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Trade and inequality in developing countries: a general equilibrium analysis

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Abstract

Developing and newly industrialized countries that have experienced the sharpest increases in wage inequality are those whose export shares have shifted towards more skill-intensive goods. We argue that this can be explained by technological catch-up. We develop this insight using a model that features both Ricardian and endowments-based comparative advantage. In this model, Southern catch-up causes production of the least skill-intensive Northern goods to migrate South (where they become the most skill-intensive Southern goods). This raises wage inequality in *both* the South and the North. We provide empirical evidence that strongly supports this causal mechanism: Southern catch-up exacerbates Southern inequality by redirecting Southern export shares towards more skill-intensive goods.

Keywords: International trade; Inequality; Southern catch-up

JEL classification: F1

The trade-and-wages debate has settled comfortably into what Sherlock Holmes might have called ‘the 20% solution’. Using a variety of methodologies, many researchers have demonstrated that international trade accounts for no more than a fifth of the rising inequality experienced by the United States in the last two decades, e.g., Feenstra and Hanson (1996, 1999), Borjas et al. (1997), and Baldwin and Cain (2000). As American

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academic interest in the debate wanes, it is easy to forget that the trade-and-wages debate does not stop at the U.S. border. As demonstrators in Geneva, Seattle, and Québec City remind us, rising inequality is an issue of profound importance to the low- and middle-income countries that constitute the 'South'. This Southern incarnation of the trade-and-wages debate poses difficult challenges for international trade economists wedded to general equilibrium reasoning. Their workhorse general equilibrium model dishes up bland fare for a Southern palate, namely, the Stolper–Samuelson theorem. The theorem states that globalization raises the demand for unskilled Southern labor, thereby reducing inequality in Southern countries. Unfortunately, this prediction is not borne out by the data.

For example, consider the Freeman and Oostendrop (2001) occupational wage database. It has 20 developing and newly industrialized countries with consistent data on the relative wages of production versus nonproduction workers over the 1990s. Just over half of these countries experienced rising inequality over the 1990s. That is to say, globalization has *not* reduced wage inequality in Southern countries. Further, this roughly even split between rising and falling inequality illustrates just how complex the evolution of Southern inequality has been.

While this complexity calls for an alternative to Stolper–Samuelson reasoning, it offers no guidance as to what that alternative might be. For example, there is effectively a zero correlation between changes in inequality and per capita GDP. This leaves us with a frustrating problem. If the hallmark of international trade theory is general equilibrium reasoning and if the Stolper–Samuelson theorem is out of the picture, then what can international trade theory contribute to our understanding of Southern inequality? Fig. 1 is a partial regression plot that hints at a possible answer. Each point is one of 20 countries from the Freeman and Oostendorp data in one of four periods (1983–1986, 1986–1989, 1990–1993, and 1993–1997). The vertical axis measures the change in wage inequality, i.e., the log change in the wage of non-production workers relative to production workers. The horizontal axis measures the degree to which export shares have shifted towards more skill-intensive goods. (We will describe this measure in detail below.) The top panel plots the data in deviations from country means; that is, it is the partial regression plot from a regression of the growth in wage inequality on the shift in export shares towards skill-intensive goods and on country fixed effects. The correlation is 0.51 ($p<0.001$). The relationship strengthens when growth in the relative supply of skills is included in the regression.[1] This appears in the bottom panel of Fig. 1, where the correlation is 0.60. We will describe these regressions fully in the empirical sections of the paper. The main message for now is that general equilibrium trade linkages across countries likely play at least some role in the complex evolution of Southern inequality.

To explore this role, we develop a model in which Fig. 1 correlation is driven by Southern productivity catch-up. To this end, we marry the Dornbusch et al. (1980) model of Heckscher–Ohlin trade with the Dornbusch et al. (1977) model of Ricardian trade. The

[1] The relative supply of skills is the Barro and Lee (2000) ratio of secondary education completed to secondary education not completed.

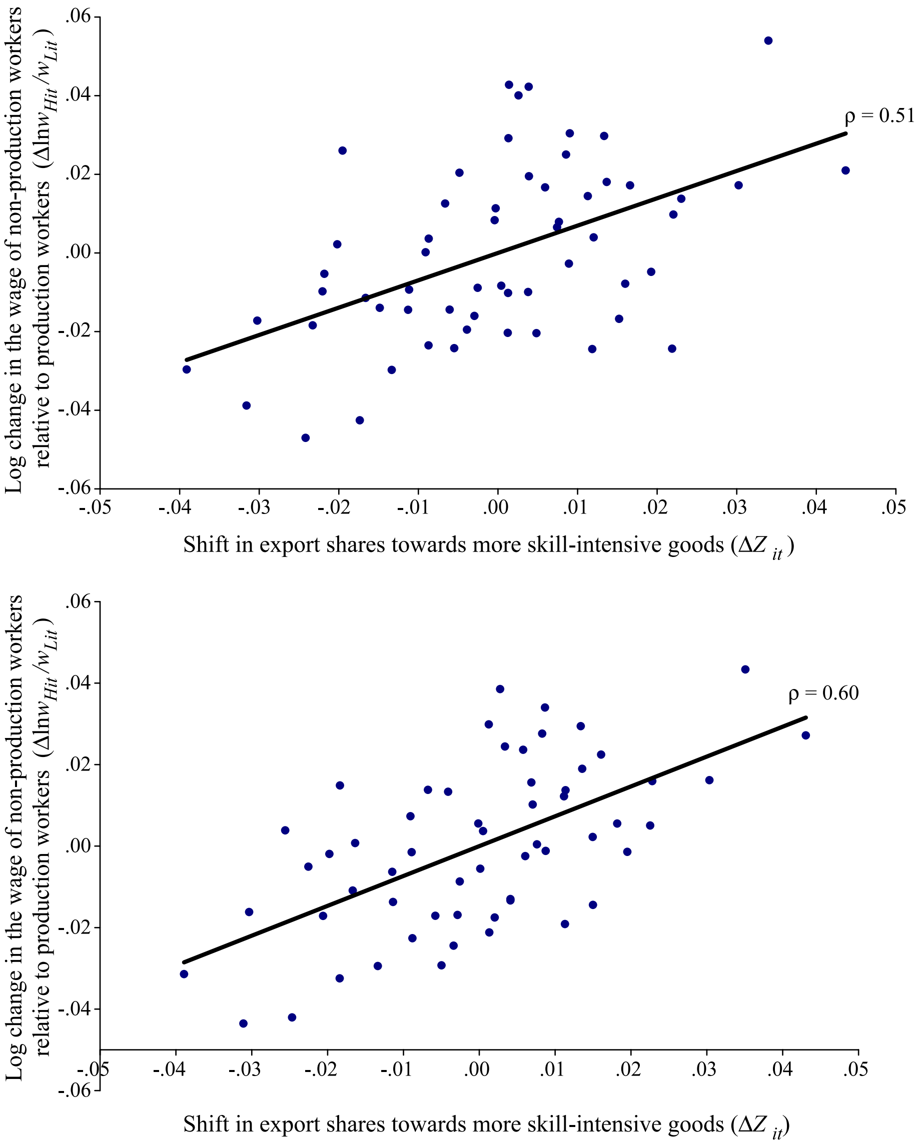

Fig. 1. The growth in wage inequality and shifting export shares. The figure plots changes in a country's wage inequality against a measure of how its export shares have shifted towards more skill-intensive goods. The panels are partial regression plots. The top panel controls for country fixed effects. The bottom panel controls for both country fixed effects and changes in the country's relative supply of skilled labor. Data are for 20 developing and newly industrialized countries over the periods 1983–1986, 1986–1989, 1990–1993, and 1993–1997.

former allows us to discuss rising wage inequality between skilled and unskilled labor. The latter allows us to discuss international technology differences and Southern productivity catch-up.

The intellectual inspiration for our modelling is an elegant observation by Feenstra and Hanson (1996) that appeared in a Bhagwati festschrift. Feenstra and Hanson point out that U.S. capital investments into Mexico pave the way for the United States to outsource its least skill-intensive goods to Mexico. Since these goods are highly skill-intensive by Mexican standards, outsourcing raises the relative demand for skills in both Mexico and the United States. This in turn increases the level of inequality in both regions. The model thus overturns the Stolper–Samuelson prediction and replaces it with a result in which foreign direct investment raises inequality in both Mexico and the United States.

In the model we will be presenting, there is no foreign direct investment. Instead, we consider a general form of Southern catch-up that goes beyond physical capital accumulation. The historical record on growth makes it clear that catching up involves far more than just physical capital accumulation.[2] In our general setting, we replicate and extend the Feenstra and Hanson result. We then show that the faster is a Southern country's *rate* of catch-up, the greater will be the *rate* at which its export shares shift towards more skill-intensive goods and the greater will be the *rate* of growth of wage inequality.

We then turn to an extended empirical assessment of this mechanism using a recursive, two-equation system implied by the model. The first equation explains the growth in wage inequality in terms of shifts in export shares towards more skill-intensive goods. This is the equation that underlies Fig. 1. The second equation relates export share shifts to Southern catch-up. The estimates of both equations are consistent with the theory. Further, the recursive structure of the model is correct. That is, Southern catch-up does not directly effect inequality: it does so only by shifting a country's export shares towards more skill-intensive goods.

In replicating and extending the Feenstra and Hanson result, we use a model that incorporates useful features absent from their framework. These include (1) Ricardian sources of comparative advantage, (2) substitution in production between skilled and unskilled labor, and (3) skill-biased technical change. Notwithstanding these theoretical innovations, our core theoretical result is a generalization of the Feenstra–Hanson selection mechanism.

The paper is organized as follows. Sections 1–3 set up the model and Sections 4 and 5 derive the core results on catch-up, trade, and inequality. Section 6 tightly links the theory to two estimating equations, Section 7 describes the data, and Sections 8 and 9 present the estimates. Section 10 concludes.

1. The setup

We follow the Dornbusch et al. (1980) setup as closely as possible. There are two regions, North (N) and South (S). There are two factors, unskilled labor (L) and skilled

[2] Without any pretensions to comprehensiveness, see, for example, Schultz (1960) on human capital accumulation, Gerschenkron (1962) on the advantages of being a late comer, and Acemoglu et al. (2001) on institutions.

labor (H). There is a continuum of goods indexed by z with $0 \le z \le 1$. Production functions are regularly neoclassical, displaying strict quasi-concavity, constant returns to scale, and continuous derivatives. In addition, there are no factor intensity reversals. This last assumption implies that we can identify larger z with greater skill intensity. Goods markets are perfectly competitive and profits are zero in equilibrium. There are no international barriers to trade in goods. Factor markets are perfectly competitive and clear domestically. Consumers have identical Cobb–Douglas preferences. Finally, international trade is balanced. This setup is identical to Dornbusch et al. (1980), except for the presence of international technology differences.

There are two sources of comparative advantage in our model. The first is endowments. Let w_{fi} be the wage of factor f (=L,H) in region i (=N,S). Let $\omega_i \equiv w_{\mathrm{H}i}/w_{\mathrm{L}i}$ be the wage of skilled labor relative to that of unskilled labor. As in Dornbusch et al. (1980), we assume that the North is sufficiently skill-abundant so that $\omega_{\mathrm{N}} < \omega_{\mathrm{S}}$. This implies that the North has a comparative advantage in skill-intensive goods. The second source of comparative advantage—which does not appear in Dornbusch et al. (1980), but is the focus of Dornbusch et al. (1977)—is Ricardian international technology differences. We assume that these differences confer a comparative advantage to the North in skill-intensive goods. That is, the North has relatively lower marginal costs for producing relatively more skill-intensive goods. To express this mathematically, let $C_i\,(w_{\mathrm{H}i}, w_{\mathrm{L}i}, z)$ be the unit cost function for producing good z in region i. We assume that

$$\frac{\partial C_{\mathrm{N}}(\cdot,\cdot,z)/C_{\mathrm{S}}(\cdot,\cdot,z)}{\partial z} \le 0 \text{ for all } z. \tag{1}$$

With two goods ($z_1 > z_2$), inequality (1) can be written as $C_{\mathrm{N}}(\cdot,\cdot,z_1)/C_{\mathrm{N}}(\cdot,\cdot,z_2) \le C_{\mathrm{S}}(\cdot,\cdot,z_1)/C_{\mathrm{S}}(\cdot,\cdot,z_2)$. That is, it is an inequality involving two ratios of marginal costs, just as in Ricardian textbook explanations of trade. The only difference is that with two types of labor, something must be said about factor prices. Inequality (1) compares C_{N} and C_{S} at any *common* set of factor prices.

Lemma 1 establishes that our two sources of comparative advantage work in the same direction and can be neatly integrated into a single model. All proofs appear in Appendix A.

Lemma 1. *Endowments-based comparative advantage ($\omega_N < \omega_S$) and Ricardian-based comparative advantage [Inequality (1)] together imply*

$$\frac{\partial}{\partial z}\frac{C_N(w_{HN}, w_{LN}, z)}{C_S(w_{HS}, w_{LS}, z)} < 0 \tag{2}$$

for all (w_{HS},w_{LS},w_{HN},w_{LN}) such that $\omega_N < \omega_S$ and for all z. That is, the North has a comparative advantage in skill-intensive goods.

Given Lemma 1, it is easy to show that for each factor price quadruplet satisfying $\omega_{\mathrm{N}} < \omega_{\mathrm{S}}$, there is a unique $\bar{z}$ on the interior of the unit interval such that $C_{\mathrm{N}}(w_{\mathrm{HN}}, w_{\mathrm{LN}}, \bar{z}) = C_{\mathrm{S}}(w_{\mathrm{HS}}, w_{\mathrm{LS}}, \bar{z})$. (See the proof of Lemma 1.) It follows that $C_{\mathrm{N}}(w_{\mathrm{HN}}, w_{\mathrm{LN}}, z)$ is below $C_{\mathrm{S}}(w_{\mathrm{HS}}, w_{\mathrm{LS}}, z)$ if and only if $z > \bar{z}$. This is illustrated in Fig. 2. (Note that we do not know

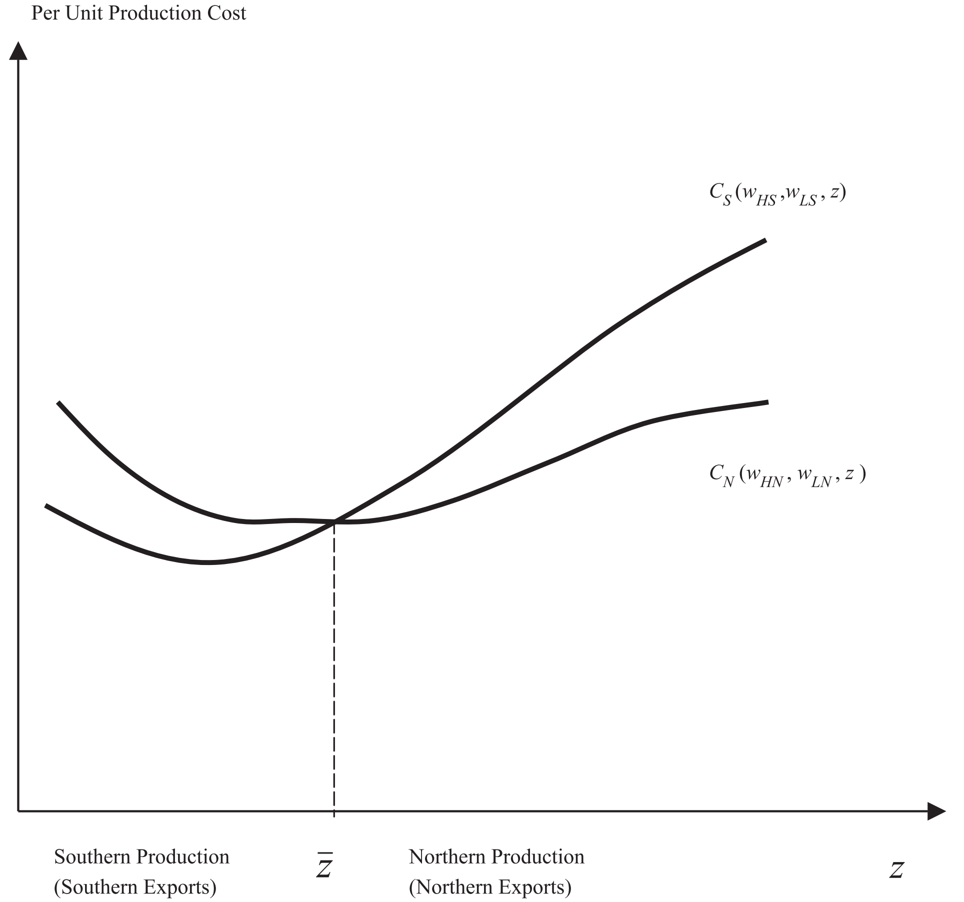

Fig. 2. Equilibrium trade patterns.

anything about the individual C_i, not even monotonicity. This is because the individual C_i deals with absolute advantage.)

It follows that even though we have an additional (Ricardian) source of comparative advantage that does not appear in Dornbusch et al. (1980), under a plausible assumption, we can still expect a similar characterization of equilibrium. Specifically, there is a 'competitive margin' $\bar{z}$ such that the North produces all goods $z>\bar{z}$ and the South produces all goods $z<\bar{z}$. That is, the North specializes in the most skill-intensive goods.

2. Equilibrium conditions

To keep the notation simple, for the remainder of the paper, we suppress the $w_{\mathrm{H}i}$ and $w_{\mathrm{L}i}$ as arguments of functions whenever possible. We emphasize that this is a notational convenience: we are making no assumptions about substitution possibilities in production. Let $P_i(z)$ be the competitive price for good z produced in region i. $\bar{z}$ is defined by

$$P_{\mathrm{N}}(\bar{z}) = P_{\mathrm{S}}(\bar{z}). \tag{3}$$

By the zero-profit condition, Eq. (3) is just the Fig. 2 crossing condition. Let Y_i be national income in region i. Preferences are given by the Cobb–Douglas utility function $U=\int_0^1 \alpha(z)\ln x(z)\mathrm{d}z$ where for each z, $\alpha(z)$ is a budget share and $x(z)$ is a quantity consumed.[3] Worldwide demand is

$$x(z) = \alpha(z)\frac{Y_{\mathrm{N}} + Y_{\mathrm{S}}}{P_i(z)} \tag{4}$$

where i=N for $z>\bar{z}$ and i=S for $z<\bar{z}$.

Let L_i and H_i be region i's endowments of unskilled and skilled labor, respectively. Let $L_i(z)$ and $H_i(z)$ be the amount of unskilled and skilled labor, respectively, needed to produce one unit of good z in region i. To keep the reader clear, we repeat that these are unit demands (not total demands) and that they depend on $w_{\mathrm{H}i}$ and $w_{\mathrm{L}i}$ (which are suppressed). Define $h_i \equiv H_i/L_i$ and $h_i(z) \equiv H_i(z)/L_i(z)$. Market clearing for Southern skilled labor is given by

$$\int_0^{\bar{z}} x(z)H_{\mathrm{S}}(z)\mathrm{d}z = H_{\mathrm{S}}. \tag{5}$$

Following Dornbusch et al. (1980), we can combine the zero-profit condition $P_i(z)=w_{\mathrm{L}i}L_i(z)+w_{\mathrm{H}i}H_i(z)$ with equations such as Eq. (5) to obtain two equations that summarize factor market clearing. To this end, define $S(\bar{z}) \equiv \int_0^{\bar{z}}[x(z)H_{\mathrm{S}}(z)/H_{\mathrm{S}}]\mathrm{d}z - \int_0^{\bar{z}}[x(z)L_{\mathrm{S}}(z)/L_{\mathrm{S}}]\mathrm{d}z$. $S(\bar{z})$ is the excess demand for skilled labor relative to unskilled labor. With some manipulation, $S(\bar{z})=0$ may be written as[4]

$$S(\bar{z}) = \frac{Y_{\mathrm{N}} + Y_{\mathrm{S}}}{w_{\mathrm{LS}}H_{\mathrm{S}}}\int_0^{\bar{z}} \alpha(z)\frac{h_{\mathrm{S}}(z) - h_{\mathrm{S}}}{1 + \omega_{\mathrm{S}}h_{\mathrm{S}}(z)}\mathrm{d}z = 0. \tag{6}$$

Likewise, the corresponding Northern factor market clearing condition $N(\bar{z}) \equiv \int_{\bar{z}}^1[x(z)H_{\mathrm{N}}(z)/H_{\mathrm{N}}]\mathrm{d}z - \int_{\bar{z}}^1[x(z)L_{\mathrm{N}}(z)/L_{\mathrm{N}}]\mathrm{d}z = 0$ may be written as

$$N(\bar{z}) = \frac{Y_{\mathrm{N}} + Y_{\mathrm{S}}}{w_{\mathrm{LN}}H_{\mathrm{N}}}\int_{\bar{z}}^1 \alpha(z)\frac{h_{\mathrm{N}}(z) - h_{\mathrm{N}}}{1 + \omega_{\mathrm{N}}h_{\mathrm{N}}(z)}\mathrm{d}z = 0. \tag{7}$$

[3] Preliminary analysis suggests that our results go through with CES preferences. Unfortunately, CES preferences introduce additional general equilibrium feedbacks that obscure the main point. We have thus not pursued this line of inquiry in any depth.

[4] Consider a $z\in[0,\bar{z}]$. From Eq. (4) and zero profits, $x(z)=(Y_{\mathrm{N}}+Y_{\mathrm{S}})\alpha(z)/[w_{\mathrm{LS}}L_{\mathrm{S}}(z)+w_{\mathrm{HS}}H_{\mathrm{S}}(z)]=[(Y_{\mathrm{N}}+Y_{\mathrm{S}})/w_{\mathrm{LS}}]\alpha(z)[(1/L_{\mathrm{S}}(z))/(1+\omega_{\mathrm{S}}h_{\mathrm{S}}(z))]$. Hence, $\int_0^{\bar{z}}[x(z)H_{\mathrm{S}}(z)/H_{\mathrm{S}}]\mathrm{d}z=[(Y_{\mathrm{N}}+Y_{\mathrm{S}})/w_{\mathrm{LS}}H_{\mathrm{S}}]\int_0^{\bar{z}}\alpha(z)[h_{\mathrm{S}}(z)/(1+\omega_{\mathrm{S}}h_{\mathrm{S}}(z))]\mathrm{d}z$. Likewise, $\int_0^{\bar{z}}[x(z)L_{\mathrm{S}}(z)/L_{\mathrm{S}}]\mathrm{d}z=[(Y_{\mathrm{N}}+Y_{\mathrm{S}})/w_{\mathrm{LS}}H_{\mathrm{S}}]\int_0^{\bar{z}}\alpha(z)[h_{\mathrm{S}}/(1+\omega_{\mathrm{S}}h_{\mathrm{S}}(z))]\mathrm{d}z$. Plugging these into the definition of $S(\bar{z})$ yields Eq. (6).

Define the trade balance as the value of Southern imports divided by the value of Northern imports: $B(\bar{z})\equiv(Y_S\int_{\bar{z}}^{1}\alpha(z)dz)/(Y_N\int_{0}^{\bar{z}}\alpha(z)dz)$. Substituting Eq. (3) and the zero-profit condition into the balance-of-trade condition $B(\bar{z})=1$ yields[5]

$$B(\bar{z}) = \frac{L_S}{L_N}\frac{L_N(\bar{z})}{L_S(\bar{z})}\frac{1+\omega_S h_S}{1+\omega_N h_N}\frac{1+\omega_N h_N(\bar{z})}{1+\omega_S h_S(\bar{z})}\frac{\int_{\bar{z}}^{1}\alpha(z)dz}{\int_{0}^{\bar{z}}\alpha(z)dz} = 1. \tag{8}$$

Following Dornbusch et al. (1980), the search for a competitive equilibrium can be reduced to the search for a triplet $(\omega_N,\omega_S,\bar{z})$ that solves Eqs. (6)–(8). As established in Lemmas 3 and 4 of Zhu and Trefler (2001), there exists a unique equilibrium. Further, if h_N/h_S is sufficiently large, then $\omega_N<\omega_S$ will be a feature of the unique equilibrium. Given our assumption about Ricardian international technology differences [inequality (1)], note that in order to maintain $\omega_N<\omega_S$, we require international endowment differences that are larger than in the traditional Heckscher–Ohlin model without technology differences. This is because Ricardian international technology differences lead to higher demand for the abundant factor in each region, and thus technology differences reduce the gap between relative wages ω_N and ω_S. This completes the setup of the model and the characterization of the unique equilibrium.

3. Technical change and the definition of Southern catch-up

Given the complexity of the model, including its two sources of comparative advantage, we make several simplifying assumptions about the nature of technical change. For one, we assume that it involves cost-cutting process innovation rather than product innovation. This is in the spirit of a model geared to Southern technology catch-up. Product innovation is taken up in Zhu (2002). Also, we assume that technical change is exogenous and uses no real resources. Endogenizing technical change offers important insights (Acemoglu, 1998, 2002), but is not our focus here.

We are interested in comparative static exercises involving technical change. Let t denote the state of technology. Note that our model is static so that t is *not* an index of time. For each t, there is a unique equilibrium and unique equilibrium outcomes $\omega_N(t)$, $\omega_S(t)$, and $\bar{z}(t)$. Rewrite factor demands and unit costs in a way that highlights their dependence on t. Thus, the $H_i(z,t)$ and $L_i(z,t)$ are factor demands per unit of z and

[5] By zero profits, $P_i(\bar{z}) = w_{Li}L_i(\bar{z})(1+\omega_i h_i(\bar{z}))$. Plugging this into $P_N(\bar{z})=P_S(\bar{z})$ yields

$$\frac{w_{LS}}{w_{LN}} = \frac{L_N(\bar{z})}{L_S(\bar{z})}\frac{1+\omega_N h_N(\bar{z})}{1+\omega_S h_S(\bar{z})}$$

Using $Y_i = w_{Li}L_i(1+\omega_i h_i)$ and the previous equation yields

$$\frac{Y_S}{Y_N} = \frac{L_S}{L_N}\frac{L_N(\bar{z})}{L_S(\bar{z})}\frac{1+\omega_S h_S}{1+\omega_N h_N}\frac{1+\omega_N h_N(\bar{z})}{1+\omega_S h_S(\bar{z})}$$

from which Eq. (8) follows.

the $C_i(w_{Hi},w_{Li},z,t)$ are costs per unit of z. We assume that these functions are differentiable in t and use the convention that the $C_i(w_{Hi},w_{Li},z,t)$ are non-increasing in t, i.e., technical change never increases unit costs.

The natural measure of productivity growth in the production of good z in region i is $-\partial \ln C_i(w_{Hi},w_{Li},z,t)/\partial t$. This is just the dual of the Solow residual. We will write that the *South is 'catching up' if*

$$\gamma(t) \equiv \frac{\partial \ln C_{\mathrm{N}}(w_{\mathrm{HN}}, w_{\mathrm{LN}}, \bar{z}, t)}{\partial t} - \frac{\partial \ln C_{\mathrm{S}}(w_{\mathrm{HS}}, w_{\mathrm{LS}}, \bar{z}, t)}{\partial t} > 0. \tag{9}$$

Eq. (9) states that the South is catching up if, for good $\bar{z}=\bar{z}(t)$, Southern productivity rises relative to Northern productivity. We will write that the *South is 'falling behind' if* $\gamma(t)<0$.[6]

Note that we have defined Southern catch-up only in terms of productivity growth for good $\bar{z}(t)$. We could have defined it in terms applicable to all Southern goods; however, doing so offers no additional insights.[7] In what follows, we suppress the technology argument t in $\omega_{\mathrm{N}}(t)$, $\omega_{\mathrm{S}}(t)$, $\bar{z}(t)$, and $\gamma(t)$. This completes the definition of Southern catch-up.

4. Neutral technical change

In order to make the main results as clear as possible, we begin by assuming that Southern catch-up involves Hicks-neutral technical change. Skill-biased technical change is dealt with in the next section. Recall that ω_i is the wage of skilled labor relative to unskilled labor in region i (=N,S). ω_{N} and ω_{S} will be our measures of inequality. Theorem 1 relates Southern catch-up to changing patterns of trade and inequality.

Theorem 1. *Assume that technical change is Hicks neutral.*

(1) If the South is catching up ($\gamma>0$), then $d\omega_N/dt>0$, $d\omega_S/dt>0$, and $d\bar{z}/dt>0$. That is, wage inequality widens in both regions and production of the least skill-intensive Northern goods migrates South.
(2) If the South is falling behind ($\gamma<0$), then $d\omega_N/dt<0$, $d\omega_S/dt<0$, and $d\bar{z}/dt<0$. That is, wage inequality falls in both regions and production of the most skill-intensive Southern goods migrates North.

The way to start thinking about Theorem 1 is in terms of the Feenstra and Hanson (1996) sorting mechanism. Referring to Fig. 2, Southern catch-up leads to a fall in the

[6] It might be helpful to some readers if we were more careful with the notation in Eq. (9). Throughout this paper, $\partial C_i(w_{Hi},w_{Li},\bar{z},t)/\partial t$ denotes the derivative of $C_i(w_{Hi},w_{Li},\bar{z},t)$ with respect to its fourth argument (t) and evaluated at $(w_{Hi},w_{Li},\bar{z})=(w_{Hi}(t),w_{Li}(t),\bar{z}(t))$. Restated, the derivative holds factor prices and $\bar{z}(t)$ constant at their initial equilibrium values.

[7] Also, it would be nice to express technical change in terms of a more primitive parameterization. This is done in Zhu and Trefler (2001, Section 6). There, it is shown that there is a 1:1 relationship between primitive parameterizations of Southern catch-up and the more interpretable parameterization of Eq. (9).

$C_S(w_{HS},w_{LS},z,t)$ schedule relative to the $C_N(w_{HN},w_{LN},z,t)$ schedule. This leads to a rise in $\bar{z}$. In the North, the rise in $\bar{z}$ eliminates the most unskilled-intensive jobs, thereby lowering the demand for unskilled labor. Northern inequality rises. In the South, the rise in $\bar{z}$ creates jobs that are more skill-intensive than any existing Southern jobs, thereby raising the demand for skilled labor. Southern inequality rises. Of course, this Feenstra–Hanson mechanism is only part of the story. Neutral technical change has general equilibrium effects on factor prices that lead to further shifts in Fig. 2 cost curves. To describe them simply, in the next paragraph, we assume that there is no technical change in the North.

At fixed $\bar{z}$, the proportion of world income spent on Southern goods in the range $[0,\bar{z}]$ is unchanged. That is, there is no increase in the profitability of Southern firms producing these goods. Southern catch-up would only induce a fall in the prices of Southern goods without any change in Southern wages. On the other hand, if Southern wages and the prices of Southern goods were kept unchanged, there would be a deficiency of demand for Southern labor if the South did not expand the range of goods it produces. This implies that at unchanged prices and wages, the South can undercut the North for some new goods. Therefore, the equilibrating process involves a rise in $\bar{z}$ and changes in relative wages.[8]

The basic insight of Theorem 1 is simple. Technical change is factor augmenting. Thus, Southern technical catch-up increases the South's effective size and with it, the world's relative supply of unskilled labor. In a world of integrated markets, this increase depresses the relative wage of unskilled workers everywhere.

It must be emphasized that Southern catch-up can only go so far before the South leapfrogs the North or, less dramatically, before our assumptions about endowments-based comparative advantage ($\omega_N<\omega_S$) and Ricardian-based comparative advantage [Inequality (1)] are violated. When Southern catch-up advances this far, Theorem 1 is no longer relevant. This completes the discussion of Theorem 1.

Southern catch-up raises $\bar{z}$, leading to rising wage inequality in both the North and the South. The next theorem explores how $d\omega_N/dt$, $d\omega_S/dt$, and $d\bar{z}/dt$ depend on the *rate* of Southern catch-up γ.

[8] There is another way of thinking about this. At fixed (ω_N,ω_S), Southern catch-up makes the South absolutely more productive. This leads to positive profits in the South. Competition for labor among Southern firms raises the relative wage of Southern workers (w_{LS}/w_{LN} and w_{HS}/w_{HN} rise). Rising income leads the South to import more. The result is a negative Southern trade balance. To eliminate the trade imbalance, the South increases its supply of goods and reduces its demand for Northern goods. Both changes are facilitated by a rise in $\bar{z}$.

Now allow (ω_N,ω_S) to change. The rise in $\bar{z}$ eliminates the trade imbalance but creates Southern excess demand for skilled labor relative to unskilled labor. Rising ω_S eliminates this excess demand in two ways. First, it leads to a *within-good* substitution away from skilled labor. Second, it increases the relative price of skill-intensive goods which leads to a *between-good* reallocation toward the South's unskilled-intensive goods. Together, these two mechanisms clear Southern labor markets. Adjustment in the North proceeds along similar lines.

Finally, it is easy to prove that the rise in ω_S increases the relative price of skill-intensive goods. Let $\theta_{HS}(z)\equiv w_{HS}H_S(z)/[w_{HS}H_S(z)+w_{LS}L_S(z)]$ be the cost share of skilled workers in the production of good z in the South. Consider two Southern goods z_1 and z_2. Differentiating the relative price of the two goods with respect to the relative wage yields $d[P_S(z_2)/P_S(z_1)]/d\omega_S=\theta_{HS}(z_2)-\theta_{HS}(z_1)$ which is positive if and only if $z_2>z_1$.

Theorem 2. *$d\omega_N/dt$, $d\omega_S/dt$, and $d\bar{z}/dt$ are increasing in the rate of Southern catch-up (γ). In particular, the faster is Southern catch-up, the greater is the growth in Southern inequality and Southern exports.*

This theorem is helpful for empirical work because it suggests a specification in rates of growth or changes. In particular, there is a positive correlation between $\mathrm{d}\omega_S/\mathrm{d}t$ and $\mathrm{d}\bar{z}/\mathrm{d}t$.

To summarize, Theorems 1 and 2 establish that rising inequality in both the North and the South is consistent with an almost-standard trade model featuring a combination of Ricardian and Heckscher–Ohlin elements. Theorem 1 also shows that skill-biased technical change is not necessary for rising inequality. Even with neutral technical change, Southern catch-up can raise wage inequality in *both* regions.

5. Skill-biased technical change

Of course, skill-biased technical change is likely the single most important contributor to rising inequality in the North (e.g., Katz and Murphy, 1992; Autor et al., 1998; Berman et al., 1998). We also know from Berman and Machin (2000) that the South has experienced skill upgrading so that skill-biased technical change in the South is likely also relevant. We therefore need to ensure that our trade-based explanation of North–South inequality spillovers is consistent with skill-biased technical change.

Let

$$\rho_i(z,t) \equiv \frac{\partial}{\partial t}\left(\ln \frac{H_i(z,t)}{L_i(z,t)}\right)$$

be the rate of skill-biased technical change in region i=N,S. We begin with a simplifying assumption.

Assumption 1. The rate of skill-biased technical change in region i is the same for all goods produced in region i. That is, $\rho_i(z,t)=\rho_i(t)$ for all z, i=N,S.

Assumption 1 is made for expositional ease in characterizing skill-biased technical change and is otherwise entirely unnecessary.[9] In what follows, the dependence of ρ_i on t is dropped.

Under Assumption 1, $\mathrm{d}\omega_N/\mathrm{d}t$, $\mathrm{d}\omega_S/\mathrm{d}t$, and $\mathrm{d}\bar{z}/\mathrm{d}t$ are linear functions of γ, ρ_N, and ρ_S. Specifically, letting x index ω_N, ω_S, and $\bar{z}$,

$$\frac{\mathrm{d}x}{\mathrm{d}t} = c_x\gamma + a_x\rho_N + b_x\rho_S, \qquad x = \omega_N, \omega_S, \bar{z} \tag{10}$$

where a_x, b_x, and c_x are functions of preferences and the *level* of technology, but are not functions of the technology *change* parameters (γ,ρ_N,ρ_S). The proof of linearity is not complicated (see Appendix A.3).

9 Without Assumption 1, $\rho_N(t)$ is replaced throughout by b_2 of Eq. (19) and $\rho_S(t)$ is replaced throughout by b_3 of Eq. (20). b_2 and b_3 are weighted averages across z of the rates of skill-biased technical change. The generality obtained by eliminating assumption is more than offset by the notational burden of Eqs. (19) and (20).

Theorem 3. *Let Assumption 1 hold. Then (1)* $c_{\omega_N}>0$, $c_{\omega_S}>0$, $c_{\bar{z}}>0$, *(2)* $a_{\omega_N}>0$, $b_{\omega_S}>0$, *(3)* $a_{\omega_S}<0$, $a_{\bar{z}}<0$, *and (4)* $b_{\omega_N}<0$, $b_{\bar{z}}<0$.

Part 1 is a restatement of Theorem 2 and mirrors the Feenstra–Hanson selection mechanism. Part 2 makes the obvious point that skill-biased technical change in a region raises inequality in that region. Parts 3 and 4 describe a novel cross-country spillover effect associated with skill-biased technical change. Consider part 3. Skill-biased technical change in the North depresses the relative wage of Northern unskilled workers. This makes it more difficult for the South to displace Northern production of the North's least skilled goods ($a_{\bar{z}}<0$). This in turn retards the effect of Southern catch-up on Southern inequality ($a_{\omega_S}<0$). Part 4 works exactly the same way as part 3, but starts with Southern skill-biased technical change. A more detailed discussion appears in Section 5 of Zhu and Trefler (2001). This completes the characterization of the relationship between Southern catch-up, international trade, and inequality.

6. Linking theory to empirics

The core insight of our model is that Southern catch-up γ raises Southern wage inequality ω_S by raising $\bar{z}$. To examine this empirically, we need to link the theory as tightly as possible to an estimating equation. In the theoretical discussion above, we allowed for technical change, but held all of the remaining exogenous variables (i.e., endowments) constant. We will need to allow for endowment changes as specified by the theory. Further, we anticipate the empirical results by focussing on Hicks-neutral Southern catch-up.

The direct relationship between $\bar{z}$ and ω_S is fully characterized by the Southern labor-market clearing condition [Eq. (6)]. Totally differentiating Eq. (6) with respect to $\bar{z}$, ω_S, and all of the exogenous variables that appear in the equation yields the linear relationship

$$\mathrm{dln}\omega_S = \beta_{\bar{z}}\mathrm{d}\bar{z} + \theta_1\mathrm{dln}(H_S/L_S). \tag{11}$$

We expect $\beta_{\bar{z}}>0$ since this is the core Feenstra–Hanson selection mechanism. Further, we expect $\theta_1<0$ since the first-order effect of an increase in the supply of skills is a fall in wage inequality. More formally, it is straightforward to sign $\beta_{\bar{z}}$ and θ_1 using the information supplied in Appendix A.3.[10] It is also important to notice what is *excluded* from Eq. (11), namely, Northern endowment changes $\mathrm{d}H_N$ and $\mathrm{d}L_N$ and Southern catch-up $\gamma\mathrm{d}t$.

Of course, $\mathrm{d}\bar{z}$ depends on Southern catch-up. Eq. (10) above showed that the general equilibrium change in $\bar{z}$ due to Southern catch-up is $\mathrm{d}\bar{z}=c_{\bar{z}}\gamma\mathrm{d}t$ where, from Theorem 3, $c_{\bar{z}}>0$. The change in $\bar{z}$ due to changes in the remaining exogenous variables (H_S,L_S,H_N,L_N) is obtained in the same way that $\mathrm{d}\bar{z}=c_{\bar{z}}\gamma\mathrm{d}t$ was obtained. That is, it is obtained by totally differentiating Eqs. (6)–(8). This yields the linear relationship

$$\mathrm{d}\bar{z} = \beta_\gamma\gamma\mathrm{d}t + \theta_2\mathrm{dln}(H_S/L_S) + \theta_3\mathrm{dln}(L_S/L_N) + \theta_4\mathrm{dln}(H_N/L_N). \tag{12}$$

[10] In the notation of Appendix A.3, $\beta_{\bar{z}}\equiv-\omega_S c_{21}/c_{22}$ and $\theta_1\equiv\omega_S\int_0^{\bar{z}}\alpha(z)\mathrm{d}z/c_{22}$. From Eq. (18), $c_{21}>0$ and $c_{22}<0$ so that $\beta_{\bar{z}}>0$ and $\theta_1<0$.

The four endowments collapse into three ratios because there are no scale effects in the model. Our focus is on the effects of Southern catch-up on $\bar{z}$, i.e., on $\beta_\gamma \equiv c_{\bar{z}} > 0$. It is straightforward to sign the remaining coefficients using the information supplied in Appendix A.3. In particular, $\theta_2 > 0$, $\theta_3 > 0$, and $\theta_4 \lesseqgtr 0$.[11]

Our econometric strategy is to estimate Eq. (11) using Eq. (12) as a first-stage regression or instrument set for $d\bar{z}$. The fact that γ, L_S/L_N, and H_N/L_N do not appear in Eq. (11) provides the exclusion restrictions underlying this estimation strategy.

7. The data

7.1. The trade cutoff ($\bar{z}$)

We use trade data at the 4-digit SITC level from the World Trade Database (Feenstra, 2000; Feenstra et al., 1997). Unfortunately, aggregation bias prevents us from directly observing $\bar{z}$. The problem is that at the 4-digit SITC level of the World Trade Database, most countries export most goods. In many cases, there is thus no cutoff $\bar{z}$ beyond which Southern countries cease exporting. As Feenstra and Hanson (1996) and Schott (2003) have argued, this lack of specialization is likely an artifact of aggregation bias.[12] Fortunately, our inability to observe $\bar{z}$ is not an insurmountable obstacle to empirical work. In our model, an increase in $\bar{z}$ shifts the South's export shares towards the South's most skill-intensive goods. Such export share shifts are observable. We will therefore examine predictions involving observable export share shifts (as opposed to unobservable shifts in $\bar{z}$).

To measure export share shifts, we rank each industry based on its ratio of non-production workers to production workers. A high ratio corresponds to a high z. Given our assumption of no factor intensity reversals, we can rank industries based on U.S. data on the employment of production and nonproduction workers. Data by 4-digit SIC are from the NBER productivity dataset. We use data from 1990, the mid-year of our sample. In order to match these data with the trade data, we aggregate the trade data to the 4-digit SIC level using the converter supplied by Feenstra (1997).[13]

We focus on Southern exports to Northern countries. Northern countries are the major OECD countries whose 1980 real GDP per capita exceeds \$14,000 (1980 dollars). These countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the

[11] In the notation of Appendix A.3, $\theta_2 \equiv [c_{22}c_{33}Y_{HS} - c_{12}c_{33}\int_0^{\bar{z}} \alpha(z)dz]/|c_{jk}|$, $\theta_3 \equiv c_{22}c_{33}/|c_{jk}|$, and $\theta_4 \equiv [-c_{22}c_{33}Y_{HN} - c_{22}c_{13}\int_{\bar{z}}^1 \alpha(z)dz]/|c_{jk}|$. The signs of c_{jk} and the determinant $|c_{jk}|$ are given in Eqs. (17) and (18) and imply $\theta_2 > 0$, $\theta_3 > 0$, and $\theta_4 \lesseqgtr 0$.

[12] The Feenstra and Hanson argument is about the fact that within each 4-digit SIC industry (e.g., autos), there are both low-z intermediates (e.g., car seats) and high-z intermediates (e.g., engine blocks). Our model can be easily modified to allow for such intermediate inputs. This is shown in detail in Zhu and Trefler (2001, Section 9).

[13] The converter derived from Feenstra (1997) maps the UN standard 4-digit SITC codes into 4-digit US SIC (1972 basis). Since the World Trade Flow Database is classified by Statistics Canada's SITC codes instead, we carefully deal with the roll-up problems which are detailed in Feenstra et al. (1997) and Feenstra (2000).

United States. For our results, it does not matter exactly which countries are included in the North provided that the major destinations for Southern exports are included, i.e., the United States, Japan, Germany, France, and the United Kingdom.

Southern countries are countries whose 1980 real GDP per capita is below \$14,000. The richest of these is Hong Kong with a GDP per capita of \$12,578. We have also considered Southern cutoffs of \$10,000 and \$7,500. All our results hold with these lower cutoffs.

Let i index Southern countries and let t index years. While dt has been used as an index of the change in technology, for the remainder of the paper, the subscript t will be used as an index of time. This should cause no confusion. Let $X_{it}(z)$ be the *share* of country i's exports that are accounted for by industry z, i.e., exports of z divided by total exports. Then $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ is the share of country i's exports accounted for by industries in the range $(0,z)$. The left panel of Fig. 3 plots Sri Lanka's $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ for 1990 (the black curve) and 1993 (the grey curve). Between 1990 and 1993, the curves shifted to the left which means that the export shares of unskilled-intensive industries grew. The right panel of Fig. 3 plots the $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ for Thailand. Here the curves shifted to the right which indicates that Thai exports became more skill-intensive over the period.[14]

Fig. 3 suggests a useful measure of the shift in export shares towards more skill-intensive goods. The measure is just the area between the two curves in Fig. 3. Mathematically,

$$\Delta Z_{it} \equiv \int_0^1 \int_0^z [X_{i,t-1}(\tilde{z}) - X_{it}(\tilde{z})]\mathrm{d}\tilde{z}\mathrm{d}z. \tag{13}$$

In the case of Thailand, ΔZ_{it} is positive because the 1990 curve lies above the 1993 curve. For Sri Lanka, ΔZ_{it} is negative because the 1990 curve lies below the 1993 curve. More generally, ΔZ_{it} is positive (negative) when export shares have shifted towards more (less) skill-intensive goods.[15]

A few words on the relationship between $\mathrm{d}\bar{z}$ and ΔZ_{it} are in order. An increase in $\mathrm{d}\bar{z}$ (i) increases the export shares of skill-intensive industries, thereby increasing ΔZ_{it}, and (ii) increases the level of exports. This means that the use of ΔZ_{it}, by missing level-of-export effects, biases the empirical work against finding trade impacts. It is a conservative measure. Also, the fact that ΔZ_{it} and $\mathrm{d}\bar{z}$ are not equivalent means that we are not testing our model. In particular, we are not examining the model's prediction of complete specialization characterized by a cutoff $\bar{z}$. Rather, our interest is centered on the model's implications for Southern inequality, i.e., Eq. (11). We are using the theory to frame an analysis of how Southern catch-up increases the export shares of the South's most skill-

[14] Notice that the Sri Lankan $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ are concave which means that Sri Lankan exports are dominated by unskilled-intensive industries. In contrast, the U.S. $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ are strongly convex which means that U.S. exports are dominated by skill-intensive industries. Between these two extremes is the more linear Thai $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$. Thus, the shape of the $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$ reflects a 'ladder of development'.

[15] For most of our data, the two curves do not cross, i.e., technical change is a first-order stochastic dominant shift of $\int_0^z X_{it}(\tilde{z})\mathrm{d}\tilde{z}$. Occasionally, the curves cross. In this case, a positive ΔZ_{it} implies that, *on average*, export shares have shifted towards more skill-intensive goods.

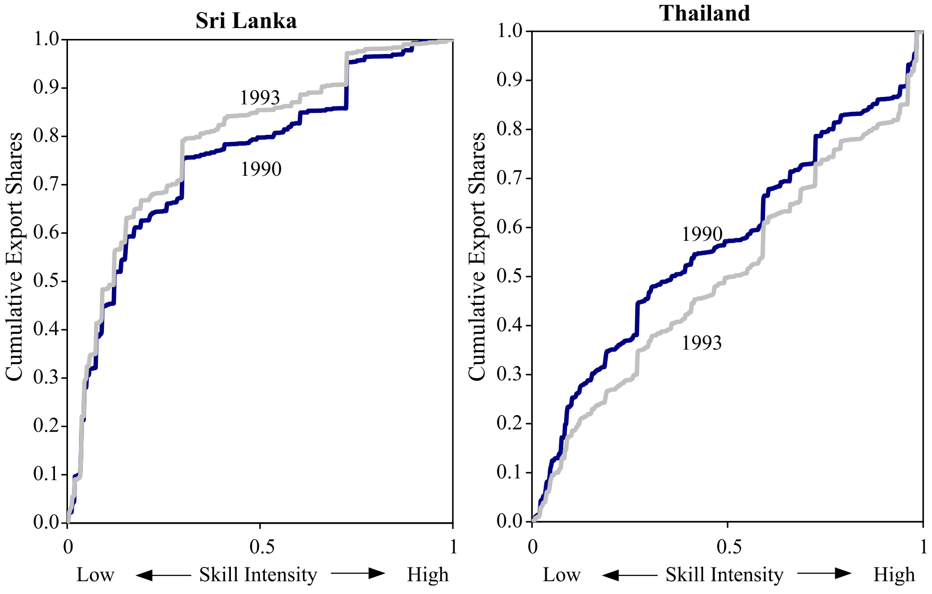

Fig. 3. Cumulative export shares by skill intensity. The figure plots export share data for 448 industries. The horizontal axis is the rank of the industry as measured by its skill intensity, i.e., by its ratio of nonproduction workers to production workers. (The industry rank is normalized by the total number of industries.) The vertical axis is the share of exports accounted for by all industries with skill intensity below that indicated on the horizontal axis. For example, roughly 80% of Sri Lankan exports in 1990 were accounted for by the 50% least skill-intensive industries.

intensive goods, thereby raising the relative demand for Southern skilled labor. This is a weaker set of predictions than those involving $\bar{z}$.

7.2. Measuring Southern inequality (ω_S)

Let w_{Hit} and w_{Lit} be the wages of skilled and unskilled workers, respectively, in country i. Our object of study is log changes in Southern relative wages, $\Delta\ln w_{Hit}/w_{Lit}$. Wage data are from the Freeman and Oostendrop (2001) NBER database on wages by occupation and industry for 1983–1997. The authors have cleaned up the original ILO data, which is notorious for its many missing values. We select only those developing and middle-income countries for which there are substantial data over the 1983–1989 period and/or the 1990–1997 period. Since annual changes are too noisy for our purposes, we consider changes in inequality either over the two periods 1983–1989 and 1990–1997 or the four periods 1983–1986, 1986–1989, 1990–1993, and 1993–1997.[16] We require that each country have data for at least two periods so that we can use country fixed effects. This

[16] The exact periods vary somewhat across countries depending on data availability. See Table A.1. Throughout the paper, all log changes are annualized. That is, they are divided by the number of years involved in order to ensure comparability across changes of different lengths.

leaves us with 20 countries and 58 observations in the four-period case and 17 countries and 34 observations in the two-period case. Clearly, we will need parsimonious specifications. Table A.1 lists the countries and year intervals in our dataset.

To be consistent with our definition of ΔZ_{it}, we define w_{Hit} as the average wage of manufacturing workers in nonproduction occupations (managers, professionals, technicians, and clerks) and w_{Lit} as the average wage of manufacturing workers in production occupations (craft workers, operators, and laborers). See Appendix A.4 for details.

7.3. Measuring Southern catch-up (γdt) and endowments

We measure Southern catch-up γdt as the log change of labor productivity in manufacturing. Denote this by γ_{it}^{m} where the m superscript refers to '*m*easured'.[17] The labor productivity data (value added per worker in manufacturing) used to construct γ_{it}^{m} are from Antweiler and Trefler (2002). We updated these data using the 1999 UNIDO industrial statistics database.

Let H_{it} and L_{it} be the endowments of skilled and unskilled workers, respectively, in Southern country i. Let H_{Nt} and L_{Nt} be the endowments of skilled and unskilled workers, respectively, in the North. Following Barro and Lee (2000), skilled workers are those who completed at least a secondary education and unskilled workers are all others. Notice that this classification differs from the production/nonproduction classification used elsewhere in the empirical work.

8. Estimation

Summarizing the previous section's discussion of the data, our empirical counterparts of Eqs. (11) and (12) are:

$$\Delta \ln \frac{w_{Hit}}{w_{Lit}} = \alpha_i + \beta_{\Delta Z} \Delta Z_{it} + \theta_1 \Delta \ln \frac{H_{it}}{L_{it}} + \varepsilon_{it} \tag{14}$$

$$\Delta Z_{it} = \alpha_i' + \beta_\gamma \gamma_{it}^{m} + \theta_2 \Delta \ln \frac{H_{it}}{L_{it}} + \theta_3 \Delta \ln \frac{L_{it}}{L_{Nt}} + \theta_4 \Delta \ln \frac{H_{Nt}}{L_{Nt}} + v_{it} \tag{15}$$

where α_i and α_i' are country fixed effects that capture unobserved country heterogeneity. Given the small sample size, we will mostly report results for changes over the four

[17] γ is defined in Eq. (9). Noting that $-\partial C_S/\partial t$ and $-\partial C_N/\partial t$ of Eq. (9) are, by duality, standard measures of productivity, a measure of γ that corresponds directly to Eq. (9) is

$$\tilde{\gamma}_{it}^{m} \equiv \gamma_{it}^{m} - \sum_{n \in N} \phi_{int} \gamma_{nt}^{m}$$

where n indexes the Northern trading partners of Southern country i and ϕ_{int} is a weight reflecting the size of bilateral trade flows between countries i and n. As an empirical matter, the term $\sum_{n \in N} \phi_{int} \gamma_{nt}^{m}$ does not vary much over time so that with country fixed effects, the variation in $\tilde{\gamma}_{it}^{m}$ is mainly driven by variation in γ_{it}^{m}. Thus, fixed effect results based on $\tilde{\gamma}_{it}^{m}$ and γ_{it}^{m} are all but identical and we only report results using γ_{it}^{m}.

periods 1983–1986, 1986–1989, 1990–1993, and 1993–1997. Very similar results, albeit with larger standard errors, are obtained when changes over the two periods 1983–1989 and 1990–1997 are used.

A difficulty in relating empirical Eqs. (14) and (15) to theoretical Eqs. (11) and (12) is that the theory has only one Southern country while the empirical work has many Southern countries. Extending the model to allow for many countries is complicated, a point Wilson (1980) showed for the simpler Ricardian model. The problem is that South–South trade in the model complicates our prediction about North–South trade. Since South–South trade is relatively small and not the focus of our work, we ignore South–South complications and move straight to multicountry empirical work.

8.1. The wage inequality equation: OLS

In estimating Eq. (14), we are primarily interested in whether $\beta_{\Delta Z}$ is positive as predicted by the theory. The top panel of Table 1 displays estimates of Eq. (14). The dependent variable is the growth in the relative wage of nonproduction workers ($\Delta \ln w_{Hit}/w_{Lit}$). From column 1, the estimated coefficient on ΔZ_{it} is positive as predicted ($\hat{\beta}_{\Delta z}$=0.73). Further, the t-statistic is 4.48 which is remarkably high given that there are only 58 observations and 20 country fixed effects, i.e., there are only 36 degrees of freedom. The partial regression plot for the column 1 specification appeared above in the bottom panel of Fig. 1 and shows no evidence of outliers or other features of the data that might create misleading inferences.

Most theories, including ours, predict that a rise in the relative supply of skills lowers the relative wage of skilled workers. In fact, we find the opposite ($\hat{\theta}_1$=0.34 in column 1 of Table 1). An endogeneity problem is almost certainly behind this positive coefficient. Whatever is causing firms to catch-up in the production of more skill-intensive goods is also causing workers to acquire more skills. Fortunately, our estimates of $\beta_{\Delta Z}$ are not sensitive to how $\Delta \ln H_{it}/L_{it}$ is modelled. In the extreme case where $\Delta \ln H_{it}/L_{it}$ is omitted from the regression, $\hat{\beta}_{\Delta Z}$=0.70 (t=3.64) which is very similar to the 0.73 estimate in column 1 of Table 1. The partial regression plot for the case where $\Delta \ln H_{it}/L_{it}$ is omitted from the regression appeared above as the top panel of Fig. 1.

We have considered a large number of alternative specifications. We briefly summarize these here. First, when period dummies are introduced, they are jointly insignificant even at the 10% level and $\hat{\beta}_{\Delta Z}$=0.67 (t=3.51) is not much changed. Second, instead of dividing the sample into four periods, we divided it into two periods, 1983–1989 and 1990–1997. This leaves the estimated $\beta_{\Delta Z}$ virtually unchanged ($\hat{\beta}_{\Delta Z}$=0.70, t=2.40) despite halving the sample size. Third, lowering the Southern GDP per capita cutoff does not alter our conclusions. For example, using a \$10,000 cutoff, the estimate of $\beta_{\Delta Z}$ is 0.72 (t=4.10), which is virtually identical to its Table 1 baseline estimate of 0.73.

8.2. The export shares equation: OLS

In estimating Eq. (15), we are primarily interested in whether β_γ is positive as predicted by the theory. That is, does Southern catch-up shift export shares towards more skill-intensive goods? Columns 5–7 in the bottom panel of Table 1 report the estimates of Eq.

Table 1
Baseline estimates

	OLS				IV			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Wage inequality Eq. (14)	*Dependent variable: $\Delta\ln(w_{Hit}/w_{Lit})$*							
Export share shifts ΔZ_{it}	0.73	0.72	0.67	0.71	0.77	1.00	0.79	0.78
	(4.48)	(3.83)	(3.58)	(3.44)	(2.04)	(2.62)	(2.69)	(2.35)
Southern skill supply $\Delta\ln(H_{it}/L_{it})$	0.34	0.35	0.37	0.35	0.34	0.35	0.34	0.34
	(3.82)	(3.55)	(3.84)	(3.48)	(3.80)	(3.75)	(3.81)	(3.81)
Southern catch-up[a]: $\gamma^m_{i,t-1}$		0.00						
		(0.14)						
Southern catch-up[a]: $\gamma^m_{i,t-3}$			0.02					
			(1.20)					
Southern catch-up[a]: $\gamma^m_{i,t-10}$				0.02				
				(0.24)				
Relative size $\Delta\ln(L_{it}/L_{Nt})$		−0.00	0.00	−0.00				
		(−0.02)	(0.10)	(−0.04)				
Northern skill supply $\Delta\ln(H_{Nt}/L_{Nt})$		−0.09	−0.13	−0.12				
		(−0.27)	(−0.41)	(−0.34)				
Adjusted R^2	0.64	0.60	0.62	0.61	0.59	0.58	0.60	0.60
F-test for exclusion restrictions[b]		0.04	0.52	0.05				
Export share shift Eq. (15)					*Dependent variable: ΔZ_{it}*			
Southern catch-up[a]: $\gamma^m_{i,t-1}$					0.02			
					(1.55)			
Southern catch-up[a]: $\gamma^m_{i,t-3}$						0.02		
						(1.70)		
Southern catch-up[a]: $\gamma^m_{i,t-10}$							0.17	0.18
							(3.02)	(3.42)
Relative size $\Delta\ln(L_{it}/L_{Nt})$					0.02	0.02	0.01	
					(1.98)	(2.28)	(1.47)	
Northern skill supply $\Delta\ln(H_{Nt}/L_{Nt})$					−0.22	−0.33	−0.39	
					(−0.72)	(−1.10)	(−1.41)	
Southern skill supply $\Delta\ln(H_{it}/L_{it})$					0.03	0.03	0.08	0.04
					(0.34)	(0.35)	(0.90)	(0.55)
R^2					0.40	0.41	0.50	0.45
F-test: $\Delta\ln(L_{it}/L_{Nt})$=$\Delta\ln(H_{Nt}/L_{Nt})$=0					1.97	2.71	1.67	
Hausman Test (t-statistics)[c]					0.12	0.80	0.23	0.16
Overidentification test (χ^2)[c]					0.19	1.44	0.19	

The top panel reports estimates of Eq. (14). The bottom panel reports estimates of Eq. (15). *All specifications of Eqs. (14) and (15) include country fixed effects*. Columns 5–8 report the IV estimates of Eq. (14) for the case where ΔZ_{it} is endogenous. The bottom panel serves as the first-stage regression for these IV estimates. There are 58 observations involving 20 countries and four periods (1983–1986, 1986–1989, 1990–1993, and 1993–1997). t-Statistics are in parentheses.

[a] Catch-up in country i is the growth in manufacturing labor productivity in country i. The 1-, 3-, and 10-year lags of Southern catch-up are given by $\gamma^m_{i,t-1}$, $\gamma^m_{i,t-3}$, and $\gamma^m_{i,t-10}$, respectively.

[b] F-test for the joint hypothesis H_0: $\gamma^m_{i,t-j}$=$\Delta\ln(L_{it}/L_{Nt})$=$\Delta\ln(H_{Nt}/L_{Nt})$=0 (j=1,3,10). The 5% critical value is 2.89 which means that the exclusion restrictions are accepted.

[c] A Hausman test statistic in excess of 2.03 indicates rejection of the endogeneity of ΔZ_{it} at the 5% level. An overidentification χ^2-statistic in excess of 5.99 indicates rejection of the instrument set at the 5% level.

(15). To help us get closer to causality, we introduce γ_{it}^{m} with a lag. In columns 5–7, the lags are 1, 3, and 10 years, respectively.[18] The $\hat{\beta}_{\gamma}$ are all positive as predicted and largest for the 10-year lag ($\hat{\beta}_{\gamma}$=0.17, t=3.02). Again, we find the t-statistic of 3.02 to be remarkable given the limited degrees of freedom. That it takes up to a decade before the full effects of Southern labor productivity growth on exporting are worked through corresponds to the Bernard and Jensen (1999) observation that productivity growth precedes exporting.

The remaining Eq. (15) endowment coefficients are of less interest, so we review them only briefly. From columns 5–8 in the bottom panel of Table 1, the endowment coefficients almost always have the theoretically predicted signs. The coefficients on $\Delta L_{it}/L_{Nt}$ and $\Delta \ln H_{it}/L_{it}$ are positive as expected. The theory does not predict the sign on $\Delta \ln H_{Nt}/L_{Nt}$. We estimate it to be positive. Given that $\Delta \ln H_{Nt}/L_{Nt}$ only varies across time, not countries, it is not surprising that its coefficient is never statistically significant.

8.3. The wage inequality equation: IV

Next, we return to the wage inequality equation [Eq. (14)] in order to address the endogeneity of ΔZ_{it}. ΔZ_{it} is instrumented using the first-stage Eq. (15) specification that we just described. We begin by checking that the instruments γ_{it}^{m}, $\Delta \ln L_{it}/L_{Nt}$, and $\Delta \ln H_{Nt}/L_{Nt}$ L_{Nt} do not belong directly in the second stage. The theory predicts exactly this exclusion restriction. Columns 2–4 in the top panel of Table 1 include these instruments directly into the second-stage equation and show that the exclusion restrictions are satisfied. Specifically, the last line in the top panel of Table 1 shows that the three instruments are jointly insignificant. The F-statistics in columns 2–4 are tiny compared even to the 5% critical level of 2.89.

The IV results appear in columns 5–8 of the top panel of Table 1. Since any omitted variable that raises Southern inequality likely reduces the export shares of skill-intensive goods, the OLS estimate is likely biased downward. As expected, the OLS estimate $\hat{\beta}_{\Delta Z}$=0.73 is smaller than each of the IV estimates. However, the OLS and IV estimates are not that far apart so that the Hausman test rejects endogeneity. This is reported in the second last line of the table. The last line reports overidentification tests. The tiny χ^2-statistics further validate our instruments.

Column 8 restricts the number of instruments to the point where the model is just identified. Note that $\Delta \ln H_{Nt}/L_{Nt}$ and $\Delta \ln L_{it}/L_{Nt}$ in the bottom panel of Table 1 are not jointly significant. For example, the F-test of their joint significance in column 7 is only 1.67 which is well below even the 5% critical value of 3.28. Thus, in column 8, we omit these two instruments. (We keep $\Delta \ln H_{it}/L_{it}$ in the column 8 specification because it appears in the second stage and so must be included in the first stage.) As a result, the t-statistic for $\gamma_{i,t-10}^{m}$ increases slightly to 3.42. This strengthens a core prediction of the model. Nevertheless, endogeneity continues to be rejected.

To summarize, Table 1 shows three things. First, Southern catch-up shifts the South's export shares towards more skill-intensive goods ($\hat{\beta}_{\gamma}$=0.18, t=3.42). Second, the resulting shift in export shares increases the level of wage inequality ($\hat{\beta}_{\Delta Z}$=0.73, t=4.48). *Taken*

[18] For example, if ΔZ_{it} is a change over the 1990–1993 period, then $\gamma_{i,t-3}^{m}$ is a change over the 1987–1990 period.

together, these conclusions mean that Southern catch-up has contributed to rising wage inequality in the South. Third, the model's exclusion restrictions are accepted by the data, i.e., Southern catch-up raises wage inequality only indirectly by shifting export shares ΔZ_{it}. Thus, the implications of the model, with ΔZ_{it} replacing $d\bar{z}$, are supported by the data.

9. Alternative trade mechanisms

Table 2 examines whether ΔZ_{it} may be capturing trade effects per se that have little to do with the causal mechanisms outlined in the model. Column 1 of Table 2 reports our baseline specification carried over from column 1 of Table 1. In column 2 of Table 2, ΔZ_{it} is replaced by the log change in exports of manufactured goods. Thus, we are abstracting from changes in the composition of export *shares* and focusing on changes in the *level* of total exports. The estimated coefficient on export growth is 0.04 with a t-statistic of 1.50. That is, the relationship between export growth per se and wage inequality is *not* significant. In column 3, we reintroduce ΔZ_{it} into the regression. Its coefficient and t-statistic are very similar to those of our baseline specification. In contrast, the coefficient on export growth literally drops to zero. Note that what matters for inequality is the technological change that induces a change in export shares to more skill-intensive goods. These results make it clear that the change in export shares is better correlated with this technological change than is general growth in Southern manufacturing exports.

Table 2
Alternative trade mechanisms

	Baseline channel	Total exports channel[a]		Newly exported goods channel[b]	
				Newly exported goods	Previously exported goods
	(1)	(2)	(3)	(4)	(5)
Wage inequality Eq. (14)	*Dependent variable:* $\Delta\ln(w_{Hit}/w_{Lit})$				
Export share shifts ΔZ_{it}	0.73 (4.48)		0.74 (4.04)	0.42 (4.07)	0.54 (2.94)
Southern skill supply $\Delta\ln(H_{it}/L_{it})$	0.34 (3.82)	0.29 (2.64)	0.34 (3.69)	0.38 (4.10)	0.40 (3.86)
Total exports: $\Delta\ln(X_{it})$		0.04 (1.50)	−0.00 (−0.06)		
Adjusted R^2	0.64	0.47	0.63	0.61	0.54

The table reports OLS estimates of the wage inequality Eq. (14). All specifications include country fixed effects. There are 58 observations involving 20 countries and four periods (1983–1986, 1986–1989, 1990–1993, and 1993–1997). t-Statistics are in parentheses.

[a] This specification includes the log change in the level of country i's manufacturing exports to Northern countries. It thus examines generic ways in which export growth may affect wage inequality.

[b] Newly exported goods are those goods that were not exported at the beginning of the 1980s (or 1990s), but started to be exported later in the 1980s (or 1990s). In column 4, ΔZ_{it} is constructed using only newly exported goods. Previously exported goods are those goods that were exported throughout the 1980s (or 1990s). In column 5, ΔZ_{it} is constructed using only previously exported goods.

Zhu (2002) has explored the role of product cycles for understanding skill upgrading at the industry level. Her analysis suggests that it might be useful to distinguish goods that the South has long exported ('previously exported goods') from goods that the South began exporting in the sample period ('newly exported goods'). Increases in $\bar{z}$ are associated with newly exported goods. Identifying newly exported goods in our setting is not easy because of aggregation problems. At the level of our 4-digit SITC trade data, most countries appear to export most goods so that there are very few newly exported goods. With this caveat in mind, we proceed to decompose total exports into previously exported and newly exported goods. Here, newly exported goods are identified as goods that were not exported at the beginning of the 1980s (or 1990s), but started to be exported later in the 1980s (or 1990s). Correspondingly, previously exported goods are defined as goods that were exported throughout the 1980s (or 1990s). Columns 4 and 5 of Table 2 report the results for newly and previously exported goods, respectively. In both columns, the coefficient on ΔZ_{it} is positive; however, the newly exported goods coefficient is statistically much more significant (t=4.07 versus t=2.94). Further, the newly exported goods specification has a much higher $\bar{R}^2$ (0.61 versus 0.54). This takes us one step closer to relating our export share finding ($\beta_{\Delta Z}$>0) to changes in $\bar{z}$.[19]

10. Conclusion

Among developing and newly industrialized countries, the Freeman and Oostendrop (2001) database shows that rising wage inequality during the 1983–1997 period was a common occurrence. This is sharply at odds with the Stolper–Samuelson theorem which predicts that Southern inequality should have fallen. In trying to explain this complex evolution of Southern inequality, we pointed out that there is a positive correlation across Southern countries between the growth in wage inequality and the shifting of export shares towards the South's most skill-intensive goods. This suggested to us that trends in wage inequality across developing and newly industrialized countries are linked via general equilibrium trade movements triggered by technological catch-up.

To model this, we married the Ricardian international technology differences model (Dornbusch et al., 1977) with the Heckscher–Ohlin model (Dornbusch et al., 1980).

[19] It is perhaps worth pointing out the differences between our paper and Zhu (2002). First, Zhu (2002) is concerned with industry-level skill upgrading in a product-cycle model. Her dependent variable is thus the payroll share of nonproduction workers. In contrast, we are concerned with wage inequality in a model of Southern catch-up. Since labor markets clear at the national level, our analysis is appropriately at the country level, not the industry level. Second, Zhu (2002) uses only U.S. trade data. Because her data are at the 5-digit SITC level, the additional detail allows her to carefully distinguish between newly and previously exported goods. In contrast, our focus on Southern countries means that we must use the World Trade Database which only has data at the 4-digit SITC level. Third, Zhu (2002) exploits wage *and employment* data from the United Nations General Industrial Statistics over the period 1978–1992. In contrast, we use the Freeman and Oostendorp ILO-based dataset for the period 1983–1997. This dataset contains better data on wage inequality but does not contain the employment data Zhu (2002) needs to examine skill upgrading.

In our model, technological catch-up causes production of the least skill-intensive Northern goods to migrate South where they become the most skill-intensive Southern goods. Thus, the demand for skills and hence wage inequality rise in both regions. This mechanism is closely related to that described by Feenstra and Hanson (1996).

We found empirical support for three predictions associated with this mechanism. First, Southern catch-up shifts export shares towards the South's most skill-intensive goods ($\hat{\beta}_{\gamma}$>0). Second, the resulting shift in export shares increases the level of wage inequality ($\hat{\beta}_{\Delta Z}$>0). Third, Southern catch-up does not directly raise wage inequality. Rather, Southern catch-up raises wage inequality only indirectly by raising the export shares of the South's most skill-intensive goods.

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Appendix A

A.1. Proof of Lemma 1

Let $L_N(z)$ and $H_N(z)$ be the amount of unskilled and skilled labor, respectively, needed to produce one unit of good z in the North. Define $h_N(z)\equiv H_N(z)/L_N(z)$. To keep the notation clear, the relative wage ω_N has been suppressed. Since $C_N(w_{HN},w_{LN},z)$ is homogenous of degree one in w_{HN} and w_{LN}, $C_N(w_{HN},w_{LN},z)=w_{LN}C_N(\omega_N,1,z)$. Differentiating this with respect to w_{LN} yields $\partial C_N(w_{HN},w_{LN},z)/\partial w_{LN}=C_N(\omega_N,1,z)-\omega_N\partial C_N(\omega_N,1,z)/\partial\omega_N$. By Shepard's Lemma, we have $L_N(z)=\partial C_N(w_{HN},w_{LN},z)/\partial w_{LN}$. Combining the above two equations yields $\partial C_N(\omega_N,1,z)/\partial\omega_N=H_N(z)$. Thus, we have

$$\begin{aligned}\frac{\partial}{\partial\omega_N}\left[\frac{\partial \ln C_N(w_{HN},w_{LN},z)}{\partial z}\right] &= \frac{\partial}{\partial\omega_N}\left[\frac{\partial \ln[w_{LN}C_N(\omega_N,1,z)]}{\partial z}\right] = \frac{\partial}{\partial\omega_N}\left[\frac{\partial \ln C_N(\omega_N,1,z)}{\partial z}\right] \\ &= \frac{\partial}{\partial z}\left[\frac{\partial \ln C_N(\omega_N,1,z)}{\partial\omega_N}\right] = \frac{\partial}{\partial z}\left[\frac{H_N(z)}{L_N(z)+\omega_N H_N(z)}\right] \\ &= \frac{\partial}{\partial z}\left[\frac{h_N(z)}{1+\omega_N h_N(z)}\right] = \frac{\partial h_N(z)/\partial z}{[1+\omega_N h_N(z)]^2} > 0.\end{aligned}$$

Hence, if $\omega_N<\omega_S$, then $\partial\ln C_N(w_{HN},w_{LN},z)/\partial z<\partial\ln C_N(w_{HS},w_{LS},z)/\partial z$. From inequality (1), we have $\partial\ln C_N(w_{HS},w_{LS},z)/\partial z\le\partial\ln C_S(w_{HS},w_{LS},z)/\partial z$. Combining these two inequality yields $\partial \ln C_N(w_{HN},w_{LN},z)/\partial z<\partial \ln C_S(w_{HS},w_{LS},z)/\partial z$. This implies that inequality (2) holds.

This completes the proof of Lemma 1. Note that given factor prices, $\bar{z}$ must be unique because $C_N(w_{HN},w_{LN},z)$ and $C_S(w_{HS},w_{LS},z)$ intersect only once. □

A.2. Downward sloping aggregate relative demands

Lemma 2. *Given $\bar{z}$, $\partial N(\bar{z})/\partial \omega_N<0$ and $\partial S(\bar{z})/\partial \omega_S<0$. That is, the aggregate demand for skilled labor relative to unskilled labor is downward sloping.*

Proof. We only consider the Southern labor market. Let $\varepsilon_S(z)\equiv -\partial \ln h_S(z,t)/\partial \omega_S>0$ be the elasticity of substitution between skilled and unskilled workers for Southern good z. Let $\theta_{HS}(z)$ and $\theta_{LS}(z)$ be the cost shares of skilled and unskilled workers, respectively. Define $Y_{HS}\equiv w_{HS}H_S/Y_S$ and $Y_{LS}\equiv w_{LS}L_S/Y_S$. Then given $\bar{z}$,

$$\frac{\partial S(\bar{z})}{\partial \omega_S} = -\frac{1}{\omega_S Y_{HS}}\int_0^{\bar{z}} \alpha(z)\theta_{HS}(z)\{\theta_{LS}(z)[\varepsilon_S(z)-1]+Y_{LS}\}\mathrm{d}z.$$

By inspection, if $\partial S(\bar{z})/\partial \omega_S<0$ for $\varepsilon_S(\cdot)=0$, then $\partial S(\bar{z})/\partial \omega_S<0$ for all $\varepsilon_S(\cdot)\geq 0$. We therefore only consider the case where $\varepsilon_S(\cdot)=0$. Then

$$\frac{\mathrm{d}S(\bar{z})}{\mathrm{d}\omega_S} = \frac{1}{\omega_S Y_{HS}}\int_0^{\bar{z}} \alpha(z)[\theta_{LS}(z)-Y_{LS}]\theta_{HS}(z)\mathrm{d}z. \tag{16}$$

Since $\int_0^{\bar{z}}\alpha(z)[\theta_{LS}(z)-Y_{LS}]\mathrm{d}z=0$,[20] and $\theta_{LS}(z)-Y_{LS}$ decreases in z, there exists a $z^0\in(0,\bar{z})$ such that (i) when $z=z^0$, $\theta_{LS}(z)-Y_{LS}=0$; (ii) when $z<z^0$, $\theta_{LS}(z)-Y_{LS}>0$; (iii) when $z>z^0$, $\theta_{LS}(z)-Y_{LS}<0$. Further, since $\theta_{HS}(z)$ increases in z, we have (i) when $z\leq z^0$, $\theta_{HS}(z)\leq\theta_{HS}(z^0)$ and (ii) when $z>z^0$, $\theta_{HS}(z)>\theta_{HS}(z^0)$. Therefore, Eq. (16) implies

$$\frac{\mathrm{d}S(\bar{z})}{\mathrm{d}\omega_S} < \frac{1}{\omega_S Y_{HS}}\left[\int_0^{z^0} \alpha(z)[\theta_{LS}(z)-Y_{LS}]\theta_{HS}(z^0)\mathrm{d}z + \int_{z^0}^{\bar{z}} \alpha(z)[\theta_{LS}(z) - Y_{LS}]\theta_{HS}(z^0)\mathrm{d}z\right] = \frac{\theta_{HS}(z^0)}{\omega_S Y_{HS}}\int_0^{\bar{z}} \alpha(z)[\theta_{LS}(z)-Y_{LS}]\mathrm{d}z = 0$$

as required. □

[20] Plugging Eq. (4) into Eq. (5) and using the zero-profit condition yield

$$H_S = (Y_N+Y_S)\int_0^{\bar{z}} \alpha(z)\frac{H_S(z,t)}{w_{HS}H_S(z,t)+w_{LS}L_S(z,t)}\mathrm{d}z.$$

Multiplying the result by w_{HS} implies $w_{HS}H_S/(Y_N+Y_S)=\int_0^{\bar{z}}\alpha(z)\theta_{HS}(z)\mathrm{d}z$. The balance-of-trade condition implies $(Y_N+Y_S)/Y_S=1/\int_0^{\bar{z}}\alpha(z)\mathrm{d}z$. Therefore,

$$Y_{HS} = \frac{w_{HS}H_S}{Y_S} = \frac{w_{HS}H_S}{Y_N+Y_S}\,\frac{Y_N+Y_S}{Y_S} = \frac{\int_0^{\bar{z}}\alpha(z)\theta_{HS}(z)\mathrm{d}z}{\int_0^{\bar{z}}\alpha(z)\mathrm{d}z}.$$

Likewise, $Y_{LS}\int_0^{\bar{z}}\alpha(z)\mathrm{d}z=\int_0^{\bar{z}}\alpha(z)\theta_{LS}(z)\mathrm{d}z$.

A.3. Proofs of the core theorems 1–3

The following proofs are based on differential equation system (17), which is derived by totally differentiating equilibrium conditions (6)–(8). This yields

$$[c_{jk}]\begin{bmatrix} \mathrm{d}\bar{z}/\mathrm{d}t \\ \mathrm{d}\omega_{\mathrm{S}}/\mathrm{d}t \\ \mathrm{d}\omega_{\mathrm{N}}/\mathrm{d}t \end{bmatrix} = [b_j],\ \text{where } [c_{jk}] = \begin{bmatrix} B_{\bar{z}} & B_{\omega_{\mathrm{S}}} & B_{\omega_{\mathrm{N}}} \\ S_{\bar{z}} & S_{\omega_{\mathrm{S}}} & 0 \\ N_{\bar{z}} & 0 & N_{\omega_{\mathrm{N}}} \end{bmatrix} \text{ and } [b_j] = \begin{bmatrix} -B_t \\ -S_t \\ -N_t \end{bmatrix}. \quad (17)$$

Note that subscripts on B, S, and N denote partial derivations, e.g., $B_{\bar{z}} \equiv \partial B/\partial \bar{z}$.

The elements of $[c_{jk}]$ and $[b_j]$ are as follows. Note that all variables except $\alpha(\cdot)$ depend on the technology state t. To simplify notion, t is suppressed unless it is necessary.

$$\left.\begin{aligned}
c_{11} &= \frac{\alpha(\bar{z})}{\int_0^{\bar{z}} \alpha(z)\mathrm{d}z \int_{\bar{z}}^1 \alpha(z)\mathrm{d}z} - \frac{\partial}{\partial \bar{z}}\ln\left[\frac{C_{\mathrm{N}}(w_{\mathrm{HN}}, w_{\mathrm{LN}}, \bar{z}, t)}{C_{\mathrm{S}}(w_{\mathrm{HS}}, w_{\mathrm{LS}}, \bar{z}, t)}\right] > 0 \\
c_{12} &= \frac{1}{\omega_{\mathrm{S}}}[\theta_{\mathrm{HS}}(\bar{z}) - Y_{\mathrm{HS}}] > 0 \quad c_{13} = \frac{1}{\omega_{\mathrm{N}}}[Y_{\mathrm{HN}} - \theta_{\mathrm{HN}}(\bar{z})] > 0 \\
c_{21} &= \alpha(\bar{z})\frac{\theta_{\mathrm{HS}}(\bar{z}) - Y_{\mathrm{HS}}}{Y_{\mathrm{HS}}} > 0 \\
c_{22} &= -\frac{1}{\omega_{\mathrm{S}} Y_{\mathrm{HS}}}\int_0^{\bar{z}} \alpha(z)\theta_{\mathrm{HS}}(z)[\theta_{\mathrm{LS}}(z)(\varepsilon_{\mathrm{S}}(z) - 1) + Y_{\mathrm{LS}}]\mathrm{d}z < 0 \quad c_{23} = 0 \\
c_{31} &= \alpha(\bar{z})\frac{Y_{\mathrm{HN}} - \theta_{\mathrm{HN}}(\bar{z})}{Y_{\mathrm{HN}}} > 0 \quad c_{32} = 0 \\
c_{33} &= -\frac{1}{\omega_{\mathrm{N}} Y_{\mathrm{HN}}}\int_{\bar{z}}^1 \alpha(z)\theta_{\mathrm{HN}}(z)[\theta_{\mathrm{LN}}(z)(\varepsilon_{\mathrm{N}}(z) - 1) + Y_{\mathrm{LN}}]\mathrm{d}z < 0
\end{aligned}\right\} \quad (18)$$

$$b_1 \equiv \gamma$$

$$b_2 = -\frac{1}{Y_{\mathrm{HS}}}\int_0^{\bar{z}}\left[\frac{\partial \ln h_{\mathrm{S}}(z,t)}{\partial t}\right]\alpha(z)\theta_{\mathrm{LS}}(z)\theta_{\mathrm{HS}}(z)\mathrm{d}z \quad (19)$$

$$b_3 = -\frac{1}{Y_{\mathrm{HN}}}\int_{\bar{z}}^1\left[\frac{\partial \ln h_{\mathrm{N}}(z,t)}{\partial t}\right]\alpha(z)\theta_{\mathrm{LN}}(z)\theta_{\mathrm{HN}}(z)\mathrm{d}z \quad (20)$$

where $\theta_{Li}(z) \equiv w_{Li}L_i(z,t)/[w_{Li}L_i(z,t)+w_{Hi}H_i(z,t)]$, $\theta_{Hi}(z)=1-\theta_{Li}(z)$, $Y_{Li} \equiv w_{Li}L_i/(w_{Li}L_i+w_{Hi}H_i)$, $Y_{Hi}=1-Y_{Li}$, $\varepsilon_i(z) \equiv -\partial \ln h_i(z,t)/\partial \ln \omega_i$.

c_{11} is positive because the North has a comparative advantage in more skill-intensive goods (Lemma 1). By Lemma 2, $c_{22} \equiv \partial S(\bar{z})/\partial \omega_S$ and $c_{33} \equiv \partial N(\bar{z})/\partial \omega_N$ are negative. The signs of other elements in $[c_{jk}]$ follow from the convention that a higher z good uses relatively more skilled labor. Finally, the signs of the c_{jk} imply that the determinant $|c_{jk}|$ is strictly positive.

Using the fact that $|c_{jk}|>0$, one can invert Eq. (17) to yield Eq. (10) with

$$\frac{d\bar{z}}{dt} = (c_{22}c_{33}\gamma - c_{12}c_{33}b_2 - c_{22}c_{13}b_3)\,|c_{jk}|^{-1}, \tag{21}$$

$$\frac{d\omega_S}{dt} = [-c_{21}c_{33}\gamma + (c_{11}c_{33} - c_{13}c_{31})b_2 + c_{21}c_{13}b_3]\,|c_{jk}|^{-1}, \tag{22}$$

$$\frac{d\omega_N}{dt} = [-c_{31}c_{22}\gamma + c_{12}c_{31}b_2 + (c_{11}c_{22} - c_{21}c_{12})b_3]\,|c_{jk}|^{-1}. \tag{23}$$

Proof of Theorem 1. With neutral technical change, $b_2=b_3=0$. Eqs. (21)–(23) thus imply that $d\bar{z}/dt$, $d\omega_N/dt$, and $d\omega_S/dt$ have the same signs as γ. The theorem follows immediately. □

Proof of Theorem 2. The theorem follows from the fact that the three coefficients on γ in Eqs. (21)–(23) are positive. □

Proof of Theorem 3. Define $b_2' \equiv \int_0^{\bar{z}} \alpha(z)\theta_{LS}(z)\theta_{HS}(z)dz/Y_{HS}>0$, and $b_3' \equiv \int_{\bar{z}}^1 \alpha(z)\theta_{LN}(z)\theta_{HN}(z)dz/Y_{HN}>0$. Under Assumption 1, $b_2=-\rho_S b_2'$ and $b_3=-\rho_N b_3'$. Substituting these expressions for b_2 and b_3 into Eqs. (21)–(23) yields Eq. (10) with

(1) $c_{\bar{z}} = c_{22}c_{33}/|c_{jk}| > 0$, $a_{\bar{z}} = c_{22}c_{13}b_3'/|c_{jk}| < 0$, and $b_{\bar{z}} = c_{12}c_{33}b_2'/|c_{jk}| < 0$;
(2) $c_{\omega_S} = -c_{21}c_{33}/|c_{jk}| > 0$, $a_{\omega_S} = -c_{21}c_{13}b_3'/|c_{jk}| < 0$, and $b_{\omega_S} = -(c_{11}c_{33} - c_{13}c_{31})b_2'/|c_{jk}| > 0$;
(3) $c_{\omega_N} = -c_{22}c_{31}/|c_{jk}| > 0$, $a_{\omega_N} = -(c_{11}c_{22} - c_{12}c_{21})b_3'/|c_{jk}| > 0$, and $b_{\omega_N} = -c_{12}c_{31}b_2'/|c_{jk}| < 0$. □

A.4. Data Appendix

Our choice of countries is mainly dictated by the availability of data from the Freeman–Oostendorp database. The countries selected for our sample are those satisfying the following criteria. (a) The country had real GDP per capita below \$14,000 in 1980. Transitional economies are excluded. (b) The country had observations on a fixed set of manufacturing occupations for at least two periods. Although the Freeman–Oostendorp dataset has 55 industry–occupation pairs in the manufacturing sector, most countries only reported data for a relatively small set of occupations. (c) The country had consistent data for both nonproduction occupations (managers, professionals, technicians, and clerks) and production occupations (craft workers, operators, and laborers). (d) The country had data on labor productivity, bilateral trade flows, and human capital. These criteria leave us with 20 countries in the sample. The list of countries and key variables are given in Table A.1.

Table A.1
Countries and key variables

Countries	Year interval	$\Delta\ln(w_{Hit}/w_{Lit})$	ΔZ_{it}	$\Delta\ln(H_{it}/L_{it})$	$\gamma^{m}_{i,t-10}$
Algeria	1985–1989	−0.005	−0.001	0.120	−0.048
	1990–1992	−0.021	−0.000	0.102	−0.021
Argentina	1991–1993	0.012	0.010	0.044	0.035
	1993–1995	−0.047	−0.017	0.042	−0.082
Barbados	1985–1989	−0.060	−0.040	0.054	0.016
	1990–1993	−0.007	0.015	0.031	0.033
	1993–1995	0.004	0.000	0.030	0.002
Bolivia	1991–1994	−0.002	0.051	0.029	−0.009
	1994–1997	−0.037	−0.010	0.022	−0.046
Central African Republic	1987–1989	0.000	−0.007	0.214	−0.080
	1991–1993	−0.061	−0.031	−0.001	−0.045
	1993–1997	−0.067	0.014	−0.003	0.058
Cyprus	1983–1986	0.008	−0.023	0.070	−0.005
	1986–1989	0.026	−0.008	0.029	0.000
	1990–1993	−0.011	0.011	0.016	0.002
	1993–1997	0.031	0.016	0.016	0.020
Honduras	1983–1987	0.054	−0.015	0.072	−0.106
	1990–1993	−0.019	−0.019	0.020	−0.001
	1993–1997	0.049	0.049	0.016	0.010
Hong Kong	1983–1985	−0.006	−0.007	0.039	0.029
	1985–1989	0.015	0.004	0.073	0.032
	1991–1994	−0.007	0.008	0.058	0.025
	1994–1997	0.011	0.012	0.024	0.022
India	1986–1989	0.053	0.005	0.017	0.022
	1990–1994	0.015	0.001	0.018	0.030
	1994–1997	0.004	0.005	0.022	0.040
South Korea	1983–1986	−0.005	−0.009	0.088	0.070
	1986–1989	−0.031	0.006	0.091	0.057
	1991–1993	0.011	0.025	0.072	0.057
	1993–1997	−0.003	0.024	0.048	0.070
Sri Lanka	1983–1985	−0.023	0.014	0.010	0.005
	1985–1988	−0.029	−0.010	0.014	0.073
	1990–1993	−0.006	−0.011	0.023	−0.030
	1993–1997	0.034	0.001	0.022	0.065
Madagascar	1983–1987	−0.073	0.013	0.062	−0.023
	1994–1995	−0.093	−0.031	0.032	−0.038
Mauritius	1983–1985	−0.018	−0.065	0.052	−0.282
	1985–1989	0.053	−0.022	0.106	0.015
	1990–1993	0.003	−0.010	0.014	0.039
	1993–1997	0.006	−0.007	0.014	0.045
Mexico	1990–1993	0.023	0.018	0.032	0.028
	1993–1997	−0.006	−0.005	0.027	0.048
The Philippines	1983–1986	−0.031	−0.001	0.036	0.091
	1986–1989	−0.030	−0.004	0.042	−0.052
	1990–1994	0.015	0.011	0.022	0.060
Singapore	1985–1989	−0.019	−0.004	0.027	0.079
	1991–1993	0.011	0.017	0.125	0.062
	1993–1997	−0.008	0.020	0.069	0.071
Thailand	1984–1986	0.071	0.006	0.082	0.008
	1991–1995	0.030	0.016	0.037	0.036

Table A.1 (*continued*)

Countries	Year interval	$\Delta\ln(w_{Hit}/w_{Lit})$	ΔZ_{it}	$\Delta\ln(H_{it}/L_{it})$	$\gamma^m_{i,t-10}$
Trinidad and Tobago	1985–1988	−0.020	−0.008	0.066	−0.051
	1990–1996	0.019	−0.000	0.035	−0.027
Uruguay	1985–1989	0.021	0.000	0.037	−0.018
	1990–1993	0.035	−0.010	0.002	0.044
	1993–1995	0.038	0.006	0.002	0.002
Venezuela	1984–1986	−0.021	−0.011	0.003	−0.003
	1986–1989	−0.052	−0.012	−0.027	−0.015
	1990–1997	0.044	0.039	0.039	0.021

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