explore how the emergence of global supply chains affects wage inequality within countries.

We start from the same basic environment as in Arnaud Costinot and Jonathan 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.

Like in our earlier work, our analysis is simplified by two observations. First, factor prices are always equalized in a free trade equilibrium. Thus the effect of trade integration on wage inequality is isomorphic to the effect of a change in the skill distribution in a closed economy. Second, the assignment of workers to stages of production exhibits positive assortative matching. Since workers operating in later stages of the production process can leverage their productivity on larger amounts of input, efficiency requires workers to be more productive at the top.

Using these two observations, we first demonstrate how the assignment of workers to stages of production and the distribution of wages can be described by a system of two ordinary differential equations. Armed with this system of equations, we then ask: How would the emergence of global supply chains caused by the integration of intermediate and final good markets affect matching and 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 at the bottom of the skill distribution, but increases at the top, an anti-Stolper-Samuelson effect.

This theoretical prediction is consistent with a situation in which Southern workers employed in early stages of the production process, e.g. mining, benefit from the emergence of global supply chains, but workers employed in later stages, e.g. manufacturing, lose, with the least skilled of those losing disproportionately more. In our model, the increase in inequality at the top of the Southern income distribution does not arise because of market imperfections, but because of the sequential nature of production.[1]

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.

I. Basic Environment

We consider a world economy with two countries, North (N) and South (S). Each country

* Costinot: MIT and NBER, Department of Economics, MIT, 50 Memorial Drive Building E52, Room 243B, Cambridge, MA (e-mail: costinot@mit.edu). Vogel: Columbia University and NBER, Department of Economics, 1022 International Affairs Building (e-mail: jvogel@columbia.edu. Wang: MIT, Department of Economics, MIT, 50 Memorial Drive Building E52, Room 262G, Cambridge, MA (e-mail: su_wang@mit.edu).

[1] In this regard, our paper bears some ressemblance to Pol Antràs, Luis Garicano, and Esteban Rossi-Hansberg (2006) who use a perfectly competitive assignment model to study the consequences of offshoring on wage inequality in a knowledge economy, though their model does not feature the input-ouput linkages that are central to our analysis.

is populated by a measure one of heterogeneous workers with skill $s \in [\underline{s}, \bar{s}] \subset (0,1)$. 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. Note that 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

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

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.[2] 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 paper, 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* $M : [\underline{s}, \bar{s}] \to [0,1]$ *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) $M(\bar{s}) = 1$.

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). Given these results, one can then proceed by contradiction. Suppose that there exist $s' > s$ and $\sigma' < \sigma$ such that $M(s') =$

[2] 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 $(1 - \ln s d\sigma)\, p(\sigma) + w_c(s)\, d\sigma$.

σ' 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. **QED**.

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 Norther 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*

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

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

with boundary conditions such that:

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

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

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

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

By Lemma 1, we know that $M(\underline{s}) = 0$ and $M(\bar{s}) = 1$. 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 $w'(\bar{s}) = 0$ since $p(0) = 0$ and $p(1) = 1$, by choice of numeraire. **QED**.

Note that the system of differential equations characterizing the free trade equilibrium is block-recursive. In order to construct an equilibrium, one can first characterize the matching function using equations (6) and (8) together

with the initial condition $M(\underline{s}) = 0$. Once the assignment of workers is known, the wage schedule can then be computed using equations (7) and (9). 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 $L(\cdot) \equiv L_N(\cdot) + L_S(\cdot)$. Mathematically, 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 $i = N, S$. Using this notation, 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 $s_0 \in (\underline{s}, \bar{s})$ 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 $s' \geq s$, 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 $\ln M'(s_1) = \ln M'_S(s_1)$, we must therefore have $\ln M'(s) \geq \ln M'_S(s)$, and hence, $M'(s) \geq M'_S(s)$ for all $s \in [s_1, \bar{s}]$, with strict inequality for some s. Since $M(s_1) = M_S(s_1)$, this further implies $M(\bar{s}) > M_S(\bar{s})$, which contradicts $M(\bar{s}) = M_S(\bar{s}) = 1$. **QED**.

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.

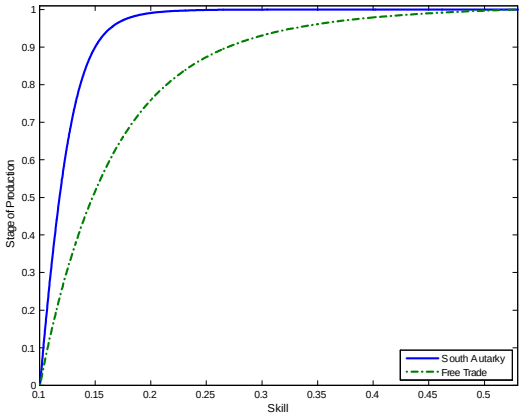

FIGURE 1. CHANGE IN SOUTHERN MATCHING

To conceptualize changes in wage inequality in an environment with many skill levels, 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 $s_2 \geq s'' > s' \geq s_1$.

Our second main result 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 $\hat{s} \in [\underline{s}, \bar{s}]$. 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

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

If $\hat{s} = \bar{s}$, the proposition trivially holds. Now suppose that $\hat{s} < \bar{s}$. 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. **QED**.

The impact of global supply chains 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, by contrast, 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 in which we use the same parameters as in Figure 1.[3]

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

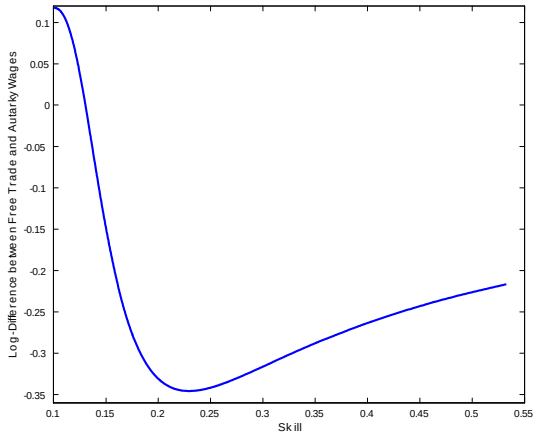

FIGURE 2. CHANGE IN SOUTHERN WAGE DISTRIBUTION

The logic of such non-monotonic 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 new force dominates in the second portion of Figure 2.

IV. Concluding Remarks

In this paper we have developed a multifactor extension of **CVW** to investigate the consequences of global supply chains on wage inequality within countries. Our model of trade with sequential production features a continuum of heterogeneous workers and allows for general skill distributions, but remains highly tractable. A surprising result that emerges from our analysis is that global supply chains tend to increase inequality at the top of the income distribution in less skill-abundant countries, an anti-Stolper-Samuelson effect. Although our model

is admittedly very stylized, our analysis leads to one simple, but we feel robust insight: because of global supply chains, 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.

REFERENCES

Antràs, Pol, Luis Garicano, and Esteban Rossi-Hansberg. 2006. "Offshoring in a Knowledge Economy," *Quarterly Journal of Economics* 121(1): 31-77.

Costinot, Arnaud, and Jonathan Vogel. 2010. "Matching and Inequality in the World Economy." *Journal of Political Economy* 118(4): 747-786.

Costinot, Arnaud, Jonathan Vogel, and Su Wang. 2011. "An Elementary Theory of Global Supply Chains." National Bureau of Economic Research WP 16936.