Skill Acquisition and the Dynamics of Trade-Induced Inequality*

Eliav Danziger
Simon Fraser University, Burnaby, BC V5A 1S6, Canada

Abstract

I develop and calibrate a dynamic general-equilibrium trade model with endogenous skill demand and supply. Simulations show that removing US trade barriers would lead to aggregate gains in the United States of 4.5%. Individual workers' gains, however, depend on their education, age and birth cohort. The biggest winners, the oldest educated workers alive during trade liberalization, gain 6.7%, while their uneducated peers gain the least, only 1.1%. A major finding is that ignoring either the endogeneity of the skill supply or the post-liberalization dynamics, as the existing literature does, leads to a substantial bias in the quantitative assessment of trade liberalization.

Keywords: Trade liberalization; Wage inequality; Skill premium; Education
JEL Classifications: F16; F66; I24; J24; J31

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1 Introduction

The main objective of this paper is to quantify the differential impact of trade liberalization on workers of different education levels and across age groups when the supply of educated workers is endogenous. In contrast to the existing literature, my quantification of the impact of trade liberalization highlights the importance of accounting for both the endogeneity of the skill supply and, since skill supplies cannot adjust immediately, the associated transitional dynamics. This fills an important gap in the literature because existing studies have generally examined the quantitative impact of trade liberalization on the skill premium at fixed skill supplies.

The importance of both the offsetting effect of endogenous skill supplies on the skill premium as well as the ensuing transitional dynamics following a trade-induced increase in skill demand is not merely theoretical. Mexico provides a case in point. Beginning in the mid-1980's Mexico implemented a series of trade-liberalizing policies that culminated in the implementation of NAFTA in 1994. During this period of liberalization, increased demand for college graduates led to a steady increase in the college premium. However, after 1994 the college premium experienced a prolonged decline with a contemporaneous increase in the supply of college graduates.[1] A similar pattern has been documented in Korea where, after trade liberalizations and the implementation of export-promoting policies, the income gap between college graduates and high-school graduates first widened from 1971 to 1976 and subsequently narrowed in response to a growing supply of college graduates.[2] These episodes suggest that ignoring the endogeneity of the skill supply or considering only long-run impacts provides only a partial picture of the effects of trade on the skill premium.

In order to incorporate these observations into the quantitative analysis of the impact of trade liberalization on inequality, I build an overlapping-generations model with endogenous skill acquisition. I embed this model of skill acquisition into a quantitative multisector model of trade and skill demand à la Bustos (2011) and Yeaple (2005). By combining firm investment in technology with worker investment in skills and simulating the economy's entire transition path following trade liberalization, I am able to get a fuller picture of the effects of trade liberalization. Indeed, one of the main results of the paper is that ignoring either the endogenous skill supply response or the transition dy-

[1] See Robertson (2007) and Campos-Vazquez (2010) who attribute the decrease in the college premium to an increase in the supply of college graduates after NAFTA.

[2] See Kwark and Rhee (1993) and Kim and Topel (1995).

namics leads to a substantially biased quantitative assessment of the gains from trade and of the inequality brought about by trade liberalization. Thus, this paper presents a significant challenge to the existing literature on trade and inequality in which skill supplies are generally taken to be exogenous and only steady-state equilibria are considered.

In the model, uneducated workers can either work full time and supply low-skill labor or pursue a costly education that ultimately will enable them to provide high-skill labor. Complementarity between education and ability implies that only the more able individuals find it worthwhile to invest in an education. Trade liberalization triggers an increase in relative skill demand driving up the returns to education, making education a good investment for some workers for whom previously it was not. This precipitates an increase in workers seeking an education that, over time, augments the skill supply and thereby depresses the high returns to education.

Skill supplies do not adjust immediately to the increase in relative skill demand for two reasons. First, pursuing an education is a time-consuming activity. Second, old workers, who would have acquired an education had post-liberalization conditions prevailed in their youth, no longer find it profitable to do so, as they stand to reap the fruits of their investment for only a short period. Skill supplies can only fully adjust when these workers are replaced in the labor force by younger cohorts. The rate at which skill supplies adjust determines, through its general-equilibrium effect on the skill premium, the differential impact of trade liberalization on workers during the economy's transition phase.

Trade liberalization does not impact all workers symmetrically. Educated and uneducated workers are affected differentially because of the asymmetric effects on the demand for their services. Old and young, even within the same education class, are also affected differentially for two reasons. First, old uneducated workers are less likely than young workers to acquire an education in response to the increased returns to education. Second, old workers' lifetime earnings are affected only by the wages in the near future, whereas young workers' lifetime earnings depend also on wages in the more distant future.

To rationalize trade-induced shifts in relative skill demand, I use a multisector version of the model introduced in Bustos (2011) in which heterogeneous firms choose a production technology from a sector-specific menu of technologies that differ in productivity and skill intensity. Trade liberalization induces the reallocation of production shares towards exporters as in Melitz (2003), which affects relative skill demand through two channels. First, if exporters, on average, employ more skill-intensive technologies than non-exporters, this reallocation will tend to increase relative skill demand. Second, exporters expand their production and therefore upgrade their technologies, while the reverse is true for non-exporters. To the extent that technologies differ in their skill intensity, this technology switching shifts relative skill demand.[3]

The model focuses on shifts in relative skill demand emanating from within-sector between-firm labor reallocations. However, since I use a multisector model, I do not rule out trade-induced labor reallocations across sectors. Nevertheless, by examining the impact of trade liberalization between symmetric countries, I abstract from reallocations across sectors triggered by Heckscher-Ohlin forces and hence from Stolper-Samuelson effects on the skill premium.[4] While this is a potential limitation, empirical support for a substantial Stolper-Samuelson effect is sparse. Indeed, recent findings suggest that within-sector reallocations are substantially more important than between-sector reallocations in accounting for the impact of trade liberalization on workers. Specifically, my model is in line with the empirical finding that trade shocks lead to substantial labor reallocation between firms within sectors, but to little reallocation across sectors.[5] In addition, Burstein and Vogel (2016) find that, of the increase in the skill premium associated with increased trade in the United States, two thirds are attributable to within-sector reallocations, while only one third is attributable to between-sector reallocations.

Notwithstanding, the simulation results are more likely to be informative in the case of trade liberalization between similar countries (or country-like entities), such as the United States and the European Union, compared to trade liberalization between dissimilar countries such as the United States and China. This is because in the former case within-sector effects are likely to be dominant relative to Heckscher-Ohlin effects, while in the latter Heckscher-Ohlin forces may play a more important role. Therefore, the results in this paper are particularly useful for analyzing the potential impact of some recently proposed trade agreements, such as Transatlantic Trade and Investment Partnership (TTIP) (between the United States and the European Union) and the Trans-Pacific Partnership (TTP) (between eleven countries throughout the Asia-Pacific region, includ-

[3] Lileeva and Trefler (2010) show that Canadian firms that started exporting after trade liberalization upgraded technology. Bustos (2007) provides evidence that Argentinean firms induced to export by the implementation of MERCOSUR upgraded technology. Bustos (2011) shows that this technology upgrade was associated with an increase in skill intensity among upgraders, suggesting that these firms upgraded to more skill-intensive technologies.

[4] See Goldberg and Pavcnik (2007) for a survey on the link between trade and inequality in developing countries. Their main focus is on older trade theories in the spirit of Heckscher-Ohlin.

[5] See, for example, Haltiwanger et al. (2004) and Wacziarg and Wallack (2004).

ing Japan and Australia). Both of these agreements call for trade liberalization between similar countries where the emphasis on within-sector reallocations of labor seems particularly appropriate.

To study an economy's response to the types of trade liberalizations mentioned above, I calibrate the model to US data and simulate the economy's entire transition path following a removal of policy trade barriers, i.e., barriers not attributable to distance. Although, the model's assumption do not dictate that trade liberalization should necessarily lead to an increase in the skill premium, it turns out that this is indeed the case for the United States. In fact, if skill supplies are counterfactually fixed at their pre-liberalization levels, the skill premium would increase by 8%.[6]

I find that the gains from trade liberalization, defined as the increase in discounted real lifetime earnings relative to their pre-liberalization level, aggregated over present and future generations, are 4.5%. However, the gains generated by the policy change are not evenly divided among workers. Old educated workers alive at the time of implementation of the new trade policy gain 6.7%, making them the biggest winners from trade. In contrast, their uneducated peers gain only 1.1%. Moreover, older educated workers gain more than younger educated workers, while the opposite is true for uneducated workers.

I find that there is a large increase in inequality immediately following trade liberalization, both between educated and uneducated workers and across age groups. However, over time, the skill-supply adjustment and resulting wage dynamics mitigate the adverse distributional impact of trade liberalization. Nevertheless, even in the long run, trade liberalization does lead to a small increase in inequality. In fact, in the post-liberalization steady state, workers who pursue an education gain 5% relative to pre-liberalization as compared to just 4% for those that remain uneducated.

Finally, I assess the quantitative importance of accounting for the endogeneity of the skill supply and the economy's transition path. On the one hand, I find that assuming that the skill supply is exogenous leads to a substantial overstatement of trade-induced inequality as it does not account for the equalizing effect of the endogenous skill-supply adjustment. On the other hand, ignoring the economy's transition and considering instead only steady-states leads to a substantial understatement of trade-induced inequality. In-

[6]Given that the United States is relatively skill abundant, it is likely that the presence of Heckscher-Ohlin forces would reinforce the increase in the skill premium and hence the patterns of skill accumulation following trade liberalization. In the context of skill-scarce countries, it is possible that the Heckscher-Ohlin forces will serve as a countervailing force on the skill premium. If this effect is sufficiently strong, it is possible that trade liberalization can lead to a reduction in skill accumulation, as Atkin (2012) found for Mexico.

deed, much of the inequality is manifested during the transition when skill supplies are adjusting to the increased relative skill demand. These results underscore the importance of accounting for the the endogeneity of the skill supply and the transition dynamics in a full quantification of the impact of trade liberalization.

Relation to Literature

This paper contributes to a growing literature emphasizing the role of firm heterogeneity as a crucial link between trade and inequality.[7] Much of this literature builds on the key theoretical insight, first proposed by Melitz (2003), that trade shifts production shares from less-efficient to more-efficient firms. To explain why more-efficient firms pay similar workers different wages than less-efficient firms, thereby linking trade and inequality, Helpman, Itskhoki and Redding (2010) develop a model with search frictions, bargaining and screening; Egger and Kreickemeier (2009) propose fair-wage considerations; and Davis and Harrigan (2007) propose an efficiency-wage model. In these models, workers are ex-ante homogeneous and therefore non-competitive wage setting is needed to rationalize inequality.[8]

In my model, however, wage setting is competitive, but workers command different wages depending on their educational attainment. Thus, my approach to linking relative skill demand to trade is most closely related to Bustos (2011) and Samson (2014), in which firms choose technologies that differ in skill intensity, but with more productive technologies assumed to be more skill intensive.[9] A key difference is that I allow the data to determine the relationship between skill intensity and productivity rather than assuming that more-productive technologies are also more skill intensive. Indeed, such an assumption hardwires the increase in relative skill demand caused by a reduction in trade costs into the model. More importantly, all of the aforementioned models are static and take the skill supply as fixed, whereas in my model dynamics play an important role

[7]Bernard and Jensen (1997) show that a substantial fraction of the increase in the skill premium observed in the 1980's occurred through labor reallocations between plants within industries, and, in particular, the effect occurred almost entirely among exporting firms. Tybout (2000) is an early survey of the evidence linking firm heterogeneity and trade.

[8]Verhoogen (2008) suggests that an expansion of exports increases inequality in developing countries because exporters produce high-quality goods, which are produced more skill-intensively than low-quality goods. In Matsuyama (2007), serving the export market is a more skill-intensive activity than serving the domestic market as it requires knowledge of international business as well as language skills. See Harrison, McLaren and McMillan (2011) for a review of the recent theoretical and empirical contributions to the literature on trade and inequality.

[9]The approach is also related to Burstein and Vogel (2016), in which skill intensity is an innate characteristic of firms.

as skill supplies respond to the changing incentives to acquire skill induced by changes in trade policy.

This paper is also related to a nascent literature on the dynamic impact of trade on workers.[10] One strand of this literature has highlighted frictions in intersectoral mobility of workers as the source of slow adjustment to trade liberalization.[11] This approach has broadened our understanding of the dynamic impact of trade liberalization on workers, in particular for episodes that lead to substantial *between-sector* reallocations. However, my emphasis is on trade between similar countries where most labor reallocation occurs *within sectors*. In such cases, the skill supply adjustment emphasized in this paper may be the most important factor in accounting for the slow transition following trade liberalization.

Given the emphasis in the trade literature on the effect of trade on the skill premium, there has been surprisingly little research on the effect of trade on skill acquisition. Early work by Findlay and Kierzkowski (1983) analyzes the consequences of introducing endogenous skill acquisition into a Heckscher-Ohlin model. More recent research has modified and extended this approach.[12] Harris and Robertson (2013) study a dynamic small open-economy trade model in which a representative household decides how much time to allocate to skill acquisition. Falvey, Greenaway and Silva (2010) study a dynamic model of skill acquisition in a small open economy in which workers differ in ability and age. As opposed to my model which highlights the importance of wage dynamics, these dynamics are nonexistent in their model. This is because their small open-economy setting eliminates the general-equilibrium feedback between workers' decisions and future wages. Indeed, a defining feature of my framework is that tomorrow's wages are determined by today's schooling decisions and vice versa.

[10]There has also been some recent research into the dynamic impact of trade on firms in the presence of sunk costs. See Atkeson and Burstein (2007) and Costantini and Melitz (2007).

[11]In Artuç, Chaudhuri and McLaren (2010) workers do not immediately move to a high-wage sector because of mobility costs, while in Artuç (2009) and Dix-Carneiro (2013) sector-specific human capital represents an additional barrier to intersectoral mobility. In a related paper, Cosar (2010) merges sector-specific human capital with search frictions to determine the relative importance of those two factors in the labor market's adjustment to trade liberalization. More recently, Caliendo et al. (2015) develop a model that emphasizes both labor and goods mobility frictions in accounting for the impact of trade shocks.

[12]In an alternative approach, Atkin (2012) finds that increased trade in Mexico led to an increase in school drop out rates due to an increase in the availability of low-skill jobs.

2 The Model

The model is set in discrete time with periods indexed by t. There are two symmetric countries, Home and Foreign, indexed by $i \in \{H, F\}$. Each economy is populated by a unit continuum of workers who maximize consumption of an aggregate final good. This aggregate final good is itself a Cobb-Douglas aggregate of sector-level final goods from S sectors indexed by s, so that in any given period t supply and price of the aggregate final good in country i is

$$Q_{it} = \prod_{s=1}^{S} Q_{ist}^{\eta_s}, \quad P_{it} = \prod_{s=1}^{S} \left(\frac{P_{ist}}{\eta_s} \right)^{\eta_s},$$

where η_s is the expenditure share on sector s in aggregate-final-good expenditure and Q_{ist} and P_{ist} are, respectively, the quantity supplied and price index of the sector-s final good in country i. The sector-level final goods are CES aggregates of sector-specific intermediate goods with elasticity $\sigma_s > 1$, and therefore their supply and price in country i in period t is

$$Q_{ist} = \left[\int_{\omega \in \Omega_{ist}} q_{ist}(\omega)^{\rho_s} d\omega \right]^{1/\rho_s}, \quad P_{ist} = \left[\int_{\omega \in \Omega_{ist}} p_{ist}(\omega)^{1-\sigma_s} d\omega \right]^{1/(1-\sigma_s)} \tag{1}$$

where Ω_{ist} is the endogenous set of sector-s intermediate goods available in country i in period t, $q_{ist}(\omega)$ and $p_{ist}(\omega)$ are the quantity supplied and consumer price of a given sector-s intermediate ω and $\rho_s = (\sigma_s - 1)/\sigma_s$. These sector-specific intermediate goods are produced by profit-maximizing firms that hire the labor services of workers and make use of the aggregate final good to cover fixed production costs.

Since I consider symmetric countries, the exposition will focus only on symmetric equilibria. The price of the aggregate final good will henceforth be normalized to unity in all periods, which, together with market clearing and symmetry, implies that in both countries expenditure on the aggregate final good, R_t, is equal to the supply of the aggregate final good, Q_t, for every t.[13] The model and subsequent results are presented from the point of view of the Home country.

[13]Where there is no risk of confusion, I will do away with the country subscripts.

2.1 Firms

In this section I consider firms within a given sector. In sector s, there is a mass, M_s, of infinitely-lived, profit-maximizing intermediate-good producing firms in the Home country. Each firm has the ability to produce a unique sector-specific intermediate good, and its profits are shared equally among all workers.[14] In each period a firm must choose a technology, v_s, from a (sector-specific) technology menu. Each technology is characterized by a triplet $(\alpha_{v_s}, \lambda_{v_s}, f_{v_s})$, where α_{v_s} is a Hicks-neutral productivity factor, λ_{v_s} is skill intensity and f_{v_s} is a per-period fixed cost in terms of the aggregate final good.[15]

The production function of a firm employing technology v_s is $\varphi \alpha_{v_s} \min\{\ell, h/\lambda_{v_s}\}$, where ℓ and h are the measures of low- and high-skill labor, respectively, hired by the firm, and φ is a firm-specific idiosyncratic productivity factor independent of the chosen technology. The idiosyncratic productivities, φ, are distributed according to a Pareto distribution, $G_s(\cdot)$, with scale parameter 1 and shape parameter θ_s.[16] Technologies can be thought of as modes of firm organization or machines that require a specific mix of low- and high-skill labor to be operated. The Leontief structure of a particular technology does not preclude firms from substituting between skills. Rather, this substitution is achieved by switching technologies since technologies differ in their skill intensities, λ_{v_s}.[17]

To serve the foreign market, a sector-s firm must pay f_{xs} units of the final good as a per-period fixed cost of exporting. In addition, exporting entails an iceberg cost, $\tau_s > 1$. The total cost function of a (φ, v_s) firm, i.e, a firm with idiosyncratic productivity φ employing technology v_s, that sells q_H and q_F units of its intermediate good in the Home and Foreign countries is $(q_H + \tau_s q_F)/[\varphi \mu_{v_s}(w_t)] + f_v + 1_{\{q_F>0\}} f_{xs}$, where $w_t = \{w_{\ell t}, w_{ht}\}$ are the (economy-wide) wages of low- and high-skill labor and $\mu_{v_s}(w_t) = \alpha_{v_s}/(w_{\ell t} + \lambda_{v_s} w_{ht})$ is the cost efficiency of technology v_s.

Because there are no sunk costs, a firm's decision in period t depends only on conditions prevailing in period t. In particular, a sector-s firm's optimization in period t

[14] This is the Chaney (2007) variant of a Melitz model.

[15] In every sector, there exists a technology with $\alpha_0 = f_0 = 0$ so that a firm can always break even by choosing to produce nothing.

[16] A change in the scale parameter will proportionally change all the technology-specific productivities in the calibration. Thus, for example, doubling the scale parameter to two will simply lead to a halving of α_{v_s} for all v_s, but would not affect any of the results. Thus, the choice of scale parameter is without loss of generality.

[17] An alternative interpretation is that the firm chooses the quality of its intermediate good rather than its production technology. In this interpretation, a firm increases the demand for its good by increasing quality, so that α_{v_s} is a demand parameter rather than a technology parameter.

depends only on current wages, $w_{\ell t}$ and w_{ht}, current expenditure on goods in its sector, R_{st}, and the price index of the sector-level final good, P_{st}, all of which the firm takes as given. The time subscript, t, is therefore suppressed in the subsequent analysis of firm behavior.

Firm Behavior In each period, firms maximize profits by choosing prices, (p_H, p_F), and associated quantities, (q_H, q_F), in each market, as well as a technology, v_s, from the technology menu. Formally, in each period the firms solves

$$\max_{v_s, q_H, q_F, p_H, p_F} \left(p_H q_H + p_F q_F - \frac{(q_H + \tau_s q_F)}{\varphi \mu_{v_s}(w_t)} - f_{v_s} - 1_{\{q_F > 0\}} f_{xs} \right)$$

This can be solved in two stages. First, the firm solves for the optimal prices and quantities *given* technology choice, v_s. Second, it chooses the technology that yields the maximal profit.

Consider a firm with idiosyncratic productivity φ employing technology v_s. Such a firm optimally sets prices, $p_H(\varphi, v_s) = [\varphi \rho_s \mu_{v_s}(w)]^{-1}$ at home and, in case it exports, $p_F(\varphi, v_s) = \tau_s [\varphi \rho_s \mu_{v_s}(w)]^{-1}$ abroad. The optimal quantity *sold* in each market $i \in \{H, F\}$, conditional on serving market i, is $\left(R_s / P_s^{1-\sigma}\right) p_i(\varphi, v_s)^{-\sigma}$. Variable profits in market i, conditional on serving this market, are then $\pi_{is}(\varphi, v_s) = A_{is} [\varphi \mu_{v_s}(w)]^{\sigma_s - 1}$, where $A_{Hs} = \left(R_s / P_s^{1-\sigma}\right) \rho_s^{1-\sigma_s} / \sigma_s$ and $A_{Fs} = \tau_s^{1-\sigma_s} A_{Hs}$.

A firm will choose to export if and only if its variable profits in the Foreign country exceed the fixed exporting cost. Thus, the profit of a (φ, v_s) firm is $\pi_s(\varphi, v_s) = \pi_{Hs}(\varphi, v_s) + \max\{\pi_{Fs}(\varphi, v_s) - f_{xs}, 0\} - f_{v_s}$. Finally, any firm with idiosyncratic productivity φ will choose the technology that maximizes this profit, $v_s(\varphi) = \arg\max_{v_s} \pi_s(\varphi, v_s)$.

Properties of Firm Optimization Having specified the firm's problem, I now derive several properties of firms' optimal behavior. This will serve two purposes. First, it will build an intuition for the mechanisms embedded in the model and in particular, those linking trade liberalization to changes in relative skill demand. Second, these properties will guide the numerical implementation of the model.

Denote by $\tilde{v}_s \in \left\{0, 1, ..., \tilde{V}_s\right\}$ the technologies from the full technology menu that are employed in the period under discussion, where this subset is indexed in increasing order of fixed cost.[18] This set of technologies has two properties which will prove useful in the calibration and the subsequent quantitative analysis. First, $\mu_{\tilde{v}_s}$ is an increasing function

[18] In general, not all available technologies will be used in every period. In Appendix B, I provide an algorithm for determining which technologies are used in equilibrium and by which firms.

of $\tilde{v}_s$. If not, there would exist technologies $\tilde{v}_s < \tilde{v}'_s$ such that $f_{\tilde{v}_s} < f_{\tilde{v}'_s}$ and $\mu_{\tilde{v}_s} \geq \mu_{\tilde{v}'_s}$. But, technology $\tilde{v}'_s$ would not be used as it offers lower cost-efficiency at a higher fixed cost.

The second property of the set of employed technologies is that if $\varphi < \varphi'$, then $\mu_{v_S(\varphi)} \leq \mu_{v_s(\varphi')}$. More cost-efficient technologies offer greater savings on variable cost, but are more expensive in terms of fixed cost. Therefore, the attractiveness to a firm of adopting a more cost-efficient technology increases with the quantity it produces. Since, for a given technology, the quantity a firm produces is increasing in its idiosyncratic productivity, more productive firms adopt more cost-efficient technologies. Taken together, these two properties imply that if $\varphi < \varphi'$, then $v_s(\varphi) \leq v'_s(\varphi')$. In particular, there are $\tilde{V}_s$ intervals, $(\varphi_{\tilde{v}_s}, \varphi_{\tilde{v}_s+1})$, each of which is associated with a unique technology. We shall refer to a firm whose idiosyncratic productivity is on any of the interval endpoints as a technology upgrader.

The benefit of gaining access to the Foreign market increases with a firm's productivity, whereas the cost of market access does not. Therefore, in each sector there exists a φ_{xs} such that any firm with productivity $\varphi > \varphi_{xs}$ exports and any firm with productivity $\varphi < \varphi_{xs}$ serves only the Home market. As a result, there exists a technology $\tilde{v}_{xs}$, such that firms employing technologies $\tilde{v}_s < \tilde{v}_{xs}$ serve only the Home market, while firms employing technologies $\tilde{v}_s > \tilde{v}_{xs}$ also serve the Foreign market. The set of firms using technology $\tilde{v}_{xs}$ can be partitioned into non-exporting firms, $(\varphi_{\tilde{v}_{xs}}, \varphi_{xs})$, and exporting firms, $(\varphi_{xs}, \varphi_{\tilde{v}_{xs}+1})$. We shall refer to a firm with productivity φ_{xs} as a marginal exporter.[19]

A technology upgrader must be indifferent between upgrading technology or not, and its idiosyncratic productivity must therefore be[20]

$$\varphi_{\tilde{v}_s} = \left[\frac{f_{\tilde{v}_s} - f_{\tilde{v}_s-1}}{\tilde{A}_s \left[(\alpha_{\tilde{v}_s} / (1 + \lambda_{\tilde{v}_s} \omega))^{\sigma_s - 1} - (\alpha_{\tilde{v}_s-1} / (1 + \lambda_{\tilde{v}_s-1} \omega))^{\sigma_s - 1} \right]} \right]^{1/(\sigma_s - 1)}, \qquad (3)$$

where $\omega = w_h / w_\ell$ is the skill premium and $\tilde{A}_s = \left(\tilde{A}_{Hs} + 1_{q_F > 0} \tilde{A}_{Fs}\right)$ with $\tilde{A}_{is} = w_\ell^{1-\sigma} A_{is}$ being the market size facing the firm normalized by the wage level. Equation (3) shows

[19] If the marginal exporter is also a technology upgrader, then one of these intervals is degenerate.

[20] The condition that the marginal exporter be indifferent between exporting and selling only domestically is analogous to the technology choice condition (an analogous condition can be derived if the marginal exporter is also a technology upgrader),

$$\varphi_{xs} = \left[\frac{f_{xs}}{\tilde{A}_{Fs} (\alpha_{\tilde{v}_{xs}} / (1 + \lambda_{\tilde{v}_{xs}} \omega))^{\sigma_s - 1}} \right]^{1/(\sigma_s - 1)}. \qquad (2)$$

the tradeoffs facing a firm in its technology choice. The larger the additional fixed cost associated with the more-productive technology, $f_{\tilde{v}_s} - f_{\tilde{v}_s - 1}$, the more productive a firm must be to make it profitable to adopt the more cost-efficient technology. The opposite is true for the technology's Hicks-neutral component, $\alpha_{\tilde{v}_s}$. The greater the market size, $\tilde{A}_s$, the greater the quantity a firm will sell and therefore the more likely it is to adopt a more cost-efficient technology. Therefore, by increasing $\tilde{A}_s$ for exporters, trade liberalization increases relative demand for skills both through an intensive margin (increased production by firms using relatively skill intensive technologies) and an extensive margin (adoption of more productive and skill intensive technologies). Finally, if $\lambda_{\tilde{v}_s} > \lambda_{\tilde{v}_s - 1}$, then a higher skill premium makes technology $\tilde{v}_s$ less attractive relative to technology $\tilde{v}_s - 1$. This results in a countervailing effect on the rise in the skill premium following trade liberalization because the initial increase in the skill premium is tempered by firms adopting less skill-intensive technologies in response.

Aggregation The result that within each sector the firm productivity space can be divided into $\tilde{V}_s$ intervals, one per technology, makes it straightforward to aggregate firm-level factor demand and intermediate-good supply. The firm-level demand for labor is the per-unit labor requirement times the quantity produced by the firm, derived in the previous section. In sector s the aggregate low- and high-skill labor demanded by firms are

$$L_s^d = \sum_{\tilde{v}_s} \int_{\Phi_{\tilde{v}_s}} \frac{q}{\alpha_{\tilde{v}_s} \varphi} dG_s(\varphi), \quad H_s^d = \sum_{\tilde{v}_s} \int_{\varphi_{\tilde{v}_s}} \lambda_{\tilde{v}_s} \frac{q}{\alpha_{\tilde{v}_s} \varphi} dG_s(\varphi). \tag{4}$$

where $\Phi_{\tilde{v}_s}$ is the interval of idiosyncratic productivities in which technology $\tilde{v}_s$ maximizes profits and $q = q_H + 1_{\varphi > \varphi_{xs}} \tau_s q_F$. The final-good demand by firms to cover fixed costs and firms' profit net of these costs are

$$F_s^d = \sum_{\tilde{v}_s} \int_{\Phi_{\tilde{v}_s}} \left(f_{\tilde{v}_s} + 1_{\varphi > \varphi_{xs}} f_{xs} \right) dG_s(\varphi), \; \Pi_s = \sum_{\tilde{v}_s} \int_{\Phi_{\tilde{v}_s}} \left(\pi_{Hs} + 1_{\varphi > \varphi_{xs}} \pi_{Fs} \right) dG_s(\varphi) - F_s^d \tag{5}$$

Finally, sector-level final-good supply is[21]

$$Q_s = \left[\sum_{\tilde{v}_s} \int_{\Phi_{\tilde{v}_s}} \left(q_H^{\rho_s} + 1_{\varphi > \varphi_{xs}} q_F^{\rho_S} \right) dG_s(\varphi) \right]^{1/\rho_s}. \tag{6}$$

[21] I have used the fact that, due to symmetry, the quantity exported by Home firms to Foreign, q_F, equals the quantity imported by Home from Foreign firms.

2.2 Workers

In this section, I develop an overlapping-generations model of endogenous skill acquisition. Workers are divided into age groups, $b \in \{1, 2, ..., B+1\}$, with $B+1$ corresponding to death. Workers are born uneducated into age group $b = 1$. In each period, a worker who was in age group $b \leq B$ in the preceding period ages into $b+1$ with probability δ_b and remains in b with probability $1 - \delta_b$. Upon birth each worker draws an idiosyncratic ability a from a Pareto distribution, $G_w(\cdot)$, with scale parameter ξ and shape parameter ψ.[22] The population of workers in age groups $b \leq B$, i.e., active workers, is constant at unity as the measure of deaths and births is equal in every period.

In each period t, an uneducated worker faces a choice: work full time or pursue an education. By choosing the former, she provides one unit of low-skill labor regardless of her ability and thereby earns $w_{\ell t}$. By choosing the latter she becomes a student, works part time providing $m < 1$ units of low-skill labor and pays a tuition cost C denominated in units of the aggregate final good.[23] A student in period t begins period $t+1$ as an educated worker with probability δ_e and remains uneducated with the complementary probability.[24]

Once educated, a worker remains educated for the remainder of her life. An educated worker with ability a provides a units of high-skill labor in each period and earns aw_{ht} in period t. Thus, there exists a complementarity between ability and education, so that the benefit to education is increasing in a worker's ability.[25]

[22] In the model, ability only directly determines the income of high-earners. A Pareto distribution of abilities is therefore consistent with the empirical finding that the upper tail of the income distribution in the United States is well-approximated by a Pareto distribution. See, for example, Reed (2001).

[23] An alternative assumption is that the cost of education is in terms of labor rather than goods. The main difference between the two assumptions is how trade liberalization affects the cost of education. Since trade liberalization increases real wages, when the cost of education is in terms of wages it becomes relatively more expensive following trade liberalization, while the opposite is true when the cost of education is in terms of the aggregate final good. Nevertheless, the quantitative results are not significantly affected by which of the two assumption I choose. In addition, I focus only on the opportunity cost (foregone wages) and monetary cost (tuition) of an education, while abstracting from other costs, e.g. psychic costs (see Heckman et al. (2007)), which are unlikely to be affected by trade policy. Other considerations, such as credit constraints and uncertainty about the returns to schooling, may affect an individual's schooling decision. However, credit constraints are unlikely to play a major role in the United States (see Cameron and Taber (2004)). Also, even if workers were risk averse, the inclusion of uncertainty (for example, in their ability) is unlikely to significantly change the quantitative results since this would affect workers similarly pre- and post-liberalization.

[24] The stochastic modeling of aging and education is to ensure tractability of the model by limiting the size of the workers' state space.

[25] While it is relatively straightforward to extend the model to incorporate a larger number of levels of education, I limit the model to just two in keeping with the simulation in the quantitative analysis (see

Workers can costlessly switch between between working for one firm or another regardless of the firms' sectors. This ensures that in each period all workers command the same wage per unit of labor, conditional on education. Workers are price takers, discount the future by $\beta < 1$ and maximize expected discounted consumption of the final good. Thus, in period t', workers' optimization decisions depend only on current and future wages, $\{w_{\ell t}, w_{ht}\}_{t=t'}^{\infty}$, which, although endogenous, are exogenous from an individual worker's point of view.

Worker Value and Optimization A worker is characterized by a triplet (a,b,e), where a is the worker's ability, b is the worker's age group and e is an indicator taking the value one if the worker is educated and zero otherwise. Letting $V_t(a,b,e)$ be the value of worker in period t, it will be useful to define $\tilde{V}_t(a,b,e) = (1-\delta_b)V_{t+1}(a,b,e) + \delta_b V_{t+1}(a,b+1,e)$ as the expected value of the worker in the subsequent period taking into account that the worker may age. An educated worker's value is her current wage plus the discounted expected continuation value of being educated in period $t+1$,

$$V_t(a,b,1) = \max\{w_\ell, aw_{ht}\} + \beta\tilde{V}_{t+1}(a,b,1), \tag{7}$$

where the maximum operator indicates the fact that nothing prevents an educated worker from working as an uneducated worker if she finds it worthwhile to do so. This together with the condition $V_t(a,B+1,e) = 0$ for $e \in \{0,1\}$ makes it straightforward to compute $V_t(a,b,1)$ for any (a,b) pair.

The value of an uneducated worker is the maximum of the value of working full time and becoming a student

$$V_t(a,b,0) = \max\left\{V_t^{full}(a,b), V_t^{student}(a,b)\right\}, \tag{8}$$

where these values are given by

$$V_t^{full}(a,b) = w_{\ell t} + \beta\tilde{V}_{t+1}(a,b,0) \tag{9}$$

$$V_t^{student}(a,b) = -C + mw_{\ell t} + \beta\left[(1-\delta_e)\tilde{V}_{t+1}(a,b,0) + \delta_e\tilde{V}_{t+1}(a,b,1)\right]. \tag{10}$$

where the first two terms in (10) are the worker's income net of tuition costs and the remaining terms are the worker's continuation values accounting for the fact that the student will become educated with only a δ_e probability.

footnote 28).

Given a path of wages, $\{w_{\ell t}, w_{ht}\}_{t=t'}^{\infty}$, workers can compute the value functions (7)-(10) by iterating backwards. These value functions therefore fully characterize the worker's optimization problem. The solution to the worker's problem is characterized by path of education cutoffs, $\left\{\{a_{bt}\}_{b=1}^{B}\right\}_{t=t'}^{\infty}$. That is, for each period t and age group b, uneducated workers of age b with ability $a > a_{bt}$ pursue an education, and those with $a < a_{bt}$ work full time as uneducated workers. Such cutoffs must exist because, while the cost of pursuing an education is independent of ability, the benefit of acquiring an education increases with ability within any age group. Similarly, while the cost of pursuing an education does not depend on a workers age, the benefits of education increase with the expected remaining lifetime of a worker. Therefore, older workers are less likely to pursue an education, i.e., if $b > b'$, then $a_{bt} > a_{b't}$ for any t. This contributes to the sluggish skill supply response following trade liberalization, since older workers, who would have pursued an education had skill demand increased in their youth, no longer find it profitable to do so.

Law of Motion of the Worker Distribution and Labor Supply Letting $W_t(a,b,e)$ be the distribution of workers in period t, the law of motion for uneducated workers is

$$\begin{aligned} W_{t+1}(a,b,0) = {} & 1_{a \le a_{bt}}(1-\delta_b)W_t(a,b,0) + 1_{a > a_{bt}}(1-\delta_b)(1-\delta_e)W_t(a,b,0) \\ & + 1_{a \le a_{(b-1)t}}\delta_{b-1}W_t(a,b-1,0) + 1_{a > a_{(b-1)t}}\delta_{b-1}(1-\delta_e)W_t(a,b-1,0), \end{aligned} \tag{11}$$

where the first two terms refer to workers who did not age and either worked full time or pursued an education but failed, and the last two terms are the similar but for workers who aged into age group b.[26] The law of motion for educated workers is

$$\begin{aligned} W_{t+1}(a,b,1) = {} & (1-\delta_b)W_t(a,b,1) + 1_{a > a_{bt}}(1-\delta_b)\delta_e W_t(a,b,0) \\ & + \delta_{b-1}W_t(a,b-1,1) + 1_{a > a_{(b-1)t}}\delta_{b-1}\delta_e W_t(a,b-1,0), \end{aligned} \tag{12}$$

where as before the first line refers to workers who did not age and were either already educated or were students in period t and succeeded in becoming educated. The second line is analagous, but for workers who aged into age-group b.

Using (11) and (12), an initial worker distribution, $W_{t'}(a,b,e)$, and a path of education

[26] Newborns enter the law of motion with the additional condition that for every t, $W_t(a,0,0) = Ng_w(a)$, where N is the measure of newborns and $g_w(\cdot)$ is the density function associated with the distribution of worker ability.

cutoffs, $\left\{\{a_{bt}\}_{b=1}^{B}\right\}_{t=t'}^{\infty}$, are sufficient to compute the entire future path of worker distributions, $\{W_t(a,b,e)\}_{t=t'}^{\infty}$. The education cutoffs and worker distribution in any given period can then be used to determine labor supply in that period. Consider, therefore, any period with worker distribution $W(a,b,e)$ and worker policy $\{a_b\}_{b=1}^{B}$, the supply of low- and high-skill labor are

$$L^{sup} = L_{full} + mJ = \sum_{b=1}^{B} \int_{1}^{a_b} W(a,b,0)\,da + m \sum_{b=1}^{B} \int_{a_b}^{\infty} W(a,b,0)\,da \tag{13}$$

$$H^{sup} = \sum_{b=1}^{B} \int_{1}^{\infty} aW(a,b,1)\,da, \tag{14}$$

where L_{full} is the mass of full-time uneducated workers given by the sum over workers with ability below the education cutoff for each age group and J is the mass of students given by the sum over all the age groups of uneducated workers with ability exceeding the education cutoff. The supply of high-skill labor is simply the sum over all educated workers in each age group weighted by their ability.

2.3 Equilibrium

An equilibrium of the open economy for an initial worker distribution, $W_{t'}(a,b,e)$, is characterized by paths of wages, $\{w_{\ell t}, w_{ht}\}_{t=t'}^{\infty}$; firm-level variables for each sector, $\left\{\{p_{Hst}(\varphi), q_{Hst}(\varphi), p_{Fst}(\varphi), q_{Fst}(\varphi), \pi_{st}(\varphi), v_{st}(\varphi)\}_{s=1}^{S}\right\}_{t=t'}^{\infty}$; sector-level aggregates, $\left\{\{R_{st}, P_{st}\}_{s=1}^{S}\right\}_{t=t'}^{\infty}$; and worker value functions and distributions, $\{V_t(a,b,e), W_t(a,b,e)\}_{t=t'}^{\infty}$. These paths constitute an equilibrium if the following conditions hold:[27]

1. Workers maximize consumption of the aggregate final good, and therefore the

[27] There exists the theoretical possibility of multiple equilibria in this model. For example, there may exist one equilibrium with a high skill premium in which relatively many workers acquire an education and firms adopt relatively skill-intensive technologies. Alternatively, there may exist an equilibrium with a low skill premium in which relatively few workers acquire an education supported by firms' adoption of relatively less-skill-intensive technologies. The prevailing equilibrium will depend on expectations. It is even possible to have asymmetric equilibria in this way if workers in one counry expect a high skill premium and those in the other country expect a low skill premium. Although the possibility of multiple (or asymmetric) equilibria cannot be ruled out on theoretical grounds, I have addressed the possibility by simulating the model with several potential initial guesses of the equilibrium paths (see Appendix B.2), and the simulation always converges to the same equilibrium independently of the initial guess. This lowers the likelihood of the existence of multiple equilibria, at least for the particular set of parameters I use in the simulation.

value functions, $\{V_t(a,b,e)\}_{t=t'}^{\infty}$, follow (7)-(10).

2. The worker distributions, $\{W_t(a,b,e)\}_{t=t'}^{\infty}$, follow the laws of motion (11) and (12).

3. Firms maximize profit, so $\left\{\{p_{Hst}(\varphi), q_{Hst}(\varphi), \pi_{Hst}(\varphi), v_{Hst}(\varphi)\}_{s=1}^{S}\right\}_{t=t'}^{\infty}$ are given by the corresponding equations in Subsection 2.1.

4. In every period, labor supply for each type of labor, given by (13) and (14), equals demand for labor given by (4).

5. In every period and in every sector, sector-level final-good supply ($Q_sP_s = R_s$), given by (1) and (6), is equal to sector-level final good expenditure ($R_s = \eta_s\left[\sum_{s=1}^{S} F_s^d + \sum_{s=1}^{S}\Pi_s + w_\ell L^{sup} + w_h H^{sup}\right]$), where the aggregates are given by (5), (13) and (14).

3 Calibration

The calibration ensures that the model matches both micro and macro features of the US economy in 2007. Worker data comes from the Integrated Public Use Microdata Series (IPUMS) - Current Population Survey (CPS), a publicly available dataset that consists of a random sample of the March supplement of the CPS. The CPS provides information on a wide array of individual level data, including age, income, educational attainment and labor-market participation.

In the calibration, I interpret educated workers in the model to be workers who have completed at least a BA degree. Individuals with no post-secondary degree correspond to uneducated workers.[28] I consider only workers between ages nineteen and sixty-eight. Nineteen corresponds to the first year of college for most college attendees, and by age sixty-eight only a small percentage of the population is still in the labor force.

[28]I focus on these two levels of education for two reasons. First, the college premium is the main skill premium that the trade literature has emphasized, at least in the case of the United States. Second, I capture the impact of trade on the vast majority of American workers, since only relatively few workers have less than a high school degree or more than a college degree. Because I abstract from these education levels, the simulation is silent about how those workers are affected by trade liberalization. Indeed, it is possible that while the incentive to pursue a college degree increases, the incentive to pursue a postgraduate degree decreases. In addition, alternative interpretations of what counts as a college educated worker do not appear to alter the quantitative results in any meaningful way. For example, considering individuals with a degree from a two-year post-secondary institution, such as an Associate degree, as half a college-educated worker and half an uneducated worker yields very similar results.

I also use the CPS data to infer skill intensity by firm size for each industry, as the CPS provides information on the size and industry of the firm in which the individual works as well as the individual's educational attainment. The remainder of data on firms comes from the Economic Census, which provides data on the number of firms and total payroll of firms by employment size for each sector.[29] Finally, I divide the economy into 20 sectors; agriculture, mining, nine manufacturing sectors and nine service sectors. This is important because it ensures that the parameters are sector specific and therefore it minimizes the concern that the results are biased by aggregating many sectors into one.[30]

3.1 Parameters from the Data

In the simulations each period corresponds to one year. Each age group corresponds to a five-year window (19-23, 24-28, etc.) so that in total there are ten age groups ($B = 10$). To ensure that workers spend on average five years in each age group, I take $\delta_b = 0.2$, for all b. Similarly, I take $\delta_e = 0.22$ to ensure that on average it takes four and a half years to complete a BA degree as per Department of Education data. Finally, the discount factor β is taken to equal 0.97 to match a real annual interest rate of 3%.

I take the elasticity of substitution between intermediate goods to be 3.8 within all sectors. This matches the estimate in Bernard, Jensen, Eaton and Kortum (2003). The theoretical model implies that the share of exports in total shipments of a firm, conditional on exporting, is $\tau_s^{1-\sigma} / \left(1 + \tau_s^{1-\sigma}\right)$. Together with data reported in Bernard, Jensen, Redding and Schott (2007) on the proportion of total shipments that are sent abroad, this implies τ_s's that range from 1.53 in computer and electronic manufacturing to 2.28 in furniture manufacturing with a mean iceberg cost of 1.9.[31]

[29] See Appendix A for further details on the firm-level data.

[30] The sectors correspond to NAICS sectors: 11; 21; 22; 23; 311-312; 313-316; 321-323; 324-325; 326-327; 331-332; 333-336; 337; 339; 42; 44-45; 48-49, 51-56; 61-62; 71-72; 81. See Appendix A for further details. This is the finest division I could achieve while simultaneously ensuring a reasonable amount of data in each sector and comparability between the Economic Census and CPS data. Moreover, each additional sector adds significant computational time to solving the model, since the sectoral price level must be solved for each period in each iteration (see Appendix B.2 for details).

[31] This is in line with, for example, the iceberg trade cost used in Melitz and Redding (2013) of 1.83. In general, this level of trade costs is consistent with the trade-cost estimates in the literature. For a review of these estimates, see Anderson and van Wincoop (2003).

3.2 Parameters Calibrated by Simulating the Model

Below I describe the calibration for parameters calibrated by simulating the model, given the parameter choices described above. These parameters can be partitioned into those determining skill supply and those determining skill demand. By choosing both the skill-supply parameters and the skill-demand parameters to match (among other things) the empirical skill supply in 2007, I ensure that the labor market clears in the calibrated model. Moreover, as described below, the calibration of the skill-demand parameters ensures that the goods market clears as well in every sector. Thus, the calibration determines all the parameters jointly and guarantees that the calibrated model delivers an equlibrium that matches all the targeted moments.

3.2.1 Skill-Supply Parameters

The only skill-supply parameters that require calibration are the Pareto scale and shape parameters for worker ability, ξ and ψ. I calibrate ξ and ψ to match the skill premium, that is, the average income of an educated worker relative to that of an uneducated worker, as well as the number of educated workers relative to uneducated workers in both 1992 and 2007.[32] By using two points in time I am able to match not only the level of relative skill supply, but also how it changes in response to changes in the skill premium.[33] This is important because the quantitative results, in particular those further along the transition path, depend on how changes in skill demand and the resulting changes in the skill premium feed back into changes in skill supply.

[32] I use the year 1992 because it is the earliest year in which the variables in the CPS education data are consistent with those in the 2007 CPS data. I also use the cost of education in 1992 and 2007, respectively, \$13,000 and \$18,000, (both in 2007 dollars) as per Department of Education data. I also use $m = 0.5$ based on the fact reported in Carnevale et al. (2015) that nearly two thirds of college students work and those average about 30 hours of work a week. Therefore, the average student (including those who do not work) works approximately 20 hours a week, or the equivalent of half of a full-time job.

[33] Technically, calibration of ξ and ψ involves simulating the skill-supply side of the model and adjusting the parameters until they match the targeted moments for each of the years 1992 and 2007. This can be done because skill supply depends only on wages and is therefore independent of the skill-demand side of the model for given wages. The reader may wonder why four moments (two in each year) are needed to calibrate just two Pareto parameters. The reason is that to simulate the supply-side of the model in a given year, y, requires $w_{\ell y}$ and w_{hy}. However, while $w_{\ell y}$ equals the average income of an uneducated worker, w_{hy} is a theoretical construct which equals the wage per unit of high-skill labor rather than the average income of an educated worker. Thus, in addition to the Pareto parameters, the calibration will also need to determine values for w_{h1992} and w_{h2007}. Thus, given $(w_{\ell 1992}, w_{\ell 2007})$ I find the values of $(w_{h1992}, w_{h2007}, \xi, \psi)$ for which the model's prediction matches the four moments discussed in the text. Equivalently, the calibration requires finding not only the Pareto parameters, but also the average number of high-skill labor units per educated worker in each year.

Although both Pareto parameters are determined jointly, their calibrated values are mostly affected by different moments. On the one hand, for a given number of educated workers, a higher Pareto scale parameter is associated with more units of high-skill labor per educated worker, or alternatively, a higher skill premium for given wages. That is, the scale parameter is mostly determined by the level of skill supplies. On the other hand, a higher Pareto shape parameter is associated with larger shifts in the number of workers who choose to get an education for a given change in the skill premium. Thus, the ψ essentially governs the elasticity of relative skill supply with respect to the skill premium. The higher is ψ, the greater is this elasticity.

This then also provides some insight into how the calibrated value of ψ affects the quantitative results. When trade is liberalized, the relative demand for skill increases and as a result so does the skill premium. The initial increase in the skill premium is almost entirely unaffected by the skill-supply parameters because in the short run skill supplies are nearly fixed. However, in the long run as skill supplies adjust ψ exerts its influence. Specifically, the greater is the elasticity of relative skill supply with respect to the skill premium, i.e., the greater is ψ, the more workers acquire an education in response to a given change in the skill premium, and therefore the smaller is the long run increase in the skill premium in response to trade liberalization. Thus a higher ψ has a negligible impact on the initial increase in the skill premium following trade liberalization, but leads to a smaller increase in the skill premium in the long run.

3.2.2 Skill-Demand Parameters

The only remaining parameters that require calibration are those related to skill demand, or to production side of the model. These are, corresponding to three loops in the calibration described below: (1) the sectoral expenditure shares on goods, η_s, (or equivalently the revenue in a sector, R_s) determined in the outer loop; (2) the mass off firms, M_s, and the distribution of firm idiosyncratic productivity, θ_s, determined in the middle loop; and (3) the firm-level technological parameters, $\{\alpha_{v_s}, \lambda_{v_s}, f_{v_s}\}_{v_s=1}^{V_s}$ and f_{xs}, determined in the inner loop. In what follows, I describe the calibration for one of the sectors, s.

Inner Loop - Calibration of Technologies Since the technology calibration is the inner loop, it takes as an input R_s and θ_s, which are chosen in the outer and middle loops, respectively. The Economic Census firm data is divided into 25 size bins, where size is determined by total employment. I assume that all firms within a bin adopt the same technology, so that $V_s = 25$, and I will therefore use the notation v_s to denote both a particular technology and the bin in which that technology is used.[34]

Although they are not parameters of the model, it will be useful to begin by computing the data-implied cutoff productivity, φ_{v_s}, for any particular v_s. Using Economic Census data on the number of firms in each bin yields $\varphi_{v_s} = (1 - d_{v_s})^{-1/\theta_s}$, where d_{v_s} is the proportion of firms in bins smaller than v_s. Similarly, the export cutoff, φ_{xs}, can be computed by replacing d_{v_s} with the the proportion of firms that do not export.[35] Turning now to the technological parameters, I begin with the skill intensity for technology v_s, λ_{v_s}, which can be deduced directly from CPS data on the share of the total wage bill that goes to educated workers in bin v_s.[36]

The smallest firm in bin v_s has total employment determined by the bins lower boundary and idiosyncratic productivity φ_{v_s} as calculated above. Moreover, since the firm optimally chooses this size, the model implies that

$$size_{v_s} = (1 + \lambda_{v_s}) \left(1 + 1_{\varphi_{v_s} > \varphi_{xs}} \tau_s\right)^{1-\sigma} \rho^{\sigma} R_s \frac{(\varphi_{v_S} \alpha_{v_s})^{\sigma-1}}{(w_\ell + \lambda_{v_s} w_h)^{\sigma}},$$

where $size_{v_s}$ is the total employment in units of labor in the smallest firm in bin v_s, i.e., the firm on the bin boundary. Since α_{v_s} is the only unknown, solving this equation yields the technology-specific productivity.

Turning to the calibration of the fixed costs, if $\varphi_{xs} \in (\varphi_{v_s}, \varphi_{v_s+1})$, then the marginal exporter uses technology v_s. Furthermore, since the marginal exporter must be indifferent between exporting and selling only domestically, the fixed cost of exporting must satisfy $f_{xs} = \pi_{Fs}(\varphi_{xs}, v_s)$, where $\pi_{Fs}(\varphi, v_s)$ is the variable profit from exporting for a firm with productivity φ using technology v_s, defined in Section 2.1. Since this variable profit can be readily calculated from previously calibrated parameters, this equation yields the fixed cost of exporting. Similarly, the marginal technology upgrader in any bin v_s must be indifferent between using technology v_s and $v_s - 1$. This implies that $f_{v_s} = \pi_s(\varphi_{v_s}, v_s) - [\pi_s(\varphi_{v_s}, v_s - 1) - f_{v_s - 1}]$, where $\pi_s(\varphi, v_s)$ is the total variable profit of

[34] For expositional clarity, I will describe the calibration as if the CPS bins and Economic Census bins are identical. In Appendix A, I describe how I account for the differences in the CPS bins and Economic census bins.

[35] I use data from Bernard, Jensen, Redding and Schott (2007).

[36] For $k = \ell, h$, $I^k_{v_s}/w_k$ represents the units of k-skill labor employed in bin v_s, where $I^k_{v_s}$ is the wage bill of k-skilled workers in bin v_s in the CPS data and w_k are the wages determined above (see footnote 33). Therefore, $\lambda_{v_s} = \left(w_\ell I^h_{v_s}/w_h I^\ell_{v_s}\right)$. To ensure consistency with the theoretical model in which educated workers supply different quantities of labor depending on their ability, the data points on skill intensity by firm size are calculated using total wage bill by education rather than number of workers or hours worked by education level.

a firm from domestic sales and, if $\varphi > \varphi_{xs}$, foreign sales as well. This equation together with the initial condition $\pi_s(\varphi, 0) = 0$ and $f_0 = 0$ allows me to compute all the fixed costs.[37]

Middle Loop - Firm Distribution Since the calibration of the firm distribution is the middle loop, it takes as given R_s determined in the outer loop. For any R_s, the parameters θ_s and M_s yield a particular set of technology parameters by the procedure described in the inner loop above. Equation (4) then yields the model's prediction for the wage bill of educated and uneducated workers in sector s, for that particular set of parameters. The parameters θ_s and M_s are adjusted until the model's predictions for both the level of the wage bill and educated workers' share in the total wage bill match the data for 2007.[38]

Outer Loop - Expenditure Shares In the outer loop, I determine expenditure on goods in each sector. For a given value of expenditures on goods, the middle and inner loop described above yield the remaining parameters. Equation (6) then yields total firm revenue in the sector for that particular set of parameters, which must equal expenditures on goods in the sector in equilibrium.[39] The expenditure share of sector s, η_s, is then the expenditure in sector s divided by the sum of expenditures in all sectors.

Results and Discussion of Skill-Demand Calibration The results for the technology calibration are presented in Appendix A.1. Calibration of the firm distributions yields an average value for the θ_s's of 7.4.[40] To see the impact of θ_s on the quantitative results, note that a higher value implies a larger mass of firms between any two productivity levels, that is, if $\varphi' > \varphi''$, then $G_s(\varphi') - G_s(\varphi'')$ increases with θ_s. Therefore, for a given change in the incentive to adjust technologies, i.e., for a given change in the technology

[37]The initial condition means that the marginal technology upgrader in the first bin, i.e., the smallest active firm, is indifferent between producing and being inactive, i.e., has zero profit.

[38]Although the technology calibration guarantees that educated workers' share of the wage bill will match the data within each bin, it does not guarantee that it will do so in the aggregate because this depends on employment shares across bins. Ensuring that this is indeed the case is the role of the calibration of θ_s.

[39]Units of the sector-level final good are chosen so that $P_s = 1$ for all s in the calibration year.

[40]This is higher than some of the values used in other studies. For example, Melitz and Ghironi (2005) use a value of 3.4 to match a standard deviation of log of firm sales of 1.67, using the same elasticity of substitution as I do. In their model, idiosyncratic productivity is the only source of size variability across firms. However, in my model, the differences in size between firms resulting from differences in idiosyncratic productivities are amplified by firms' technology choices. Thus, differences in idiosyncratic productivities need only account for part of the overall size variability in the data. As a consequence, in order to match the empirical size distribution, my model requires a higher θ_s, i.e., less idiosyncratic variability, than a model in which idiosyncratic productivity is the only source of size difference across firms.

adoption cutoffs, φ_{v_s}, more firms switch technology the greater is θ_s. Thus, when trade is liberalized, more firms in sector s are induced to upgrade technology when θ_s is greater. Since more productive technologies tend to me more skill intensive (although not always) a higher θ_s is associated with larger increases in relative skill demand in response to trade liberalization.[41]

One advantage of my calibration of the firm-level technologies is that, in contrast to most other studies, I do not impose a particular relationship between the productivity of a technology and its skill intensity. Indeed, I find that in four sectors skill intensity is monotonically increasing with productivity; in twelve sectors it first decreases and then increases (or has minor deviations from that pattern); in two sectors skill intensity first increases then decreases; and in two sectors there is no obvious pattern.[42] The calibrated productivities, α_{v_S}, and fixed costs, f_{v_s}, are both increasing with v_s in all sectors, as would be expected.

The most important technology parameter for the quantitative results is the skill intensity of the technologies. For reasons discussed in Section 2.1, trade liberalization induces exporters to upgrade their technology. Moreover, many of these technology upgraders, and certainly the overwhelming majority when weighted by employment, are at the tail end of the distribution where upgrading technology means moving to a more skill-intensive technology. As a result, a larger increase in skill intensity for more productive technologies is associated with larger increases in skill demand following trade liberalization and hence larger increases in the skill premium.[43]

Since I calibrate the technologies to a cross section, a potential concern is whether the calibration matches the aggregate elasticity of substitution between high- and low-skill labor. Katz and Murphy (1992) estimate that in the United States a 10% increase in relative skill supply leads to a 7% decrease in the skill premium, a ratio of 1.4 with a standard error of 0.3. To assess the performance of the calibrated model in this dimension,

[41] The mass of firms in a sector, M_s, affects only the level of demand for labor and not the relative demand for skills, so that it has little effect on the main results of the paper regarding the differential impact of trade liberalization on educated relative to uneducated workers.

[42] Other studies have assumed a monotonic relationship between firm productivity and skill intensity (e.g. Burstein and Vogel (2016)). Bustos (2011) studies a model in which firms choose between two technologies, the more productive of which is more skill intensive. Samson (2014) is similar, but firms choose from a continuum of technologies. While this is a reasonable assumption with only two technologies, as more productive firms are, *on average*, more skill intensive than less productive firms, with more technologies this assumption need not hold.

[43] Nonexporters downgrading technology in response to trade liberalization also affects the change in relative demand for skill. However, the effect is negligible since despite representing the vast majority of firms, only a small fraction of workers are employed in nonexporting firms.

I mimic the analogous statistic in the calibrated model by computing the change in the equilibrium skill premium in response to an exogenous shock to relative skill supply.[44] I find a ratio close to one, which is well within the confidence interval estimated by Katz and Murphy (1992).

To understand why the ratio I compute is lower than 1.4, note that their estimate relies on the assumption that relative skill supplies do not respond to shocks to skill demand. However, if skill supplies are endogenous, then an observed increase in relative skill supply is likely to be, at least in part, a response to increased skill demand. Absent the increase in skill demand, the same increase in skill supply would imply a larger decrease in the skill premium than if the increased supply were accompanied by an increase in skill demand. Thus, computing the aforementioned ratio from data in which the increase in relative skill supply is accompanied by an increase in skill demand, as in Katz and Murphy (1992), leads to a higher ratio than in my computation where skill demand is fixed.

4 Quantitative Analysis

My goal is to study the effects of a counterfactual bilateral removal of policy barriers to trade, i.e. a reduction in the iceberg cost, τ. Of course, trade policy cannot eliminate all costs as some of these are real resource costs determined by the transportation technology and distance between countries. The policy I consider, therefore, is the removal of border barriers to trade, i.e., costs not attributable to distance. Anderson and van Wincoop (2003) find that the border barrier between Canada and the United States is 26%. In line with this finding, I simulate the economy's response to an unanticipated once-and-for-all removal of border barriers equal to 26% in all sectors.[45]

Canada and the United States are likely to have fewer border barriers than the United States has with any other trading partner. The potential trade agreements mentioned in the introduction, the TTIP and the TPP, will therefore plausibly represent trade liberalizations at least as large as the one I simulate. Both proposed trade agreements are between countries of similar levels of development, access to technologies and skill endowment. Therefore, as I emphasize in the introduction, the labor reallocation within sectors and

[44]Recall that in addition to relative skill demand changing because of reallocation of production shares between firms using different technologies, firm-level substitution between high and low skill labor also occurs because firms can switch technologies.

[45]The shooting algorithm I use to solve the equilibrium transition path is detailed in Appendix B.

the resulting changes in relative skill demand highlighted in the model are likely to be the dominant forces shaping post-liberalization dynamics. In addition, in the case of the TTIP, a proposed agreement between the United States and the European Union, the symmetric country assumption is particularly relevant as the two are entities of roughly similar size with similar endowments.[46]

4.1 Skill Demand and Supply

Skill Demand The catalyst for the skill supply adjustment, the source of all the dynamics in the model, is the change in relative skill demand precipitated by the new trade policy. I therefore begin the analysis with a brief description of the effect of trade liberalization on skill demand. Importantly, I do not impose assumptions on the model that guarantee that trade liberalization induces an increase in relative skill demand. Nevertheless, the simulation shows that relative skill demand does increase following trade liberalization. In fact, if skill supplies were counterfactually fixed at their pre-liberalization level, the skill premium would increase by approximately 8%.

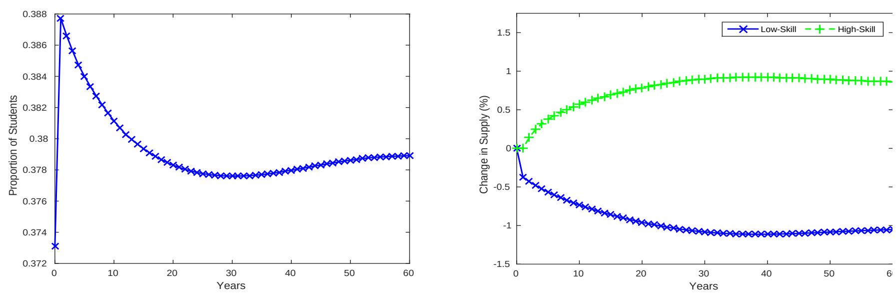
As discussed in Section 2, the increase in relative skill demand is a result of both an intensive margin (exporters, who tend to be relatively skill intensive, expand their production relative to nonexporters) and an extensive margin (firms switch technologies in response to the liberalization). To see the extensive margin in action, consider the measure of firms employing the most productive technology in their respective sectors. In the first year after trade liberalization, the measure of these firms decreases by 13%, while in the long run there is a 14% increase relative to pre-liberalization. Initially, because of the policy-induced increase in the skill premium, firms are disincentivized from using the most skill intensive technologies which also tend to be the most productive. This is despite the fact that trade liberalization increases exporters' market size which tends to make more productive technologies more attractive. However, in the long run, this market-size effect dominates the initially dominant skill-premium effect, as increasing skill supplies depress the skill premium.

Skill Supply The trade-induced increased skill demand results in greater incentives to pursue an education, leading to an immediate 1.7 percentage point jump in the propor-

[46] Although it would, of course, be of interest to consider the case of asymmetric countries, the number of variables to be solved for grows in proportion to the number of countries. Therefore, given the complexity of the model and the fact that I solve for the entire transition path, the computational cost would be prohibitive.

tion of newborns who choose to become students, as Figure 1a demonstrates.[47] This, as shown in Figure 1b, in turn, leads to an eventual 1.1% decrease in the low-skill labor supply and a 0.9% increase in the high-skill labor supply. The number of educated workers increases by even more than 0.9% (it increases by 1.5%) because the additional educated workers are of lower ability, and therefore provide fewer units of high-skill labor per worker than those who would have pursued an education absent trade liberalization. The figure also shows that the supply of high-skill labor overshoots its long-run level approximately twenty-five years following trade liberalization and then drops below its long-run level twenty-five years after that. This cobweb effect is a result of the cohort structure of the model and workers' rational expectations and is not borne out of irrational behavior or incorrect expectations regarding the general-equilibrium effect of changes in skill supply.[48]

Figure 1: Changes in Students and Skill Supply



(a) Students **(b)** Labor Supply

Notes: Panel (a) shows the proportion of newborns who pursue and education. Panel (b) shows the percentage change in labor supply relative to pre-liberalization.

To understand the cause of the overshooting in the high-skill labor supply, consider first workers who are old when the new trade policy is implemented. These workers will be undereducated relative to long-run levels as they made education decisions in their youth based on conditions prevailing prior to trade liberalization. This relative undereducation causes a shortage of high-skill labor, which drives up the skill premium to beyond its long run level. Thus, the cohort of young workers at the time of trade liberalization will be overincentivized and hence overeducated relative to the long run. As older undereducated workers die and are replaced by younger overeducated workers,

[47]The model does not rule out the possibility that students drop out of school in response to trade liberalization, as Atkin (2012) found for Mexico. The reason they do not is that trade liberalization leads to an increase in relative skill demand, which is itself a result of the simulation rather than an assumption imposed on the model.

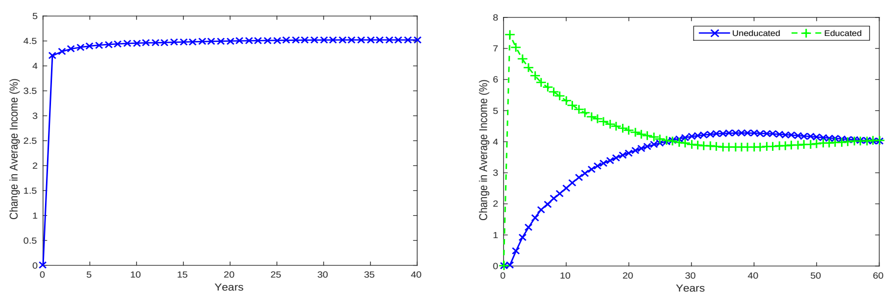
[48]This is in contrast to, for example, the cobweb model of Freeman (1976).

the scarcity of high-skill labor gives way to a surplus. This process then reverses itself as the youth become undereducated relative to the long run in response to the surplus of high-skill labor. This cycle, which is most clearly apparent in Figure 1a, continues until the economy converges to the new post-liberalization steady state. Although these oscillations will also be apparent in subsequent figures, I will not focus on them as they appear to be of relatively minor quantitative importance.[49]

4.2 Income Paths

My main concern is with the division of the gains from trade among workers and the inequality caused by the new trade policy. However, it is useful to first analyze the income paths, since they ultimately are the determinants of the gains from trade and inequality. Figure 2a charts the evolution of average income in the economy beginning with the period immediately preceding the removal of trade barriers.[50]

Figure 2: Change in Average Income by Education (%)



(a) All Workers **(b)** By Education

If this were the whole story, we might reasonably conclude that although trade has important consequences, the dynamics appear to be of minor importance. Indeed, average income in the economy increases by 4.2% in the first year after trade liberalization, but this already represents 93% of the long-run increase in average income. However, the lack of significant dynamics in the aggregate masks the fact that the fortunes of educated and uneducated workers are moving in opposite directions during the transition.

Figure 2b decomposes average income into that of uneducated and educated workers, revealing that the relatively muted dynamics observed in the aggregate are a result of the fact that educated and uneducated workers' average incomes evolve in opposite directions after the initial trade shock. The increase in relative skill demand sharply drives

[49]For a more detailed discussion see Appendix C

[50]Because the price of the final good is normalized to unity in every period, all income is real.

up wages for educated workers to beyond the long-run steady-state level. Their average income then falls back towards its long-run level as workers respond to the high wages by pursuing an education and thus augmenting the supply of high-skill labor.

For uneducated workers the situation is reversed. Their wage increases gradually together with the decrease in the relative supply of low-skill labor. Despite the surplus of low-skill labor, uneducated workers' income does not decrease initially because trade liberalization leads to an increase in the varieties of the intermediate goods available to all workers, which increases their real income.

4.3 Gains From Trade

Turning to the main results of the paper, I now analyze the gains generated by trade liberalization. These gains are defined as the percentage increase, compared to pre-liberalization, in expected discounted real income net of education costs for present and future generations. The simulation results show that the removal of policy trade barriers leads to aggregate gains from trade of 4.5% in each country. However, these gains from trade are not equally shared by all workers. The gains from trade are most unequally divided among workers alive at the time of trade liberalization, while for subsequent generations the gains are divided more equitably.

Workers Alive at the Time of Trade Liberalization Table 1 reports gains by education and across age groups for workers who are alive at the time of trade liberalization. The last row shows that although the youngest workers as a group gain the least from trade liberalization, the gains are shared quite evenly between age groups when gains are averaged over all education groups. However, the last column shows that the gains are more uneven along the education dimension. Educated workers as a group gain the most, at 5.9%, while uneducated workers who are not induced to acquire an education gain the least at 2.7%.

Although age groups as a whole gain relatively evenly from trade, this masks the differences between education levels within age groups and within education levels across age groups. For example, the older an educated worker, the greater her gains from trade. The situation is reversed for uneducated workers who gain less the older they are. The reason is that the older a worker at the time of trade liberalization, the larger is the proportion of their remaining lifetime spent with a relatively high educated-worker wage and low uneducated-worker wage. This works in favor of older educated workers, but is

Table 1: Gains from Trade for Workers Alive at Trade Liberalization (%)

Group	19-23	34-38	49-53	64-68	Total
Uneducated	3.0	2.7	2.2	1.1	2.7
Educated	5.5	5.6	6.0	6.7	5.9
Students	5.3	5.5	5.8	6.7	5.4
Switchers	3.8	3.3	3.4	3.8	3.6
Total	4.4	4.5	4.5	4.6	4.5

Notes: Columns represent age groups. Switchers are workers induced by trade liberalization to pursue an education. Uneducated workers are workers who will never be students.

particularly detrimental to old uneducated workers.

Thus, among age groups, the gains are most unevenly divided among the oldest workers. Educated old workers gain 6.7%, while uneducated old workers gain only 1.1%. For the youngest age group the inequity in the division of the gains from trade is smaller but still pronounced, with uneducated workers gaining 3% compared to the 5.5% gain for educated workers. The upshot of these results is that there is considerable heterogeneity in how workers alive at the time of implementation of the new trade policy are affected by the policy, with an individual worker's gains depending on both her education and age.

Workers Born After Trade Liberalization The ex-ante gains from trade, i.e., the expected gains at birth, are much more evenly divided among workers born after trade liberalization. There are two reasons for this. First, workers born after trade liberalization are less affected by the large initial rise in the returns to education. Second, all workers are born uneducated. Much of the inequity in the division of the gains from trade is caused by the fact that workers who had already acquired an education pre-liberalization are rewarded with a particularly large windfall.

Table 2: Gains for Workers Born After Liberalization by Cohort (%)

Group	Impact	5 years	10 years	25 years	Steady State
Uneducated	3.0	3.4	3.7	4.2	4.0
Students	5.3	5.2	5.0	4.9	5.0
Total	4.4	4.5	4.6	4.6	4.6

Notes: Uneducated workers will never pursue an education. Students are workers who begin their life as students. Columns indicate birth year after liberalization.

Table 2 reports the gains from trade, by birth cohort, for workers born after the new trade policy is implemented. The percentages reported in the table are a worker's ex-ante gains taking into account that even if they choose to pursue an education, they may not be successful in the endeavor. Of course, the gains among students will be divided more unequally ex-post as some students will become educated while others will not. The last row in Table 2 shows that the gains from trade averaged over all workers in a cohort are increasing with time, although the increase is minor. Indeed, the small increase reflects the fact that most of the aggregate gains are realized immediately, while the important dynamics are reflected in the division of these gains across education groups.

The first column of the table shows that workers whose ability is sufficiently low so they will never pursue an education gain 3.0% from the implementation of the new trade policy. In contrast, the average gains from trade for workers who do pursue an education is 5.3%. The difference in gains for the two groups diminishes along the transition path. Nevertheless, even in the post-liberalization steady state the gains for workers who pursue an education are higher than for those that do not, although the difference is only 1 percentage point.

4.4 Importance of Skill Adjustment and Transition

How do the predictions for inequality and the gains from trade differ when the transition is not taken into account or when the endogeneity of the skill supply is ignored? The results reported in Table 3 demonstrate the importance of the endogenous skill supply and the transition.

Table 3: Gains from Trade Liberalization (%)

	Actual Gains	No Transition	Fixed Skill Supply
Uneducated, 19-23	3.0	4.0	-0.8
Uneducated, 64-68	1.1	4.0	-0.8
Educated, 19-23	5.5	4.7	8.1
Educated, 64-68	6.7	4.7	8.1

Notes: Uneducated workers are those who will never pursue an education. Gains are for workers alive at liberalization. The second column assumes the new steady state is reached immediately. The third column takes education cutoffs as fixed at pre-liberalization levels.

Comparing the first two columns of Table 3 shows that considering only the post-liberalization steady state leads to an understatement of the gains for educated workers, by nearly 50% for the oldest workers, and an overstatement for uneducated workers, by nearly a factor of four for the oldest workers. Thus, ignoring the transition and focusing instead only on the steady state leads to a substantial understatement of trade-induced inequality. Indeed, much of the inequality is realized during the transition as skill supplies adjust to the increased relative skill demand.

The situation is reversed when the endogeneity of the skill supply is not taken into account, as a comparison of the first and third columns of Table 3 shows. The endogenous skill supply tends to have an equalizing effect. Hence, if the skill adjustment is ignored, trade-induced inequality is overstated. In fact, were skill supplies fixed, uneducated workers would actually be worse off after trade liberalization, whereas when skill supplies are properly treated as endogenous they are better off, albeit by less than educated workers.

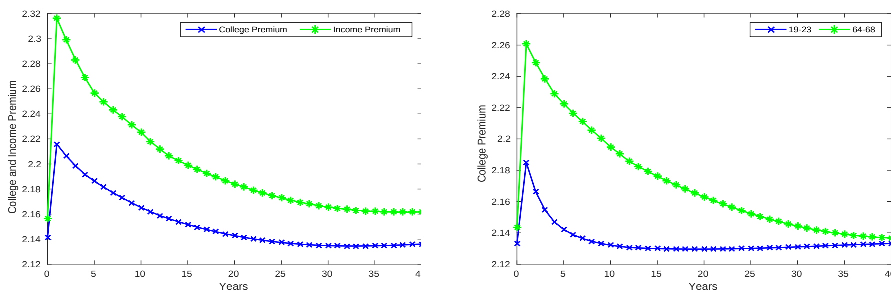
Finally, because all the dynamics in the model operate through changes in the skill supply, when the skill supply is fixed there are no dynamics. Therefore, ignoring either the transition or the endogeneity of the skill supply fails to account for the differential impact of trade across age groups. Old and young would be affected in the same way were there no transition, as seen in the last two columns of Table 3. The results in this section are some of the most important in the paper as they highlight the fact that the novel features in the model that distinguish this paper from the existing literature, the endogeneity of the skill supply and the resulting dynamics, are not only theoretically relevant but are also quantitatively meaningful.

4.5 Earnings Inequality

In this section, I consider the cross-sectional differentials in lifetime earnings among workers along the transition path. This is important mostly because it will deepen our understanding of the dynamics following trade liberalization, but also because these quantities have a more readily estimable empirical counterpart than the ex-ante gains from trade. For brevity, I will refer to the net present value of a worker's lifetime income stream net of education costs simply as lifetime earnings. In addition, when I discuss inequality between groups of workers I will be referring to relative average lifetime earnings between these groups. Thus, for example, the college premium is defined as the average discounted lifetime earnings of an educated worker relative that of an uneducated worker that will never pursue an education.

Inequality by Education Figure 3 plots the evolution of the college premium beginning with the steady state prevailing prior to trade liberalization. For all age groups there is a large immediate increase in earnings inequality between educated and uneducated workers followed by a gradual decline. The difference in the college premium for young and old workers, seen in Figure 3b, is the sum of two effects. First, as workers age, only the most able continue to pursue an education, while the least able discontinue their educational pursuit. This ensures that, for a given skill premium, the average ability of educated workers increases with age. Thus, even in the steady state, earnings inequality is highest among the oldest workers. This tends to increase the difference in the within-age-group college premium between young and old.

Figure 3: College Premium Along the Transition Path



(a) College vs. Income Premium **(b)** College Premium by Age

Notes: The college premium is the lifetime earnings of an educated worker relative to that of an uneducated worker. The income premium is the within period income of an educated worker relative to an uneducated worker.

Second, older workers' lifetime earnings depend only on wages in the near future whereas younger workers' lifetime earnings depend also on wages in the more distant future. This increases the difference in the college premium between old and young only if the skill premium is decreasing. Immediately after the transition this leads to an increase in the difference in inequality between age groups, but after the wages overshoot their long-run level, as seen in Figure 2, the effect is reversed. Nevertheless, Figure 3b shows that earnings inequality is always higher among older workers. The difference is largest immediately following trade liberalization. Indeed, the lifetime earnings of old educated workers relative to old uneducated workers are 5.5% higher immediately after trade liberalization compared to pre-liberalization, while for young workers the increase is smaller at 2.4%.[51]

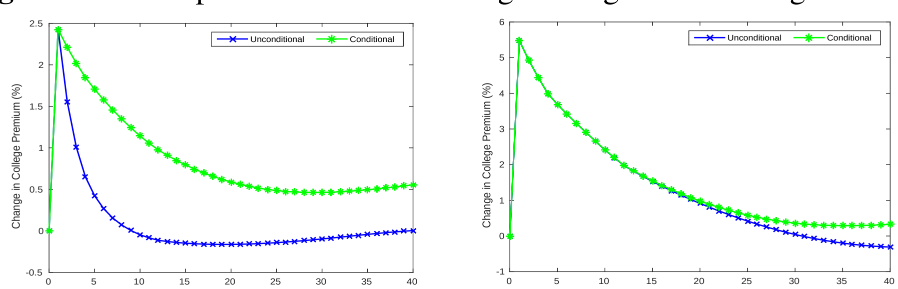
Although income inequality, defined as the within-period average income of an ed-

[51] For more detailed numerical results see Table A5 in Appendix D.

ucated worker relative to that of an uneducated worker, is often used as a measure of inequality, it is a less meaningful measure than lifetime-earnings inequality. Figure 3a shows how within-period income inequality can misstate lifetime-earnings inequality. Workers make their decisions based on lifetime earnings, and therefore high lifetime-earnings inequality tends to have an equalizing effect in the long run as it incentivizes uneducated workers to pursue an education. Income inequality, by not accounting for this equalizing effect, overstates inequality when inequality is above its long-run level and understates inequality when it is below its long-run level.

The decrease in the college premium following the initial increase after trade liberalization is a result of two effects. First, the influx of educated workers causes the wage per unit, or price, of high-skill labor to fall. Second, the high returns to education incentivize workers with lower ability to pursue an education, lowering the average ability of educated workers. Therefore, for a given price of high-skill labor, average earnings of educated workers drop. Figure 4 shows that for the oldest workers the first effect, the decreasing price of high-skill labor, explains almost the entire change in the college premium, while for the youngest workers much of the change is explained by the decreasing average ability of young educated workers. The reason for this discrepancy is that it is mostly young workers who are induced by trade liberalization to pursue an education. Indeed, for the youngest workers the college premium actually falls slightly below its pre-liberalization level approximately ten years into the transition.

Figure 4: Decomposition of the Percentage Change in the College Premium



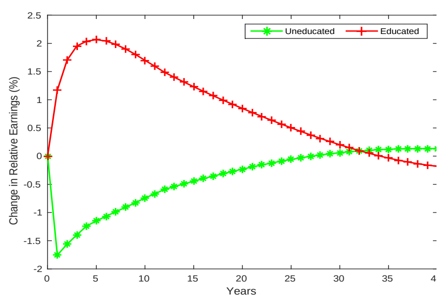
(a) Young Workers **(b)** Old Workers

Notes: The college premium is the average lifetime earnings of an educated worker relative to that of an uneducated worker. The conditional change is the percentage change in the college premium conditional on ability.

It is useful to contrast the change in the long-run college premium with the results of Findlay and Kierzkowski (1983). They study the long-run effects of introducing endogeneity of the skill supply in a Heckscher-Ohlin model with homogeneous agents. When agents are homogeneous, all workers must be indifferent between acquiring an education and remaining uneducated. Since there is a unique skill premium that ensures this indifference, the skill premium cannot change between the pre- and post-liberalization steady states, and as a consequence, the steady-state gains from trade are equal for all workers. In contrast, when workers are heterogeneous, as here, only the marginal worker is indifferent between pursuing an education and remaining uneducated. In order to increase the skill supply, the relative return to schooling must increase so as to induce less able individuals to pursue an education. As a result, even in the long run, educated workers gain from trade relatively more than uneducated workers despite the skill-supply adjustment.

Inequality by Age Figure 5 tracks the trajectory of the percentage change, relative to pre-liberalization, of the annualized lifetime earnings, or permanent income, of the oldest workers relative to that of the youngest workers within each education class. From the first period following trade liberalization uneducated worker wages increase as the supply of low-skill labor decreases. However, older workers do not live long enough to benefit from the entire recovery of low-skill wages, and therefore they have lower annualized lifetime earnings than younger workers.

Figure 5: Change in Permanent Income of Old Relative to Young Workers (%)



Educated workers experience the opposite effect. Older workers spend a greater proportion of their remaining life working for the temporarily high wages than do younger workers. Younger workers remain in the workforce even after their wages have decreased in response to the trade-induced influx of educated workers. This effect causes an initial increase in the annualized lifetime-earnings inequality between old and young educated workers.

Unlike inequality among uneducated workers the inequality among educated workers does not reverse course immediately after the initial change. The reason is that the average ability of the workers induced by trade liberalization to acquire an education is lower than the average ability of workers who were already educated at the time. Since most newly educated workers are young, this has the effect of increasing the average annualized lifetime earnings of old educated workers relative to the average for young educated workers.

After the initial trade shock, average annualized lifetime earnings of old workers relative to young workers increase by 0.1%, while this can be decomposed into a 1.2% increase among educated workers and a 1.8% decrease for uneducated workers.[52] In the long run, however, there is no change in inequality between age groups within education classes. The reason is that the inequality across age groups is a result of the wage dynamics following trade liberalization. This, like many of the results in this paper, underscores the fact that we must account for the post-liberalization dynamics brought about by the endogenous skill supply response if we are to achieve a full rendering of the impact of trade liberalization on inequality.

5 Conclusion

The objective of this paper has been to quantify the differential impact of trade liberalization on workers depending on their educational attainment and age. To this end I develop a dynamic general-equilibrium trade model with endogenous education decisions. Two insights distinguish this paper from the existing trade literature. First, if trade changes relative skill demand and as a consequence also the skill premium, then workers will react to the change by adjusting their education or skill accumulation decisions. Second, the process of skill-supply adjustment to an increase in relative skill demand is far from instantaneous.

The model I study is rich enough to provide meaningful predictions on the impact of trade liberalization on workers along several dimensions. At the same time, the model remains tractable enough to allow for a solution of the economy's entire equilibrium transition path following trade liberalization. Thus, the model sheds light not only on the effect of trade liberalization on workers by education and age, but also by birth cohort.

After calibrating the model to 2007 US data, I simulate the economy's transition path in response to the removal of policy trade barriers. I find that the gains from trade are most unevenly divided among workers alive at the time of trade liberalization. This is true both if we consider workers by education within age groups or vice versa. In particular, for this generation of workers, educated workers gain more the older they are, with

[52] For more detailed numerical results see Table A6 in Appendix D.

the oldest educated workers gaining 6.7% and the youngest gaining 5.5%. Among uneducated workers, the reverse is true, and as a result, the oldest uneducated workers gain the least from trade liberalization, a mere 1.1%. Among workers in future generations, born subsequent to trade liberalization, the gains from trade are divided much more equitably.

I find that trade leads to a substantial increase in inequality, although most of this inequality is transitory. The college premium, defined as the discounted lifetime earnings of educated workers relative to that of uneducated workers, increases initially by 3.5% when all age groups are considered. However, this can be decomposed into an 5.5% increase for the oldest workers and a 2.4% increase for the youngest workers. In addition, I find that, even within education groups, annualized lifetime earnings differ by age. All these measures of inequality are highest immediately following trade liberalization and decrease during the economy's transition. Nevertheless, even in the long run the college premium is higher than pre-liberalization, but by only 0.1 percentage points.

The upshot of these results is that the dynamics due to the endogeneity of the skill supply are essential for understanding the full impact of trade liberalization on workers. On the one hand, ignoring the transition leads to a substantial understatement of trade-induced inequality as most of the inequality is transitory. On the other hand, not allowing skill supplies to adjust to trade liberalization leads to a substantial overstatement of trade-induced inequality as it does not account for the equalizing effect of the endogenous increase in the skill supply.

One of the main lessons of my results is that accounting for changes in the educational composition of the workforce is essential for understanding the full implications of trade liberalization. In particular, this paper highlights that education plays a crucial role in mitigating the adverse distributional impact of trade liberalization, at least in the long run. This has potentially important implications for policy makers tasked with devising policies aimed at combating the unequalizing effects of trade liberalization. Indeed, policy makers have long recognized the important role education can play in complementing trade-liberalizing policies, as in the Trade Adjustment Assistance (TAA) program in the United States created under the Trade Act of 1974. While the TAA focuses merely on subsidizing the retraining of workers impacted by trade, this paper suggests that policies that target college education may also be important complements to trade policy.

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A Calibration Appendix

Bins The CPS divides the firm size space into 6 bins. The smallest bin contains firms with between one and nine workers. The remaining bins are 10-24, 25-99, 100-499, 500-999 and 1,000 or more workers. The Economic Census, beginning in 2007, divides the size space into twenty-five bins. Up to firms with fifty workers, the bins are divided by increments of five workers. The remaining bins have the following lower boundaries: 75, 100, 150, 200, 300, 400, 500, 750, 1,000, 1,500, 2,000, 2,500, 5,000 and 10,000. Each of these bins represents a unique technology in the model.

Firm Size Adjustment The firm size data reports numbers of workers, while the model predicts firms' decisions in terms of units of labor. This is because firms can, for example, hire two units of high-skill labor either by hiring one educated worker with innate ability equal to two or two educated workers with innate ability equal to one. (This problem does not arise with uneducated workers because each uneducated worker provides exactly one unit of low-skill labor regardless of ability.) For the purposes of the calibration, therefore, I need to translate the firm-size data in terms of workers to firm-size data in terms of units of labor. I do this by assuming that the average ability of an educated worker in any particular firm is also equal to the economy-wide average ability of an educated worker. For concreteness, suppose that on average an educated worker has ability η. Thus, if a proportion ζ of workers are uneducated in a particular firm of size $s^{workers}$ (in units of workers), then the size of this firm in terms of units of labor is $s^{labor} = \zeta s^{workers} + \eta\,(1-\zeta)\,s^{workers}$. The first term is the measure of low-skill and the second term is the measure of high-skill labor.

Sectors In the simulation I divide the economy into 20 sectors as follows (with NAICS in brackets): 1. agriculture, forestry, fishing and hunting (11); 2. mining, quarrying and gas extraction (21); 3. construction (22); 4. utilities (23); 5. food and beverage manufacturing (311-312); 6. textile, apparel and leather manufacturing (313-316); 7. wood and paper manufacturing and printing (321-323); 8. petroleum, coal and chemical manufacturing (324-325); 9. plastics, rubber and nonmetallic mineral manufacturing (326-327); 10. metal manufacturing (331-332); 11. machinery, computer, electrical and transportation manufacturing (333-336); 12. furniture manufacturing (337); 13. miscellaneous manufacturing (339); 14. wholesale trade (42); 15. retail trade (44-45); 16. transportation and warehousing (48-49), 17. information, financial, real estate and professional services (51-56); 18. education and health services (61-62); 19. leisure and hospitality (71-72); 20. other services (81).

Calibration of Skill Intensity As described in the main text, once we know the share of the educated worker wage bill in the total wage bill in a particular bin, then it is straightforward to calculate the skill intensity of the technology used in that bin. A problem arises, however, because only the CPS contains data about firm expenditure by education and size bin, but the partition of these bins is coarser than the Economic Census partition (see above). To overcome this problem I linearly interpolate values for skill intensity for each of the Economic census bins using the skill intensity in the CPS bins as the data. Specifically, I use the log of the average size of a firm in each of the CPS bins as the sample (data) points and the log of the average size in each of the Economic Census bins as the query points. The results of this interpolation are the λ_{v_S}'s used in the simulation and they are presented in Figure A1.

A.1 Calibration Results

The economy-wide parameters used in the simulation are summarized in Table A1. Skill-supply parameters are summarized in Table A2. Sector-specific skill-demand parameters (other than the firm-level technological parameters) and the corresponding moments in the data are summarized in Tables A3 and A4. Finally, Figures A1-A3 show the results of the calibration of the technology menus from which firms choose for each sector. That is, the figures show the skill intensity (λ_{v_s}), productivity (α_{v_s}) and fixed cost (f_{v_s}) for each technology and each sector.

Table A1: Economy-Wide Parameters and Moments

Parameter	Value	Moment
β	0.97	average annual real interest rate of 3%
B	10	workers are divided into 10 age groups
δ_b	0.2	age group corresponds to a 5-year window
δ_e	0.22	average of 4.5 years to complete BA
σ	3.8	estimate in Bernard et al. (2003)

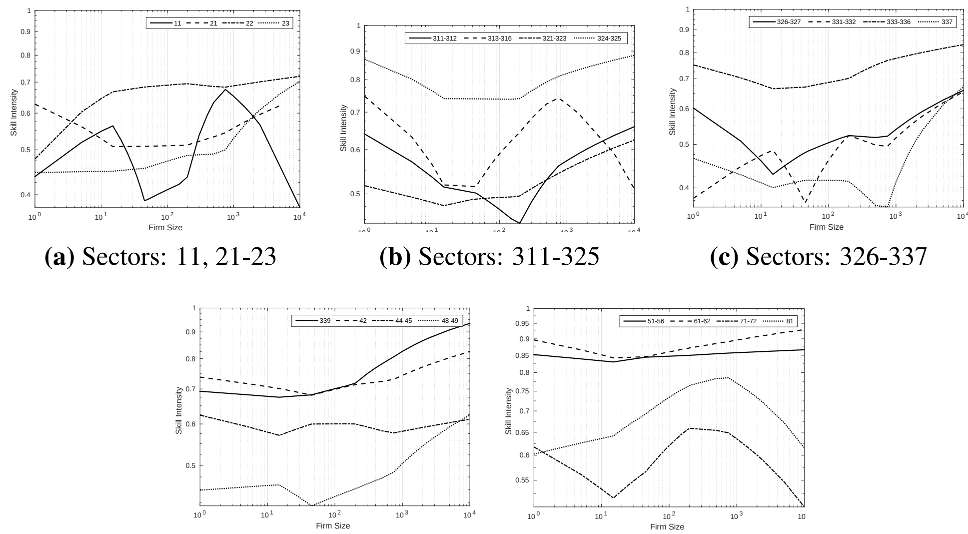
Table A2: Skill-Supply Parameters and Moments

Parameter	Value	Moment
ξ	1.45	1. skill premium in 1992 and 2007 (1.9 and 2.1, respectively)
ψ	1.05	2. educated relative to uneducated workers in 1992 and 2007 (0.48 and 0.68, respectively)
w_{h1990}	\$9,800	
w_{h2007}	\$11,900	

Table A3: Sector-Specific Skill-Demand Parameters

NAICS Codes	θ_s	M_s	η_s	τ_s	f_{xs}
11	8.9	2.0	0.7	1.86	13.4
21	5.4	0.5	0.8	1.86	44.4
22	8.1	0.3	1.3	1.86	266.0
23	10.7	16.9	7.1	1.86	72.2
311 – 312	6.9	0.5	1.3	1.89	62.0
313 – 316	4.8	0.3	0.4	1.95	49.1
321 – 323	6.7	0.8	1.1	1.93	77.1
324 – 325	4.7	0.3	1.7	1.83	41.4
326 – 327	6.4	0.3	0.8	2.03	64.5
331 – 332	7.0	1.0	1.4	2.04	40.8
333 – 336	3.7	1.0	5.6	1.76	32.3
337	8.3	0.4	0.4	2.28	45.5
339	6.9	0.9	1.1	2.28	35.3
42	7.0	4.0	3.7	1.86	122.4
44 – 45	11.3	12.0	8.8	1.86	78.7
48 – 49	6.9	4.5	4.7	1.86	101.6
51 – 56	8.4	26.6	27.6	1.86	101.2
61 – 62	11.6	14.6	23.3	1.86	7910.8
71 – 72	7.1	4.7	5.0	1.86	126.0
81	8.3	8.5	3.3	1.86	98.2

Figure A1: Skill Intensity of Technologies

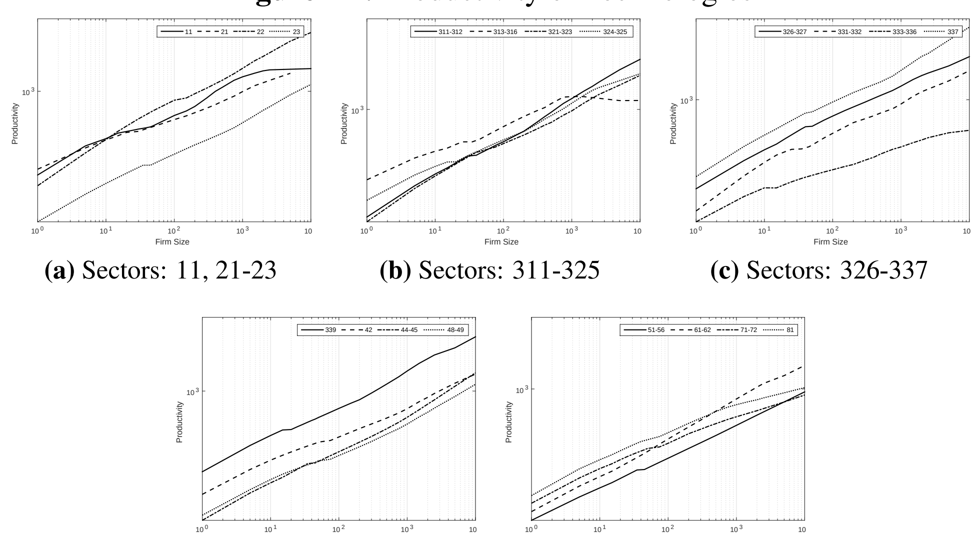


(a) Sectors: 11, 21-23 **(b)** Sectors: 311-325 **(c)** Sectors: 326-337

(d) Sectors: 339-49 **(e)** Sectors: 51-81

Notes: These figures plot high-skill units of labor as a percentage of total labor units for each technology. Each vertical gridline represents a technology. The x-axis is on a log scale.

Figure A2: Productivity of Technologies

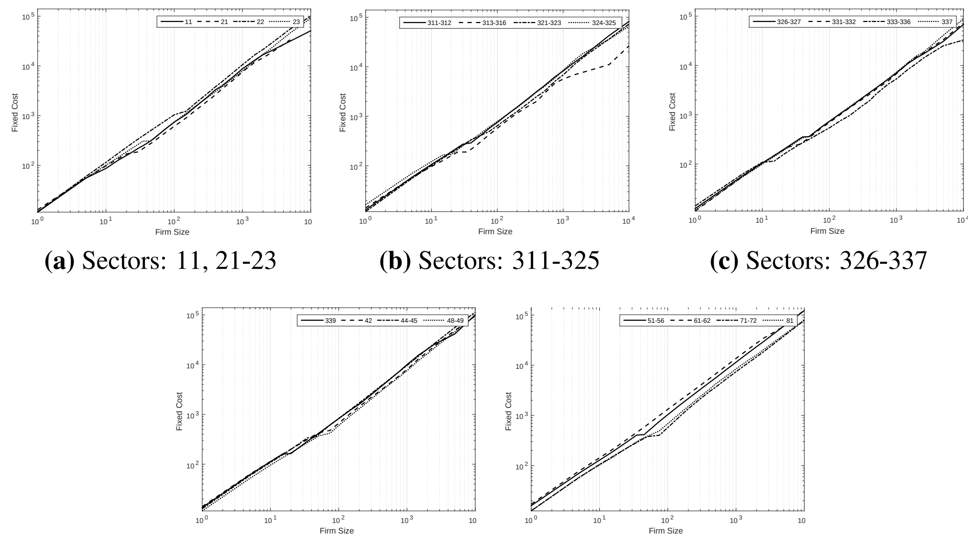


(a) Sectors: 11, 21-23 **(b)** Sectors: 311-325 **(c)** Sectors: 326-337

(d) Sectors: 339-49 **(e)** Sectors: 51-81

Notes: Each vertical gridline represents a technology. The both axes are on a log scale.

Figure A3: Fixed Cost of Technologies



(a) Sectors: 11, 21-23 **(b)** Sectors: 311-325 **(c)** Sectors: 326-337

(d) Sectors: 339-49 **(e)** Sectors: 51-81

Notes: Each vertical gridline represents a technology. The both axes are on a log scale.

B Numerical Implementation

B.1 Workers

Worker Policy

From the analysis in the main text in Section 2.2 it is apparent that if worker values are known for a given future period T, then the value functions allow for the backward induction of worker values for all periods $t \leq T$ for a given path of wages. In practice, I will calculate worker values by backward inducting from the terminal steady state of the economy. I will therefore show how worker values are computed in a steady state.

Suppose that the steady state wages are w_ℓ and w_h. The expected discounted remaining lifetime of a worker in age group b is

$$\chi_b = (1+\beta\delta_b\chi_{b+1})/(1-\beta(1-\delta_b)),$$

with the initial condition $\chi_{B+1} = 0$. Therefore, in steady state, $V(a,b,1) = \chi_b a w_h$. If an uneducated worker decides to work full time in age group b, then she will also choose to do so when she reaches older age groups because the education cutoffs, $\{a_b\}_{b=1}^{B}$, are increasing with age. For age group B, if $a < a_B$, then $V(a,B,0) = \chi_B w_\ell$. If instead

$a > a_B$, then

$$V(a,B,0) = \frac{-C + mw_\ell + \delta_e \chi_B w_h}{1 - \beta\delta_e(1-\delta_B)}.$$

Given the values for age group B, backwards induction yields

$$V(a,b,0) = \begin{cases} \chi_b w_\ell & a \le a_b \\ \frac{-C+mw_\ell+\beta\left[\delta_e\tilde{V}(a,b,1)+(1-\delta_e)\delta_b V(a,b+1,0)\right]}{1-\beta\delta_e(1-\delta_B)} & a > a_b \end{cases} \tag{15}$$

The education cutoffs themselves can be computed by finding the ability level for each age groups at which the two possibilities in Equation (15) are equal. This completes the calculation of worker values for the steady state.

Law of Motion of the Worker Distribution

In this section, I provide an alternative method of computing the worker distribution in any period given an initial worker distributions and a path of future education cutoffs. Suppose the worker distribution in period t is $W_t(a,b,e)$ and the education cutoffs are $\{a_b\}_{b=1}^{B}$. It will be useful to define an auxiliary distribution, $\tilde{W}_t(a,b,\tilde{e})$, where $\tilde{e} = 0$ if the worker is uneducated and works full time, $\tilde{e} = 1$ if the worker is educated and $\tilde{e} = 2$ if the worker is pursuing an education in the given period. This distribution describes the worker distribution given their optimization decisions in period t. For educated workers these two distributions are identical, $W_t(a,b,1) = \tilde{W}_t(a,b,1)$. For uneducated workers the education cutoffs govern the relationship between W_t and $\tilde{W}_t$

$$\tilde{W}_t(a,b,0) = \begin{cases} W_t(a,b,0) & a \le a_{bt} \\ 0 & a > a_{bt} \end{cases}, \qquad \tilde{W}_t(a,b,2) = \begin{cases} W_t(a,b,0) & a > a_{bt} \\ 0 & a \le a_{bt} \end{cases}.$$

The measure of uneducated workers for any (a,b) in period $t+1$ is the sum of two groups, workers who pursued an education in period t but failed to become educated and uneducated workers who worked full-time in period t. Each of these groups, in turn, is a sum of workers who remained in age group b and those who aged from age group $b-1$,

$$W_{t+1}(a,b,0) = \bar{W}_{t+1}(a,b,0) + (1-\delta_e)\bar{W}_{t+1}(a,b,2),$$

where $\bar{W}_{t+1}(a,b,j) = (1-\delta_b)\tilde{W}_t(a,b,j) + \delta_b \tilde{W}_t(a,b-1,j)$ for $j \in \{0,1,2\}$. Denoting the measure of newborns in each period by N, $\delta_b \tilde{W}_t(a,0,0) = N g_w(a)$ is the measure of newborns with ability a in each period, where $g_w(\cdot)$ is the density function associated with the distribution of worker ability. Since newborns are born uneducated and did not pursue an education in the previous period, $\tilde{W}_t(a,0,j) = 0$ for $j \in \{1,2\}$.

The distribution of educated workers in period $t+1$ is calculated analogously to the distribution of uneducated workers. The difference being that educated workers in $t+1$ are the sum of workers who were already educated in period t and students in period t who succeeded in becoming educated,

$$W_{t+1}(a,b,1) = \bar{W}_{t+1}(a,b,1) + \delta_e \bar{W}_{t+1}(a,b,2).$$

Finally, the measure of newborns, N, in each period is constant and ensures that the measure of births exactly equals the measure of deaths in each period. This condition, with population normalized to one, means that the measure of newborns is given by the recursive formula,

$$N = \left(\sum_{b=1}^{B} \zeta_b\right)^{-1}, \quad \zeta_b = \zeta_{b-1}\left(\frac{\delta_{b-1}}{\delta_b}\right) \quad \textit{and} \quad \zeta_1 = \frac{1}{\delta_1}.$$

B.2 Algorithms

B.2.1 Technology and Export Cutoff Algorithm

In this section, I describe the algorithm I use for computing the technology and export cutoffs. The technology used by the least productive firms is $v_s = 0$ which ensures zero profits. Given this starting point, the remaining cutoffs are computed using the following procedure starting with $v_s = 1$ and $\tilde{v}_s = 0$:

1. Find the productivity φ_{v_s} at which a firm is indifferent between using technology v_s and technology $\tilde{v}_s$, which is the highest technology used lower than v_s.

2. Calculate the profit at φ_{v_s} for every technology $v_s' > v_s$.

   (a) If there exists a v_s' such that $\pi(\varphi_{v_s}, v_s') > \pi(\varphi_{v_s}, v_s)$, then technology v_s is not used and return to step 1 with $v_s + 1$.

   (b) Otherwise, technology v_s is used and the adoption cutoff is φ_{v_s}. If φ_{xs} has already been found then return to step 1 with $v_s + 1$.

3. Denote $\varphi_{v_s x}$ the productivity at which a firm would be indifferent between exporting and selling only domestically if it uses technology v_s.
   (a) If $\varphi_{\tilde{v}_s x} < \varphi_{v_s}$, then $\varphi_x = \varphi_{\tilde{v}_s x}$.
   (b) Otherwise, if $\varphi_{v_s x} \leq \varphi_{v_s}$, then $\varphi_{xs} = \varphi_{v_s}$.
   (c) Otherwise, φ_{xs} has still not been reached, and return to step 1 with $v_s + 1$.

B.2.2 Shooting Algorithm

In this Appendix, I provide a brief description of the algorithm I use for computing an equilibrium path from any initial distribution of workers to a terminal steady state. In practice, I solve for an equilibrium path between an initial steady state and a terminal steady state, but the algorithm requires knowledge only of the initial worker distribution and the worker values in the terminal steady state.

To solve for a steady state, I find a triplet (w_ℓ, w_h, R_t), such that together with the implied optimal worker and firm policy, the equilibrium conditions laid out in Section 2.3 are satisfied. Note that this triplet (together with step 4(a) of the algorithm below which determined P_s for each sector) is sufficient to compute optimal worker and firm policy (and hence the worker distribution) in the steady state. Solving the initial and terminal steady states gives the initial worker distribution and terminal worker values, as described in Section B.1, required to compute the equilibrium transition path. The algorithm I will describe is for a given transition length T. The transition length is chosen to be long enough to ensure convergence to the terminal steady state.

1. Guess a path of wages and aggregate final good expenditure $\{w_{\ell t}, w_{ht}, R_t\}_{t=1}^{T}$.
2. Compute optimal worker policy given$\{w_{\ell t}, w_{ht}\}_{t=1}^{T}$ by solving backward for worker values and education cutoffs as described in Appendix B.1.
3. Using worker policy computed in 2 and the initial worker distribution, solve forward for the path of skill supplies and measure of students, $\{L_t, H_t, S_t\}_{t=1}^{T}$, as described in Appendix B.1 and the main text.
4. For each t, given (L_t, H_t, S_t), solve for an equilibrium, i.e. find $\left(\tilde{w}_{\ell t}, \tilde{w}_{ht}, \tilde{R}_t\right)$ such that firms optimize and all markets clear.
   (a) For each guess of $\left(\tilde{w}_{\ell t}, \tilde{w}_{ht}, \tilde{R}_t\right)$ compute the equilibrium sector-level good price, P_{st}, for each sector.

i. For each quadruplet $\left(\tilde{w}_{\ell t}, \tilde{w}_{ht}, \tilde{R}_t, P_{st}\right)$ compute optimal firm technology choice and export decision as described in Section B.2.1.

ii. Given firms choices in i above, compute total supply of the sector-level good.

iii. Adjust P_{st} until the supply calculated in ii above equals demand, $\eta_s \tilde{R}_t$.

(b) For $\left(\tilde{w}_{\ell t}, \tilde{w}_{ht}, \tilde{R}_t\right)$ and the equilibrium P_{st} found in (a) compute aggregate demand for each type of labor.

i. For each sector, compute optimal firm technology choice and export decision as described in Section B.2.1.

ii. Given firms choices in i above, compute total demand for each type of labor in each sector and total supply of the sector-level good.

iii. Sum over all sectors to get aggregate labor demand for each skill type and compute supply of the aggregate final good.

(c) Adjust $\left(\tilde{w}_{\ell t}, \tilde{w}_{ht}, \tilde{R}_t\right)$ until the aggregate goods market, as well as the market for both types of labor clears.

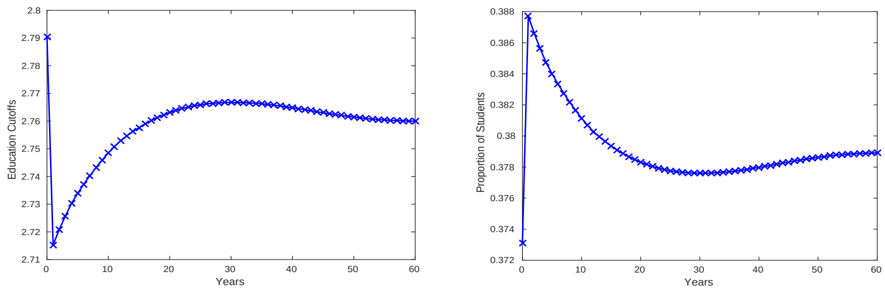
5. If the algorithm has not yet converged then adjust the guess for the path of wages and return to Step 2 and iterate until convergence. The convergence criteria is $\max\left\{\left(w_{\ell t} - \tilde{w}_{\ell t}\right)/w_{\ell t}, \left(w_{ht} - \tilde{w}_{ht}\right)/w_{ht}, \left(R_t - \tilde{R}_t\right)/R_t\right\} < 10^{-7}$.

I adjust the guesses in each iteration so that for each period the new guess is a linear combination of z and $\tilde{z}$ for $z \in \{w_{\ell t}, w_{ht}, R_t\}$ with a weight of 0.05 on $\tilde{z}$ for every t. A higher weight speeds up the convergence, but makes the convergence unstable.

C Skill Supply Adjustment

In this section, I give a brief overview of the mechanisms that shape the evolution of the skill supply along the transition path. These mechanisms are important because the skill-supply adjustment is the source of all the dynamics in the model. Given the worker distribution in the steady state prior to trade liberalization, the trajectory of the labor supply is uniquely determined by the education cutoffs for uneducated workers. The education cutoffs, therefore, are the key to understanding the model's dynamics. Figure A4a shows the evolution of the education cutoffs for the youngest age group.

Figure A4: Education Cutoffs and Students Following Trade Liberalization



(a) Education Cutoffs **(b)** Proportion of Newborn Students

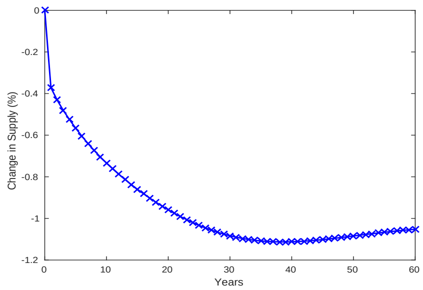
Notes: Panel (a) shows the education cutoffs for the youngest workers. Older workers have similarly shaped paths but the levels are higher. Panel (b) shows the proportion of newborns who pursue an education.

Workers who are old when the new trade policy is implemented will be undereducated relative to long-run levels as they made education decisions in their youth based on conditions prevailing prior to trade liberalization. This relative undereducation, which is reflected in Figure A4a by the relatively high pre-liberalization cutoff, causes a shortage in the relative supply of high-skill labor, which drives up the skill premium. The increase in the skill premium implies an increase in the returns to education, which leads to a drop in the education cutoff. However, because of the scarcity of high-skill labor relative to its long-run level, the education cutoff drops to below its long-run level. Thus, the cohort of young workers at the time of trade liberalization will be overeducated relative to the long run. As older undereducated workers die and the younger overeducated workers take their place, the scarcity of high-skill labor gives way to a surplus. This process then reverses itself as the youth become undereducated relative to the long run in response to the surplus of high-skill labor. This cycle continues until the economy converges to the new post-liberalization steady state.

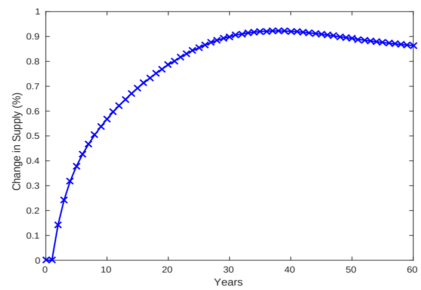
The economy experiences alternating periods of scarcity and surplus of high-skill labor relative to the long-run steady state. Figure A5b shows that the supply of high-skill labor overshoots its long-run level approximately twenty-five years following trade liberalization and then drops to below its long-run level twenty-five years after that. This cobweb effect is a result of the cohort structure of the model as well as workers' rational expectations and is not borne out of workers' irrational behavior or incorrect expectations regarding the general-equilibrium effect of changes in skill supply. These cycles explain the oscillations, apparent in Figure 2, of the educated and uneducated workers' incomes.

The high-skill labor supply does not change between the pre-liberalization steady

Figure A5: Change in Skill Supply Relative to Pre-liberalization (%)



(a) Low-Skill



(b) High-Skill

state and the first period following the liberalization. The reason is that the high-skill labor supply depends only on the distribution of educated workers, which cannot be changed within a period. Thus, the education decisions of workers only affects future, but not present, supply. High-skill labor supply only changes over time as a result of the education decisions of uneducated workers.

The low-skill labor supply, unlike the high-skill labor supply, is affected by both past and present education decisions. Past education decisions determine the current supply of uneducated workers. However, some of these workers will choose to become students and work only part time. Thus, for a given supply of uneducated workers, the supply of low-skill labor is decreasing in the proportion of uneducated workers who become students, or alternatively, increasing with the education cutoffs.

In the first period after trade liberalization, the number of uneducated workers is the same as in the steady state with the old trade policy as this number depends only on past decisions. However, because of the decrease in the education cutoffs, the supply of low-skill labor decreases in the first period after liberalization. After the first period, the number of uneducated workers decreases as more workers pursue an education. At the same time, the proportion of uneducated workers who become students decreases as the education cutoff gradually increases. These two opposing forces, the decrease in the number of uneducated workers and increase in the proportion of these workers who work full time, explain the hump in the low-skill labor supply that can be seen in the beginning of the transition in Figure A5a.

D Supplementary Tables

Inequality by Education

Table A5 gives a sense of the magnitude of the changes in inequality following trade liberalization. The lifetime earnings of old educated workers relative to old uneducated workers are 5.5% higher immediately after trade liberalization compared to before trade liberalization, while for young workers the increase is smaller at 2.4%. In the long run, the endogenous skill-supply response brought about by the high returns to education depresses the college premium. Hence, in the new steady state, inequality is only slightly higher than in the pre-liberalization steady state.

Inequality by Age

Table A6 reports the percentage changes, from the pre-liberalization steady state, in inequality between the youngest and oldest workers along the transition path. After the initial trade shock, average annualized lifetime earnings of old workers relative to young workers increases by 0.2%, while this can be decomposed into a 1.2% increase among educated workers and a 1.8% decrease for uneducated workers.

Table A4: Sector-Specific Skill-Demand Matched Moments

	θ_s	M_s	τ_s	f_{xs}
NAICS Codes	share of educated workers wages in total wage bill	expenditure on workers in sector as a % of expenditure in the whole economy	exports as a % of total shipment among exporters	% of firms that export
11	0.31	0.7	15.0	15.0
21	0.36	0.8	15.0	15.0
22	0.51	1.3	15.0	4.0
23	0.29	7.1	15.0	4.0
311 – 312	0.37	1.3	14.4	15.6
313 – 316	0.41	0.4	13.3	13.3
321 – 323	0.33	1.1	13.7	9.9
324 – 325	0.68	1.7	15.5	30.8
326 – 327	0.34	0.8	12.0	19.0
331 – 332	0.31	1.4	11.9	17.6
333 – 336	0.62	5.6	17.0	37.1
337	0.27	0.4	9.0	8.1
339	0.60	1.1	15.0	19.0
42	0.55	3.7	15.0	4.0
44 – 45	0.39	8.8	15.0	4.0
48 – 49	0.33	4.7	15.0	4.0
51 – 56	0.72	27.6	15.0	4.0
61 – 62	0.77	23.3	15.0	0.0
71 – 72	0.38	5.0	15.0	4.0
81	0.47	3.3	15.0	2.0

While disaggregated export data is available for manufacturing sectors, it is not readily available for non-manufacturing sectors. I therefore use the economy-wide average for non-manufacturing firms. I also assume that the education and health-care sectors (NAICS 61-62) are nontraded since almost no firms export in these sectors.

Table A5: Change in the College Premium After Trade Liberalization (%)

	Impact	5 years	10 years	25 years	Steady State
College Premium, All Ages	3.5	2.1	1.1	-0.2	0.1
College Premium, 19-23	2.4	0.4	-0.1	-0.2	0.0
College Premium, 64-68	5.5	3.7	2.4	0.4	0.1
Income Premium	7.4	4.6	3.1	0.8	0.7

Notes: The college premium is defined as the average discounted lifetime earnings of educated workers relative to that of uneducated workers who will never pursue an education. The income premium is the average income of an educated worker relative to an uneducated worker within a period. The columns are years following trade liberalization.

Table A6: Change in Annualized Lifetime Earnings for Old Relative to Young Workers (%)

Group	Impact	5 years	10 years	25 years	Steady State
Uneducated	-1.8	-1.2	-0.7	-0.1	0
Educated	1.2	2.1	1.7	0.5	0.1
Total	0.2	0.0	-0.1	-0.1	0.0

Notes: Uneducated workers refers to workers who will never pursue an education. The columns are years following trade liberalization.