Inequality and Unemployment in a Global Economy*

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Abstract

This paper develops a new framework for examining the distributional consequences of international trade that incorporates firm and worker heterogeneity, search and matching frictions in the labor market, and screening of workers by firms. Larger firms pay higher wages and exporters pay higher wages than non-exporters. The opening of trade enhances wage inequality and raises unemployment, but expected welfare gains are ensured if workers are risk neutral. And while wage inequality is larger in a trade equilibrium than in autarky, reductions of trade impediments can either raise or reduce wage inequality.

Key words: Wage Inequality, International Trade, Risk, Unemployment

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1 Introduction

Two core issues in international trade are the allocation of resources across economic activities and the distribution of incomes across factors of production. Recent research has emphasized the allocation of resources across heterogeneous firms, but has largely concentrated on heterogeneity in the product market (productivity and size) rather than the labor market (workforce composition and wages). Developing trade models that incorporate both product and labor market heterogeneity is therefore important for explaining firm data and understanding the consequences of trade liberalization. To the extent that wages vary across firms within sectors, reallocations of resources across firms provide an additional channel for international trade to influence income distribution.

In this paper, we develop a new framework for examining the distributional consequences of trade that incorporates this channel and captures three plausible features of product and labor markets. First, there is heterogeneity in firm productivity, which generates differences in firm profitability. Second, search and matching frictions in the labor market imply that workers outside a firm are imperfect substitutes for those inside the firm, which gives rise to multilateral bargaining between each firm and its workers. Third, workers are heterogeneous in terms of match-specific ability, which can be imperfectly observed by firms. Together these three components of the model generate variation in wages across firms within industries and imply that trade liberalization affects income distribution.

Our model accounts for a number of empirical findings from micro data on firms and workers. Wage dispersion within industries is closely linked to productivity dispersion (e.g., Davis and Haltiwanger 1991 and Faggio, Silvanes and Van Reenen 2007) and the model exhibits the empirically–observed employer–size wage premium (e.g., Oi and Idson 1991). Wage dispersion is also closely linked to trade participation, with exporters paying higher wages than non-exporters, as found empirically by Bernard and Jensen (1995, 1997) and many subsequent studies. This exporter wage premium is accompanied by differences in workforce composition across firms, as observed by Kaplan and Verhoogen (2006), Schank, Schnabel and Wagner (2007), and Munch and Skaksen (2008). Finally, the model is consistent with empirical evidence of search and matching frictions and frictional unemployment (e.g., Petrongolo and Pissarides 2001).

The key mechanisms underlying these properties of the model are as follows. Complementarities between workers' abilities in the production technology imply that firms have an incentive to screen workers to exclude those of lower ability. As the strength of these production complementarities increases with firm productivity, more productive firms screen more intensively and have workforces of higher average ability than less productive firms. Search frictions imply multilateral bargaining between a firm and its workers, and since higher ability workforces are more costly to replace, more productive firms consequently pay higher wages. When the economy is opened to trade, the selection of more productive firms into exporting increases their revenue relative to less productive firms, which further enhances their incentive to screen workers to exclude those of lower ability. The open economy is therefore characterized by differences in workforce composition and wages between exporters and non–exporters. Search frictions imply that wage dispersion is combined with equilibrium unemployment, and workers with the same characteristics can be matched with firms paying different wages. Worker screening generates the noted variation in firm workforce composition despite random search.

In the closed economy, we derive a sufficient statistic for wage inequality, which determines all scale-invariant measures of wage inequality, such as the Coefficient of Variation, Gini Coefficient and Theil Index. This sufficient statistic depends on the dispersion parameters for worker ability and firm productivity as well as other product and labor market parameters that influence workforce composition. Greater dispersion of worker ability has ambiguous effects on wage inequality, because it affects both relative wages and employment levels across firms. In contrast, greater dispersion of firm productivity raises wage inequality, because more productive firms pay higher wages.

In the open economy, only the most productive firms export; firms of intermediate productivity serve only the domestic market; and the least productive firms exit without producing because they cannot cover fixed production costs. The open economy wage distribution is a mixture of the wage distributions for employees of domestic and exporting firms, with exporters paying higher wages than non-exporters. Therefore the open economy wage distribution depends on the fraction of exporters and the exporter wage premium, as well as on the sufficient statistic for wage inequality from the closed economy. Opening closed economies to trade increases wages and employment at high-productivity exporters relative to low-productivity domestic firms. As a result the opening of trade raises wage inequality for any measure of wage inequality that respects second-order stochastic dominance.

Once the economy is open to trade, the relationship between wage inequality and the fraction of exporting firms is non-monotonic. In particular, in the limiting case in which all firms export, there is the same level of wage inequality in the open and closed economies. When all firms export, a small reduction in the share of exporting firms increases wage inequality, because of the lower wages paid by domestic firms. Similarly, when no firm exports, a small increase in the share of exporting firms raises wage inequality, because of the higher wages paid by exporters.

These results for wage inequality hold for each country and for arbitrary asymmetries between countries. Our analysis is therefore consistent with empirical findings of increased wage inequality in both developed and developing countries following trade liberalization (see for example the survey by Goldberg and Pavcnik 2007). These predictions contrast with those of the Stolper-Samuelson Theorem of the Heckscher-Ohlin model, which implies rising wage inequality in developed countries and declining wage inequality in developing countries. As changes in wage inequality in our framework are driven by reallocations across firms, our analysis is also consistent with empirical evidence that the vast majority of the reallocation observed following trade liberalization takes place within rather than between industries. Finally, as wage inequality in our model arises from heterogeneity in unobserved match-specific ability, our results are also compatible with the observation that changes in the return to observed skills typically account for a relatively small share of the overall increase in wage inequality following trade liberalization (see for example Attanasio et al. 2004 and Menezes-Filho et al. 2008).

The presence of equilibrium unemployment introduces a distinction between the distribution of *income* across *all* workers and the distribution of *wages* across *employed* workers. Labor market frictions have symmetric effects on firms of all productivities, and hence do not affect the sufficient statistic for wage inequality in the closed economy, but do affect unemployment and hence income inequality. Opening closed economies to trade generally raises unemployment, because it reduces the share of matched workers that are hired, but under some conditions trade can also raise the share of job-seekers that are matched, which reduces unemployment.

Together these predictions for wage inequality and unemployment imply that the distributional consequences of trade liberalization are quite different from those in neoclassical trade theory. Workers employed by high-productivity exporting firms receive higher real wages in the open economy than in the closed economy. In contrast, workers employed by low-productivity domestic firms may receive lower or higher real wages in the open economy than in the closed economy. Finally, because unemployment is typically higher in the open economy than in the closed economy, there are more workers with the lowest real income in the open economy.

In addition to these distributional consequences for *ex post* welfare, the opening of trade also has implications for *ex ante* expected welfare. *Ex ante* workers face income risk because of unemployment and wage dispersion across firms. With incomplete insurance, the increase in unemployment and wage inequality induced by the opening of trade increases income risk. Nonetheless, as long as workers are risk neutral, expected welfare gains are ensured.

Our paper is related to recent research on firm heterogeneity in international trade building on the influential framework of Melitz (2003), including Antràs and Helpman (2004), Bernard et al. (2007), Melitz and Ottaviano (2008), and Helpman et al. (2004).[1] While this literature yields rich predictions for the product market, firms pay workers with the same characteristics the same wage irrespective of firm productivity, which sits awkwardly with a large empirical literature that finds an employer–size wage premium and rent–sharing within firms.

This study is also related to the literature on international trade and labor market frictions. One strand of this literature assumes that firm wages are related to productivity, revenue or profits because of "efficiency wage" or "fair wage" concerns, including Amiti and Davis (2008), Egger and Kreickemeier (2007, 2008) and Grossman and Helpman (2008).[2] In contrast, the relationship between firm wages and revenue in our framework is derived from worker heterogeneity and labor market frictions. As a result, our model implies quite different determinants of wage inequality and unemployment, which include the dispersion of worker ability and the other product and labor market parameters that influence workforce composition, as well as the dispersion of firm productivity.

Another strand of this literature, more closely related to our own work, examines the implications of search frictions for trade, including Davidson et al. (1988, 1999), Felbermayr et al. (2008, 2009) and Helpman and Itskhoki (2009). Our main point of departure from this literature

[1]For alternative approaches to firm heterogeneity and trade, see Bernard et al. (2003) and Yeaple (2005).

[2]A related trade literature examines efficiency wages and unemployment, including Davis and Harrigan (2007).

is the introduction of worker heterogeneity and imperfect screening of workers by firms, which generates wage inequality that is influenced by both trade liberalization and labor market frictions. While Davidson et al. (2008) also develop a model of firm and worker heterogeneity with an exporter wage premium, they assume one–to–one matching between firms and workers and only two types of firms and workers. In contrast, our framework allows for firm matching with multiple workers, endogenous determination of employment (size), and continuous distributions of firm productivity and worker ability. As a result, the opening of trade changes both employment and wages across firms of heterogeneous productivity, which changes the wage distribution and generates the non-monotonic relationship between wage inequality and trade openness.

Our paper is also related to the broader economics literature on matching. One strand of this literature is concerned with competitive assignment models, and investigates the conditions under which there is assortative matching, including Heckman and Honore (1990), Ohnsorge and Trefler (2007), Legros and Newman (2007), and Costinot and Vogel (2009). In contrast, another strand of this literature considers search frictions in the labor market, including in particular Mortensen (1970), Pissarides (1974), Diamond (1982a,b), Mortensen and Pissarides (1994) and Pissarides (2000).

Within the search literature, several approaches have been taken to explaining wage differences across workers. One influential line of research follows Burdett and Mortensen (1998) in analyzing wage dispersion in models of wage posting and random search. Another important line of research examines wage dispersion when both firms and workers are heterogeneous, including models of pure random search such as Acemoglu (1999), Shimer and Smith (2000) and Albrecht and Vroman (2002), and models incorporating on–the–job–search such as Postel–Vinay and Robin (2002), Cahuc et al. (2006) and Lentz (2008).

Our modelling of labor market frictions is related to the one–period search models of Acemoglu (1999) and Acemoglu and Shimer (1999). For example, in Acemoglu (1999), firms decide whether to invest in either high or low capacity and are then matched with either a skilled or unskilled worker. One key difference between our approach and these models is that we allow for an endogenous measure of matched workers for each firm rather than one–to–one matching between firms and workers. As a result, more productive firms expand on the extensive margin of the measure of matched workers until the marginal contribution of each worker to variable profits is equal to the common search cost. In the absence of differences in workforce composition, this extensive margin expansion generates the same wage across firms of all productivities equal to the common replacement cost of a worker.

A second key difference is that we combine search frictions with worker screening. While search frictions give rise to equilibrium unemployment, screening generates variation in workforce composition and hence wages across firms. In contrast to models with a limited number of firm and worker types, our analysis also incorporates continuous distributions of firm productivity and worker ability. Nonetheless, our framework remains sufficiently tractable that it can be used to examine the general equilibrium implications of the opening of international trade. Trade liberalization changes the measure of workers matched and screening intensities across firms of each productivity within industries, affecting wage inequality and unemployment.

The remainder of the paper is structured as follows. Section 2 outlines the model and its sectoral equilibrium. Section 3 presents our results on sectoral wage inequality, Section 4 presents our results on sectoral unemployment, and Section 5 presents our results on sectoral income inequality. Section 6 examines alternative ways of closing the model to study the feedback from general equilibrium outcomes to the sectoral equilibrium. Section 7 concludes. A web–based Appendix contains technical details, including proofs of various results.

2 Sectoral Equilibrium

The key predictions of our model relate to the distribution of wages and employment across firms and workers within sectors. As these predictions hold for any given values of expected worker income, prices in other sectors and aggregate income, we begin in this section by characterizing sectoral equilibrium for given values of these variables, before determining these variables in general equilibrium in Section 6 below. Throughout the analysis of sectoral equilibrium, all prices, revenues and costs are measured in terms of a numeraire, where the choice of numeraire is specified in the analysis of general equilibrium in Section 6.

2.1 Model Setup

We consider a world of two countries, home and foreign, where foreign variables are denoted by an asterisk. In each country there is a continuum of workers who are *ex ante* identical. Initially, we assume workers are risk neutral, but we extend the analysis to introduce risk aversion in Section 6. The supply of workers to the sector is endogenously determined by expected income. Demand within the sector is defined over the consumption of a continuum of horizontally differentiated varieties and takes the constant elasticity of substitution (CES) form. The real consumption index for the sector (Q) is therefore defined as follows:

$$Q = \left[\int_{j \in J} q(j)^{\beta} \mathrm{dj} \right]^{1/\beta}, \qquad 0 < \beta < 1, \tag{1}$$

where j indexes varieties; J is the set of varieties within the sector; $q\left(j\right)$ denotes consumption of variety j; and β controls the elasticity of substitution between varieties. To simplify notation, we suppress the sector subscript except where important, and while we display expressions for home, analogous relationships hold for foreign. The price index dual to Q is denoted by P and depends on the prices $p\left(j\right)$ of individual varieties j. Given this specification of sectoral demand, the equilibrium revenue of a firm is:

$$r(j) = p(j)q(j) = Aq(j)^{\beta}, \tag{2}$$

where A_i is a demand-shifter for sector i, which depends on the dual price index for the sector (P_i), prices in other sectors ($\mathbf{P}_{-i}$) and aggregate income (Ω).[3] The precise functional form for the demand-shifter, $A_i = \tilde{A}_i(\mathbf{P}, \Omega)$, depends on the specification of demand across sectors, as discussed further when we analyze general equilibrium below. Each firm takes the demand shifter as given when making its decisions, because it supplies one of a continuum of varieties within the sector, and is therefore of measure zero relative to the sector as a whole.

The product market is modeled in the same way as in Melitz (2003). There is a competitive fringe of potential firms who can choose to enter the differentiated sector by paying an entry cost of $f_e > 0$. Once a firm incurs the sunk entry cost, it observes its productivity θ, which is independently distributed and drawn from a Pareto distribution $G_\theta(\theta) = 1 - (\theta_{\min}/\theta)^z$ for $\theta \geq \theta_{\min} > 0$ and $z > 1$. The Pareto distribution is not only tractable, but together with our other assumptions implies a Pareto firm-size distribution, which provides a reasonable approximation to observed data (see Axtell 2001). Since in equilibrium all firms with the same productivity behave symmetrically, we index firms by θ from now onwards.

Once firms observe their productivity, they decide whether to exit, produce solely for the domestic market, or produce for both the domestic and export market. Production involves a fixed cost of $f_d > 0$ units of the numeraire. Similarly, exporting involves a fixed cost of $f_x > 0$ units of the numeraire and an iceberg variable trade cost, such that $\tau > 1$ units of a variety must be exported in order for one unit to arrive in the foreign market.

Output of each variety (y) depends on the productivity of the firm (θ), the measure of workers hired (h), and the average ability of these workers ($\bar{a}$):

$$y = \theta h^\gamma \bar{a}, \qquad 0 < \gamma < 1. \tag{3}$$

This production technology can be interpreted as capturing either human capital complementarities (e.g., production in teams where the productivity of a worker depends on the average productivity of her team) or a managerial time constraint (e.g., a manager with a fixed amount of time who needs to allocate some time to each worker). In the web-based technical appendix, we derive the production technology under each of these interpretations. A key feature of the production technology is complementarities in worker ability, where the productivity of a worker is increasing in the abilities of other workers employed by the firm.[4]

The labor market features heterogeneity in worker ability and search and matching frictions.

[3] We use bold typeface to denote vectors, so that $\mathbf{P}_{-i}$ is a vector of all price indexes P_j other than i and $\mathbf{P}$ is a vector of all price indexes. As is well known, the demand function for a variety j in sector i can be expressed as:

$$q_i(j) = A_i^{\frac{1}{1-\beta}} p_i(j)^{-\frac{1}{1-\beta}}, \text{ where } A_i = \left(E_i / \int_{j \in J} p_i(j)^{-\frac{\beta}{1-\beta}} \mathrm{dj} \right)^{1-\beta},$$

and E_i is total expenditure on varieties within the sector, which depends on aggregate income (Ω), the price index for the sector (P_i) and prices for all other sectors ($\mathbf{P}_{-i}$).

[4] The existence of these production complementarities is the subject of a long line of research in economics, including Lucas (1978), Rosen (1982), and Garicano (2000). For empirical evidence see for example Moretti (2004).

Worker ability is assumed to be match-specific, independently distributed and drawn from a Pareto distribution, $G_a(a) = 1 - (a_{\min}/a)^k$ for $a \geq a_{\min} > 0$ and $k > 1$. Since worker ability is match-specific and independently distributed, a worker's ability draw for a given match conveys no information about ability draws for other potential matches. Search and matching frictions are modeled following the standard Diamond-Mortensen-Pissarides approach. A firm that pays a *search cost* of bn units of the numeraire can randomly match with a measure of n workers, where the search cost b is endogenously determined by the tightness of the labor market as discussed below.

Consistent with a large empirical literature in labor economics, we assume that match-specific worker ability cannot be costlessly observed when firms and workers are matched.[5] Instead, we assume that firms can undertake costly investments in worker screening to obtain an imprecise signal of worker ability, which is in line with a recent empirical literature on firm screening and other recruitment policies.[6] To capture the idea of an imprecise signal in as tractable a way as possible, we assume that by paying a *screening cost* of ca_c^δ/δ units of the numeraire, where $c > 0$ and $\delta > 0$, a firm can identify workers with an ability below a_c.[7] Screening costs are increasing in the ability threshold a_c chosen by the firm, because more complex and costlier tests are required for higher ability cutoffs.[8]

This specification of worker screening is influenced by empirical evidence that more productive firms not only employ more workers but also screen more intensively, have workforces of higher average ability and pay higher wages. Each of these features emerges naturally from our specification of production and screening, as demonstrated below, because production complementarities imply a greater return to screening for more productive firms and the costs of screening are the same for all firms. Our formulation also ensures that the multilateral bargaining game between firms and workers over the surplus from production remains tractable. As the only information revealed by screening is which workers have match-specific abilities above and below a_c, neither the firm nor the workers know the match-specific abilities of individual workers, and hence bargaining occurs under conditions of symmetric information.

2.2 Firm's Problem

The complementarities between workers' abilities in the production technology provide the incentive for firms to screen workers. By screening and not employing workers with abilities less

[5] For example, Altonji and Pierret (2003) find that as employers learn about worker productivity the wage equation coefficients on easily observed characteristics, such as education, fall relative to the coefficients on hard-to-observe correlates of worker productivity.

[6] For empirical evidence on the resources devoted by firms to the screening of job applicants, see for example Barron et al. (1985), Barron et al. (1987), Pellizari (2005), and Autor and Scarborough (2007).

[7] In this formulation, there is a fixed cost of screening, even when the screening is not informative, i.e., when $a_c = a_{\min}$. We focus on interior equilibria in which firms of all productivities choose screening tests that are informative, $a_c > a_{\min}$, and so the fixed cost of screening is always incurred. As we show below, this is the case when the screening cost, c, is sufficiently small.

[8] There are therefore increasing returns to scale in screening. All results generalize immediately to the case where the screening costs are separable in a_c and n and linear in n.

than a_c, a firm reduces output (and hence revenue and profits) by decreasing the measure of workers hired (h), but raises output by increasing average worker ability ($\bar{a}$). Since there are diminishing returns to the number of workers hired ($0 < \gamma < 1$), output can be increased by screening as long as there is sufficient dispersion in worker ability (sufficiently low k).[9] With a Pareto distribution of worker ability, a firm that chooses a screening threshold a_c hires a measure $h = n\left(a_{\min}/a_c\right)^k$ of workers with average ability $\bar{a} = ka_c/(k-1)$. Therefore the production technology can be re-written as follows:

$$y = \kappa_y \theta n^{\gamma} a_c^{1-\gamma k}, \qquad \kappa_y \equiv \frac{k}{k-1} a_{\min}^{\gamma k}, \tag{4}$$

where we require $0 < \gamma k < 1$ for a firm to have an incentive to screen.[10]

Given consumer love of variety and a fixed production cost, no firm will ever serve the export market without also serving the domestic market. If a firm exports, it allocates its output ($y(\theta)$) between the domestic and export markets ($y_d(\theta)$ and $y_x(\theta)$, respectively) to equate its marginal revenues in the two markets, which from (2) implies $\left[y_d(\theta)/y_x(\theta)\right]^{\beta-1} = \tau^{-\beta}\left(A^*/A\right)$. Therefore a firm's total revenue can be expressed as follows:

$$r(\theta) \equiv r_d(\theta) + r_x(\theta) = \Upsilon(\theta)^{1-\beta} A y(\theta)^{\beta}, \tag{5}$$

where $r_d(\theta) \equiv A y_d(\theta)^{\beta}$ is revenue from domestic sales and $r_x(\theta) \equiv A^*\left[y_x(\theta)/\tau\right]^{\beta}$ is revenue from exporting. The variable $\Upsilon(\theta)$ captures a firm's "market access," which depends on whether it chooses to serve both the domestic and foreign markets or only the domestic market:

$$\Upsilon(\theta) \equiv 1 + I_x(\theta)\,\tau^{-\frac{\beta}{1-\beta}}\left(\frac{A^*}{A}\right)^{\frac{1}{1-\beta}}, \tag{6}$$

where $I_x(\theta)$ is an indicator variable that equals one if the firm exports and zero otherwise.[11]

After having observed its productivity, a firm chooses whether or not to produce, whether or not to export, the measure of workers to sample, and the screening ability threshold (and hence the measure of workers to hire). Once these decisions have been made, the firm and its hired workers engage in strategic bargaining with equal weights over the division of revenue from production in the manner proposed by Stole and Zwiebel (1996a,b). The only information known by firms and workers at the bargaining stage is that each hired worker has an ability greater than a_c. Therefore, the expected ability of each worker is $\bar{a} = k/(k-1)\,a_c$, and each

[9] Since production complementarities provide the incentive for firms to screen, the marginal product of workers with abilities below a_c is negative, as shown in the web-based technical appendix. While worker screening is a key feature of firms' recruitment policies, and production complementarities provide a tractable explanation for it, other explanations are also possible, such as fixed costs of maintaining an employment relationship (e.g. in terms of office space or other scarce resources).

[10] In contrast, when $\gamma > 1/k$, no firm screens and the model reduces to the model of Helpman and Itskhoki (2009), which has no screening or worker heterogeneity. We do not discuss this case here.

[11] Note that $\left[y_d(\theta)/y_x(\theta)\right]^{\beta-1} = \tau^{-\beta}\left(A^*/A\right)$ and $y_d(\theta) + y_x(\theta) = y(\theta)$ imply $y_d(\theta) = y(\theta)/\Upsilon(\theta)$ and $y_x(\theta) = y(\theta)\left[\Upsilon(\theta) - 1\right]/\Upsilon(\theta)$, and hence $r_d(\theta) = r(\theta)/\Upsilon(\theta)$ and $r_x(\theta) = r(\theta)\left[\Upsilon(\theta) - 1\right]/\Upsilon(\theta)$.

worker is treated as if they have an ability of $\bar{a}$. Combining (3) and (5), firm revenue can be written as $r = \Upsilon(\theta)^{1-\beta} A(\theta\bar{a})^{\beta} h^{\beta\gamma}$, which is continuous, increasing and concave in h. As the fixed production, fixed exporting, search and screening costs have all been sunk before the bargaining stage, all other arguments of firm revenue are fixed. Furthermore, the outside option of hired workers is unemployment, whose value we normalize to zero. Therefore, the solution to the bargaining game is that the firm receives the fraction $1/(1+\beta\gamma)$ of revenue (5), while each worker receives the fraction $\beta\gamma/(1+\beta\gamma)$ of average revenue per worker.[12]

Anticipating the outcome of the bargaining game, the firm maximizes its profits. Combining (4), (5), and (6) this profit maximization problem can be written as:

$$\pi(\theta) \equiv \max_{\substack{n\geq 0,\\ a_c \geq a_{\min},\\ I_x \in \{0,1\}}} \left\{ \frac{1}{1+\beta\gamma} \left[1 + I_x \tau^{-\frac{\beta}{1-\beta}} \left(\frac{A^*}{A} \right)^{\frac{1}{1-\beta}} \right]^{1-\beta} A \left(\kappa_y \theta n^{\gamma} a_c^{1-\gamma k} \right)^{\beta} - bn - \frac{c}{\delta} a_c^{\delta} - f_d - I_x f_x \right\}, \quad (7)$$

where I_x is the export status indicator, which equals 1 when the firm exports and 0 otherwise.

The firm's decision whether or not to produce and whether or not to export takes a standard form. The presence of a fixed production cost implies that there is a zero-profit cutoff for productivity, θ_d, such that a firm drawing a productivity below θ_d exits without producing. Similarly, the presence of a fixed exporting cost implies that there is an exporting cutoff for productivity, θ_x, such that a firm drawing a productivity below θ_x does not find it profitable to serve the export market. Given that a large empirical literature finds evidence of selection into export markets, where only the most productive firms export, we focus on values of trade costs for which $\theta_x > \theta_d > \theta_{\min}$.[13] The firm market access variable is therefore determined as follows:

$$\Upsilon(\theta) = \begin{cases} 1, & \theta < \theta_x, \\ \Upsilon_x, & \theta \geq \theta_x, \end{cases} \qquad \Upsilon_x \equiv 1 + \tau^{-\frac{\beta}{1-\beta}} \left(\frac{A^*}{A} \right)^{\frac{1}{1-\beta}} > 1. \quad (8)$$

The firm's first-order conditions for the measure of workers sampled (n) and the screening ability threshold (a_c) are:

$$\frac{\beta\gamma}{1+\beta\gamma} r(\theta) = bn(\theta),$$
$$\frac{\beta(1-\gamma k)}{1+\beta\gamma} r(\theta) = c a_c(\theta)^{\delta}.$$

These conditions imply that firms with larger revenue sample more workers and screen to a higher ability threshold. While the measure of workers hired, $h = n\left(a_{\min}/a_c\right)^k$, is increasing in the measure of workers sampled, n, it is decreasing in the screening ability threshold, a_c. Under

[12] See Acemoglu, Antràs and Helpman (2007) and the web-based technical appendix for the derivation of the solution to the bargaining game.

[13] For empirical evidence of selection into export markets, see for example Bernard and Jensen (1995) and Roberts and Tybout (1997).

the assumption $\delta > k$, firms with larger revenue not only sample more workers but also hire more workers. Finally, from the division of revenue in the bargaining game, the total wage bill is a constant share of revenue, which implies that firm wages are monotonically increasing in the screening ability cutoff:

$$w(\theta) = \frac{\beta\gamma}{1+\beta\gamma}\frac{r(\theta)}{h(\theta)} = b\frac{n(\theta)}{h(\theta)} = b\left[\frac{a_c(\theta)}{a_{\min}}\right]^k. \tag{9}$$

Thus, firms with larger revenue have higher screening ability cutoffs and pay higher wages, but the expected wage conditional on being sampled is the same across all firms:

$$\frac{w(\theta)h(\theta)}{n(\theta)} = b,$$

which implies that workers have no incentive to direct their search.[14] Combining the measure of workers hired, $h = n\left(a_{\min}/a_c\right)^k$, with the first-order conditions above yields the following relationship between firm wages and the measure of workers hired:

$$\ln w(\theta) = \text{constant} + \frac{k}{\delta - k}\ln h(\theta).$$

Therefore, under the assumption $\delta > k$, the model exhibits an employer-size wage premium, where firms that employ more workers pay higher wages.

Using the firms' first-order conditions, firm revenue (5) and the production technology (4), we can solve explicitly for firm revenue as a function of firm productivity (θ), the demand shifter (A), the search cost (b) and parameters:

$$r(\theta) = \kappa_r\left[c^{-\frac{\beta(1-\gamma k)}{\delta}} b^{-\beta\gamma}\Upsilon(\theta)^{(1-\beta)}A\theta^{\beta}\right]^{1/\Gamma}, \tag{10}$$

where $\Gamma \equiv 1 - \beta\gamma - \beta(1-\gamma k)/\delta > 0$, and the constant κ_r is defined in the web-based technical appendix. An implication of this expression is that the relative revenue of any two firms depends solely on their relative productivities and relative market access: $r(\theta') = \left(\theta'/\theta''\right)^{\beta/\Gamma}\left(\Upsilon(\theta')/\Upsilon(\theta'')\right)^{\beta/\Gamma} r(\theta'')$.

Finally, using the two first-order conditions in the firm's problem (7), firm profits can be expressed solely in terms of firm revenue and the fixed production and exporting costs:

$$\pi(\theta) = \frac{\Gamma}{1+\beta\gamma}r(\theta) - f_d - I_x(\theta) f_x. \tag{11}$$

[14] We note that search frictions and wage bargaining alone are not enough to generate wage variation across firms in our model. From the firm's first-order condition for the number of workers sampled, each firm equates workers' share of revenue per sampled worker to the common search cost. In the special case of our model without worker heterogeneity and screening, all sampled workers are hired, which implies that each firm's wage is equal to the common search cost. Moreover, directed search, which is sometimes used to generate wage dispersion—as in Moen (1997) and Mortensen and Wright (2002)—will not do so here, because workers receive the same expected wage conditional on being matched irrespective of firm productivity.

2.3 Sectoral Variables

To determine sectoral equilibrium, we use the recursive structure of the model. In a first bloc of equations, we solve for the tightness of the labor market (x, x^*) and search costs (b, b^*) in each country. In a second bloc of equations, we solve for the zero-profit productivity cutoffs (θ_d, θ_d^*), the exporting productivity cutoffs (θ_x, θ_x^*), and sectoral demand shifters (A, A^*). A third and final bloc of equations determines the remaining components of sectoral equilibrium: the dual price index (P, P^*), the real consumption index (Q, Q^*), the mass of firms (M, M^*), and the size of the labor force (L, L^*). As discussed above, we solve for sectoral equilibrium for given values of expected income in the sector (ω, ω^*), prices in other sectors ($\mathbf{P}_{-i}$, $\mathbf{P}_{-i}^*$) and aggregate incomes (Ω, Ω^*), which are determined in general equilibrium below.

2.3.1 Labor Market Tightness and Hiring Costs

Following the standard Diamond-Mortensen-Pissarides search model, the search cost (b) is assumed to be increasing in labor market tightness (x):

$$b = \alpha_0 x^{\alpha_1}, \qquad \alpha_0 > 1, \qquad \alpha_1 > 0, \tag{12}$$

where labor market tightness equals the ratio of workers sampled (N) to workers searching for employment in the sector (L): $x = N/L$.[15] Under the assumption of risk neutrality, the supply of workers searching for employment in the sector depends on expected worker income, which equals the probability of being sampled (x) times the expected wage conditional on being sampled ($w(\theta)\, h(\theta)\, /n(\theta) = b$ from the analysis above):

$$\omega = xb, \tag{13}$$

where we discuss in Section 6 how this condition is modified under the assumption of risk aversion. Together (12) and (13) determine the search cost and labor market tightness (b, x) for a given value of expected income (ω):

$$b = \alpha_0^{\frac{1}{1+\alpha_1}} \omega^{\frac{\alpha_1}{1+\alpha_1}} \qquad \text{and} \qquad x = \left(\frac{\omega}{\alpha_0}\right)^{\frac{1}{1+\alpha_1}}, \tag{14}$$

where we assume $\alpha_0 > \omega$ so that $0 < x < 1$, as discussed in Section 6 below. Analogous relationships determine search costs and labor market tightness (b^*, x^*) for a given value of expected income (ω^*) in foreign. The search cost in (14) depends solely on parameters of the search technology (α_0, α_1) and expected income (ω). In particular, we have

[15] As shown by Blanchard and Gali (2008) and in the web-based technical appendix, this relationship can be derived from a constant returns to scale Cobb-Douglas matching function and a cost of posting vacancies. The parameter α_0 is increasing in the cost of posting vacancies and decreasing in the productivity of the matching technology, while α_1 depends on the weight of vacancies in the Cobb-Douglas matching function. Other static models of search and matching include Acemoglu (1999) and Acemoglu and Shimer (1999).

Lemma 1 *The search cost b and the measure of labor market tightness x are both increasing in expected worker income ω.*

Proof. The lemma follows immediately from equation (14). ■

When we characterize general equilibrium in Section 6 below, we specify conditions under which expected income (ω) is constant and those under which it changes with other endogenous variables. While we treat ω as given in solving for sectoral equilibrium, our results for sectoral inequality and unemployment continue to hold when it responds in general equilibrium to other endogenous variables, except where otherwise discussed.

2.3.2 Productivity Cutoffs and Demand

The two productivity cutoffs can be determined using firm revenue (10) and profits (11). The productivity cutoff below which firms exit (θ_d) is determined by the requirement that a firm with this productivity makes zero profits:

$$\frac{\Gamma}{1+\beta\gamma}\kappa_r\left[c^{-\frac{\beta(1-\gamma k)}{\delta}}b^{-\beta\gamma}A\theta_d^{\beta}\right]^{1/\Gamma}=f_d. \tag{15}$$

Similarly, the exporting productivity cutoff above which firms export (θ_x) is determined by the requirement that at this productivity a firm is indifferent between serving only the domestic market and serving both the domestic and foreign markets:

$$\frac{\Gamma}{1+\beta\gamma}\kappa_r\left[c^{-\frac{\beta(1-\gamma k)}{\delta}}b^{-\beta\gamma}A\theta_x^{\beta}\right]^{1/\Gamma}\left[\Upsilon_x^{(1-\beta)/\Gamma}-1\right]=f_x. \tag{16}$$

These two conditions imply the following relationship between the productivity cutoffs:

$$\left[\Upsilon_x^{(1-\beta)/\Gamma}-1\right]\left(\frac{\theta_x}{\theta_d}\right)^{\beta/\Gamma}=\frac{f_x}{f_d}. \tag{17}$$

In equilibrium, we also require the free entry condition to hold, which equates the expected value of entry to the sunk entry cost. Using the zero profit and exporting cutoff conditions, (15) and (16) respectively, and the relationship between variety revenues for firms with different productivities, the free entry condition can be written as:

$$f_d\int_{\theta_d}^{\infty}\left[\left(\frac{\theta}{\theta_d}\right)^{\beta/\Gamma}-1\right]\mathrm{d}G_\theta+f_x\int_{\theta_x}^{\infty}\left[\left(\frac{\theta}{\theta_x}\right)^{\beta/\Gamma}-1\right]\mathrm{d}G_\theta=f_e. \tag{18}$$

Equations (15), (16) and (18) can be used to solve for home's productivity cutoffs and the demand shifter (θ_d, θ_x, A) for a given value of the foreign demand shifter (A^*), which only influences home sectoral equilibrium through exporter market access ($\Upsilon_x > 1$).[16] Three analogous equations can

[16] In a symmetric equilibrium $A = A^*$ and $\Upsilon_x = 1 + \tau^{\frac{-\beta}{1-\beta}}$, which implies that the ratio of the two productivity cutoffs is pinned down by (17) alone.

be used to solve for foreign variables (θ_d^*, θ_x^*, A^*) for a given value of A. Together these six equations allow us to solve for the productivity cutoffs and demand shifters in the two countries (θ_d, θ_x, A, θ_d^*, θ_x^*, A^*) for given values of search costs (b, b^*), which were determined in the previous bloc of equations. Having solved for the productivity cutoffs and demand shifters, firm market access in each country ($\Upsilon(\theta)$, $\Upsilon^*(\theta)$) follows immediately from (6).

The productivity cutoffs and demand shifter depend on two dimensions of trade openness in (15), (16) and (18). First, both depend on an extensive margin of trade openness, as captured by the ratio of the productivity cutoffs $\rho \equiv \theta_d/\theta_x \in [0,1]$, which determines the fraction of exporting firms $[1 - G_\theta(\theta_x)] / [1 - G_\theta(\theta_d)] = \rho^z$. Second, both depend on an intensive margin of trade openness, as captured by the market access variable, $\Upsilon_x > 1$, which determines the ratio of revenues from domestic sales and exporting, as discussed in footnote 11. These two dimensions of trade openness are linked through the relationship between the productivity cutoffs (17).

2.3.3 Expenditure, Mass of Firms and the Labor Force

Having solved for the demand shifter for sector i (A_i), the price index for that sector (P_i) can be determined from consumer optimization given prices in all other sectors ($\mathbf{P}_{-i}$) and aggregate income (Ω):

$$A_i = \tilde{A}_i(\mathbf{P}, \Omega). \tag{19}$$

Having solved for the demand shifter (A) and the price index (P) for the sector (we now drop the sectoral subscript i), the real consumption index (Q) follows from consumer optimization, which from (2) implies:

$$Q = (A/P)^{\frac{1}{1-\beta}}, \tag{20}$$

and yields total expenditure within the sector $E = PQ$. Similar relationships determine the foreign price index, real consumption index and total expenditure (P^*, Q^*, E^*).

The mass of firms within the sector (M) can be determined from the market clearing condition that total domestic expenditure on differentiated varieties equals the sum of the revenues of domestic and foreign firms that supply varieties to the domestic market:

$$E = M \int_{\theta_d}^{\infty} r_d(\theta) \, \mathrm{d}G_\theta(\theta) + M^* \int_{\theta_x^*}^{\infty} r_x^*(\theta) \, \mathrm{d}G_\theta(\theta). \tag{21}$$

From $r_d(\theta) = r(\theta)/\Upsilon(\theta)$, $r_x(\theta) = r(\theta)(\Upsilon(\theta) - 1)/\Upsilon(\theta)$,[17] and total firm revenue (10), domestic and foreign revenue can be expressed in terms of variables that have already been determined (θ_d, θ_x, $\Upsilon(\theta)$). Therefore we can solve for the mass of firms in each country (M, M^*) from (21) and a similar equation for foreign.

The mass of workers searching for employment in the sector (L) can be determined by noting that total labor payments are a constant fraction of total revenue from the solution to

[17] See footnote 11.

the bargaining game:

$$\omega L = M \int_{\theta_d}^{\infty} w(\theta) h(\theta) \mathrm{d}G_\theta(\theta) = M \frac{\beta\gamma}{1+\beta\gamma} \int_{\theta_d}^{\infty} r(\theta) \mathrm{d}G_\theta(\theta), \tag{22}$$

where we have solved for the mass of firms (M) and total firm revenue ($r(\theta)$) above, and where a similar equation determines the sectoral labor force in foreign (L^*). Finally, we also require that the sectoral labor force is less than or equal to the supply of labor ($L \le \bar{L}$), as discussed in Section 6 below. This completes our characterization of sectoral equilibrium.

2.4 Firm-specific Variables

Having characterized sectoral equilibrium, we can solve for all firm-specific variables using the following two properties of the model. First, from firm revenue (10), the relative revenue of any two firms depends solely on their relative productivities and relative market access. Second, from firm profits (10), the lowest productivity firm with productivity θ_d makes zero profits. Combining these two properties with the firm's first-order conditions above, all firm-specific variables can be written as functions of firm productivity (θ), firm market access ($\Upsilon(\theta)$), the zero-profit productivity cutoff (θ_d), search costs (b) and parameters:

$$\left.\begin{array}{ll} r(\theta) = \Upsilon(\theta)^{\frac{1-\beta}{\Gamma}} \cdot r_d \cdot \left(\frac{\theta}{\theta_d}\right)^{\frac{\beta}{\Gamma}}, & r_d \equiv \frac{1+\beta\gamma}{\Gamma} f_d, \\ n(\theta) = \Upsilon(\theta)^{\frac{1-\beta}{\Gamma}} \cdot n_d \cdot \left(\frac{\theta}{\theta_d}\right)^{\frac{\beta}{\Gamma}}, & n_d \equiv \frac{\beta\gamma}{\Gamma} \frac{f_d}{b}, \\ a_c(\theta) = \Upsilon(\theta)^{\frac{1-\beta}{\delta\Gamma}} \cdot a_d \cdot \left(\frac{\theta}{\theta_d}\right)^{\frac{\beta}{\delta\Gamma}}, & a_d \equiv \left[\frac{\beta(1-\gamma k)}{\Gamma} \frac{f_d}{c}\right]^{1/\delta}, \\ h(\theta) = \Upsilon(\theta)^{\frac{1-\beta}{\Gamma}(1-k/\delta)} \cdot h_d \cdot \left(\frac{\theta}{\theta_d}\right)^{\frac{\beta(1-k/\delta)}{\Gamma}}, & h_d \equiv \frac{\beta\gamma}{\Gamma} \frac{f_d}{b} \left[\frac{\beta(1-\gamma k)}{\Gamma} \frac{f_d}{c a_{\min}^{\delta}}\right]^{-k/\delta}, \\ w(\theta) = \Upsilon(\theta)^{\frac{k(1-\beta)}{\delta\Gamma}} \cdot w_d \cdot \left(\frac{\theta}{\theta_d}\right)^{\frac{\beta k}{\delta\Gamma}}, & w_d \equiv b \left[\frac{\beta(1-\gamma k)}{\Gamma} \frac{f_d}{c a_{\min}^{\delta}}\right]^{k/\delta}, \end{array}\right\} \tag{23}$$

where market access ($\Upsilon(\theta)$) is determined as a function of firm productivity in (8). Note that firm-specific variables only depend on sectoral and general equilibrium through the zero-profit cutoff productivity (θ_d), firm market access ($\Upsilon(\theta)$) and hence the exporting cutoff productivity (θ_x), and search costs (b).

The solutions for firm-specific variables (23) capture a number of key features of the heterogeneity observed across firms within sectors. More productive firms not only have higher revenue, profits and employment, as in the benchmark model of firm heterogeneity of Melitz (2003), but also pay higher wages as shown in Figure 1. These results are consistent with empirical evidence of rent-sharing whereby higher firm revenue and profits are shared with workers through higher wages (e.g., Van Reenen, 1996) and with the large empirical literature that finds an employer size-wage premium (see the survey by Oi and Idson, 1999).[18]

[18] Combining the solutions for firm revenue and employment in (23) with the Pareto productivity distribution, firm revenue and employment are also Pareto distributed, with shape parameters that depend on the dispersion of firm productivity, the dispersion of worker ability, and product and labor market parameters that influence

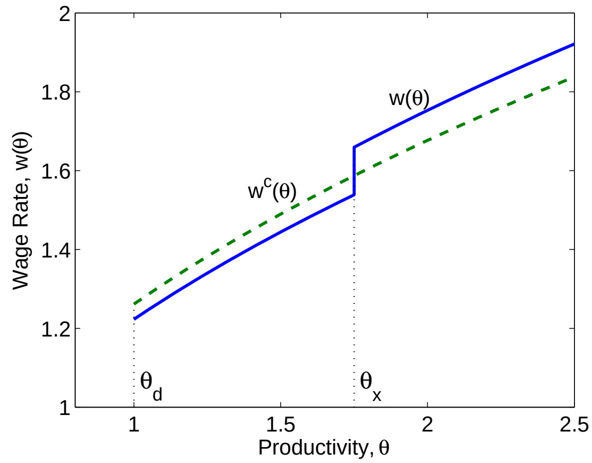

Figure 1: Wages as a function of firm productivity

Additionally, the differences in wages across firms are driven by differences in workforce composition. More productive firms have workforces of higher average ability, which are more costly to replace in the bargaining game, and therefore pay higher wages. These features of the model are consistent with findings from matched employer-employee datasets that the employer-size wage premium is largely explained by the positive correlation between employment and a firm's average worker fixed effect.[19] The reason more productive firms have workforces of higher average ability in the model is that they screen more intensively, which also receives empirical support. An emerging literature on firm recruitment policies provides evidence of more intensive screening policies for larger firms and higher-wage matches.[20]

In our framework, workers with the same observed and unobserved characteristics receive different wages depending on the firm with which they are matched. While this feature of the model is consistent with recent empirical findings of residual wage inequality (see for example Autor et al. 2008, Lemieux 2006 and Mortensen 2003), competitive models without labor market frictions can generate residual wage inequality if there are worker characteristics observed by the firm but not by the econometrician. While the firm surely observes additional worker characteristics, several features of the data suggest that this is not the only explanation for residual wage inequality. In competitive frictionless models, arbitrage typically eliminates differences in wages across firms for workers with the same characteristics. Yet the empirical literature using matched employer-employee datasets finds that firm fixed effects make a substantial contribution towards wage variation after controlling for time-varying worker characteristics and worker fixed effects (see for example Abowd et al. 1999 and Abowd et al. 2002).[21] The contribution

workforce composition. See Helpman et al. (2008a) for further discussion.

[19] See Figure 3 in Abowd et al. (1999) and the discussion in Abowd and Kramarz (1999).

[20] For example, Barron, Black and Loewenstein (1987) find that expenditures on screening workers are positively and significantly related to employer size, while Pellizari (2005) finds that matches created through more intensive screening pay higher wages.

[21] While competitive frictionless models with production complementarities induce strong assortative matching

of the firm fixed effects arises naturally in our framework from labor market frictions.[22] We do not however wish to overstate this point, as characteristics observed by the firm but not by the econometrician could be more important empirically as a source of residual wage inequality.

Finally, our solutions for firm-specific variables are also consistent with findings from the recent empirical literature on exports and firm performance. As a result of fixed costs of exporting, there is a discrete jump in firm revenue at the productivity threshold for entry into exporting (θ_x), where $\Upsilon(\theta)$ jumps from 1 to $\Upsilon_x > 1$, which implies a discrete jump in all other firm variables. Therefore, exporters not only have higher revenue and employment than non-exporters, as in the benchmark model of firm heterogeneity of Melitz (2003), but also pay higher wages, as found empirically by Bernard and Jensen (1995, 1997) and many subsequent studies. These differences in wages between exporters and non-exporters are accompanied by differences in workforce composition, which as discussed above is consistent with recent empirical findings using matched employer-employee datasets (see for example Kaplan and Verhoogen 2006, Schank, Schnabel and Wagner 2007, and Munch and Skaksen 2008).

3 Sectoral Wage Inequality

While workers are *ex ante* identical and have the same expected income, there is *ex post* wage inequality because workers receive different wages depending on the employer with whom they are matched. In this section, we consider the within-sector distribution of wages across employed workers. This sectoral wage distribution is a weighted average of the distributions of wages for workers employed by domestic firms, $G_{w,d}(w)$, and for workers employed by exporters, $G_{w,x}(w)$, with weights equal to the shares of employment in the two groups of firms.

$$G_w(w) = \begin{cases} S_{h,d} G_{w,d}(w) & \text{for} \quad w_d \leq w \leq w_d / \rho^{\frac{\beta k}{\delta \Gamma}}, \\ S_{h,d} & \text{for} \quad w_d / \rho^{\frac{\beta k}{\delta \Gamma}} \leq w \leq w_d \Upsilon_x^{\frac{k(1-\beta)}{\delta \Gamma}} / \rho^{\frac{\beta k}{\delta \Gamma}}, \\ S_{h,d} + (1 - S_{h,d}) G_{w,x}(w) & \text{for} \quad w \geq w_d \Upsilon_x^{\frac{k(1-\beta)}{\delta \Gamma}} / \rho^{\frac{\beta k}{\delta \Gamma}}, \end{cases} \tag{24}$$

where ρ and Υ_x are the extensive and intensive margins of trade openness defined above; $w_d = w(\theta_d)$ is the wage paid by the least productive firm in (23); $w_d/\rho^{k\beta/\delta\Gamma} = w(\theta_x^-)$ is the wage paid by the most productive non-exporter; and $w_d \Upsilon_x^{k(1-\beta)/\delta\Gamma} / \rho^{k\beta/\delta\Gamma} = w(\theta_x^+)$ is the wage paid by the

between firms and workers, the empirical literature using matched employer-employee datasets finds a weak and sometimes negative correlation between firm and worker fixed effects (see for example Abowd et al. 2002). In a recent paper, de Melo (2008) shows that this negative correlation can occur even with assortative matching if firms' outside options are negatively correlated with their productivity. Therefore, de Melo (2008) examines the correlation between a worker's fixed effect and the average fixed effects of their coworkers, which he finds to be positive, significant and around one third. Combining search and screening frictions generates this positive but imperfect correlation. When screening costs are infinite, there is a zero correlation between coworker abilities, because of random search. In contrast, for finite screening costs, the more intensive screening of more productive firms induces a positive correlation between coworker abilities, which becomes stronger for lower screening costs.

[22] In our model, expected wages vary with both firm productivity and a worker's match-specific ability draw. As more productive firms screen to higher ability thresholds, only workers with ability draws above those thresholds receive the higher wages paid by more productive firms. It follows that both the average wage and wage dispersion are increasing in a worker's match-specific ability draw, as discussed in Helpman et al. (2008a).

least productive exporter. Note that w_d depends on general equilibrium variables only through search costs (b). The share of workers employed by domestic firms, $S_{h,d}$, can be evaluated using the Pareto productivity distribution and the solution for firm-specific variables (23) as:

$$S_{h,d} = \frac{1-\rho^{z-\frac{\beta(1-k/\delta)}{\Gamma}}}{1+\rho^{z-\frac{\beta(1-k/\delta)}{\Gamma}}\left[\Upsilon_x^{\frac{(1-\beta)(1-k/\delta)}{\Gamma}}-1\right]}.$$

The distributions of wages across workers employed by domestic and exporting firms can also be derived from the solutions for firm-specific variables (23). Given that productivity is Pareto distributed and both wages and employment are power functions of productivity, the distribution of wages across workers employed by domestic firms is a truncated Pareto distribution:

$$G_{w,d}(w) = \frac{1-\left(\frac{w_d}{w}\right)^{1+1/\mu}}{1-\rho^{z-\frac{\beta(1-k/\delta)}{\Gamma}}} \qquad \text{for } w_d \leq w \leq w_d/\rho^{\frac{k\beta}{\delta\Gamma}}. \tag{25}$$

Similarly, the distribution of wages across workers employed by exporters, $G_{w,x}(w)$, is an untruncated Pareto distribution:

$$G_{w,x}(w) = 1-\left[\frac{w_d}{w}\Upsilon_x^{\frac{k(1-\beta)}{\delta\Gamma}}\rho^{-\frac{k\beta}{\delta\Gamma}}\right]^{1+1/\mu} \qquad \text{for } w \geq w_d\Upsilon_x^{\frac{k(1-\beta)}{\delta\Gamma}}/\rho^{\frac{k\beta}{\delta\Gamma}}. \tag{26}$$

The wage distributions for workers employed by domestic firms and exporters have the same shape parameter, $1+1/\mu$, where μ is defined as:

$$\mu \equiv \frac{\beta k/\delta}{z\Gamma-\beta}, \quad \text{where } \Gamma \equiv 1-\beta\gamma-\frac{\beta}{\delta}(1-\gamma k). \tag{27}$$

For the mean and variance of the sectoral wage distribution to be finite, we require $0<\mu<1$ and hence $z\Gamma > 2\beta$, which is satisfied for sufficiently large z (a sufficiently skewed firm productivity distribution).[23]

3.1 Sectoral Wage Inequality in the Closed Economy

The closed economy wage distribution can be obtained by taking the limit $\rho \to 0$ in the open economy wage distribution (24). In the closed economy, the share of employment in domestic firms is equal to one, and the sectoral wage distribution across workers employed by domestic firms is an untruncated Pareto distribution with lower limit w_d and shape parameter $1+1/\mu$. Given an untruncated Pareto distribution, all scale-invariant measures of inequality, such as the Coefficient of Variation, the Gini Coefficient and the Theil Index, depend solely on the distribution's shape parameter. None of these measures depends on the lower limit of the

[23]While we concentrate on the wage distribution, as this is typically the subject of the economic debate over the impact of trade liberalization, the income distribution could also be influenced by profits. As discussed in footnote 18, the model can be also used to determine the distribution of revenue (and hence profits) across firms.

support of the wage distribution (w_d), and they therefore do not depend on search costs (b) or expected worker income (ω). While these variables affect the mean of the wage distribution, they do not affect its dispersion. An important implication of this result is that the model's predictions for wage inequality are robust to alternative ways of closing the model in general equilibrium to determine expected income (ω).

Proposition 1 *In the closed economy, μ is a sufficient statistic for sectoral wage inequality. In particular: (i) The Coefficient of Variation of wages is $\mu/\sqrt{1-\mu^2}$; (ii) The Lorenz Curve is represented by $s_w = 1 - (1 - s_h)^{1/(1+\mu)}$, where s_h is the fraction of workers and s_w is the fraction of their wages when workers are ordered from low to high wage earners; (iii) The Gini Coefficient is $\mu/(2+\mu)$; and (iv) The Theil Index is $\mu - \ln(1+\mu)$.*

Proof. See the web-based technical appendix. ■

Evidently, sectoral wage inequality is monotonically increasing in μ (the lower the shape parameter of the wage distribution $1 + 1/\mu$, the greater wage inequality). Using this result, we can analyze the relationship between sectoral wage inequality and the dispersion of firm productivity and worker ability.

Proposition 2 *In the closed economy, inequality in the sectoral distribution of wages is increasing in firm productivity dispersion (lower z), and increasing in worker ability dispersion (lower k) if and only if $z^{-1} + \delta^{-1} + \gamma > \beta^{-1}$.*

Proof. The proof follows immediately from Proposition 1 and the definition of μ. ■

Since more productive firms pay higher wages, greater dispersion in firm productivity (lower z) implies greater sectoral wage inequality. In contrast, greater dispersion in worker ability (lower k) has an ambiguous effect on sectoral wage inequality because of two counteracting forces. On the one hand, a reduction in k increases relative employment in more productive firms (from (23)) that pay higher wages, which increases wage inequality. On the other hand, a reduction in k decreases relative wages paid by more productive firms (from (23)), which reduces wage inequality. When the parameter inequality in the proposition is satisfied, the change in relative employment dominates the change in relative wages, and greater dispersion in worker ability implies greater sectoral wage inequality. Additionally, the sectoral wage distribution depends on the other product and labor market parameters that influence workforce composition. These include the concavity of revenue (β) and production (γ), and the convexity of screening costs (δ), as can be seen from the definition of μ in (27).

The model's prediction that sectoral wage inequality is closely linked to the dispersion of firm productivity receives strong empirical support. In particular, Davis and Haltiwanger (1991) show that wage dispersion across plants within sectors accounts for a large share of overall wage dispersion, and is responsible for more than one third of the growth in overall wage dispersion in U.S. manufacturing between 1975 and 1986. Additionally, they find that between-plant wage dispersion is strongly related to between-plant size dispersion, which in our model is driven by productivity dispersion. Similarly, Faggio, Salvanes and Van Reenen (2007) show that a substantial component of the increase in individual wage inequality in the United Kingdom in recent decades has occurred between firms within sectors and is linked to increased productivity dispersion between firms within sectors.

While greater firm productivity dispersion (associated for example with innovations such as Information and Communication Technologies (ICTs)) is one potential source of increased wage inequality in the model, another potential source is international trade as considered in the next section. Indeed, both greater firm productivity dispersion and international trade raise wage inequality through the same mechanism of greater dispersion in firm revenue and wages within industries, and both raise measured productivity at the industry level through reallocations of resources across firms.

3.2 Open Versus Closed Economy

The sectoral wage distribution in the open economy depends on the sufficient statistic for wage inequality in the closed economy (μ) and the extensive and intensive measures of trade openness (ρ and Υ_x, respectively). In the two limiting cases of $\rho = 0$ (no firm exports) and $\rho = 1$ (all firms export), the open economy wage distribution is an untruncated Pareto with shape parameter $1+1/\mu$. From Proposition 1, all scale-invariant measures of inequality for an untruncated Pareto distribution depend solely on the distribution's shape parameter. Therefore there is the same level of wage inequality in the open economy when all firms export as in the closed economy.

To characterize sectoral wage inequality in the open economy when $0 < \rho < 1$ (only some firms export), we compare the actual open economy wage distribution ($G_w(w)$) to a counterfactual wage distribution ($G_w^c(w)$). For the counterfactual wage distribution, we choose an untruncated Pareto distribution with the same shape parameter as the wage distribution in the closed economy ($1 + 1/\mu$) but the same mean as the wage distribution in the open economy. An important feature of this counterfactual wage distribution is that it has the same level of inequality as the closed economy wage distribution. Therefore, if we show that there is more inequality with the open economy wage distribution than with the counterfactual wage distribution, this will imply that there is more wage inequality in the open economy than in the closed economy.

The counterfactual wage distribution has two other important properties, as shown formally in the web-based technical appendix. First, the lowest wage in the counterfactual wage distribution (w_d^c) lies strictly in between the lowest wage paid by domestic firms (w_d) and the lowest wage paid by exporters ($w\left(\theta_x^+\right)$) in the actual open economy wage distribution. Otherwise, the counterfactual wage distribution would have a mean either lower or higher than the actual open economy wage distribution, which contradicts the requirement that the two distributions have the same mean. Second, the counterfactual wage distribution has a smaller slope than the actual wage distribution at $w\left(\theta_x^+\right)$. Otherwise, the counterfactual wage distribution would have

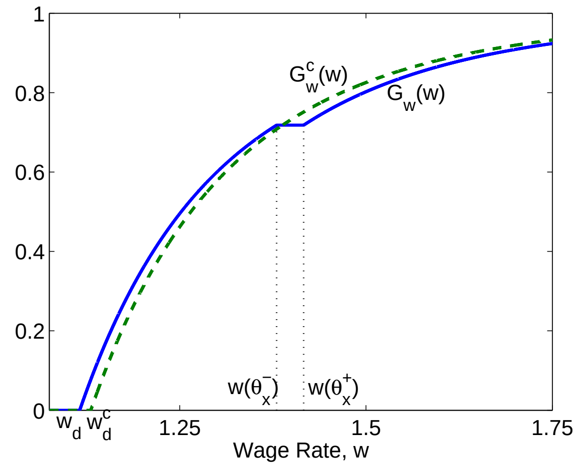

Figure 2: Cumulative distribution function of wages

a greater density than the actual wage distribution for $w \geq w\left(\theta_x^+\right)$, and would therefore have a higher mean than the actual wage distribution.

Together, these two properties imply that the relative location of the cumulative distribution functions for actual and counterfactual wages is as shown in Figure 2.[24] The actual and counterfactual cumulative distributions intersect only once and the actual distribution lies above the counterfactual distribution for low wages and below it for high wages.[25] This pattern provides a sufficient condition for the counterfactual wage distribution to second-order stochastically dominate the wage distribution in the open economy. Therefore, for all measures of inequality that respect second-order stochastic dominance, the open economy wage distribution exhibits greater inequality than the counterfactual wage distribution. It follows that the wage distribution in the open economy exhibits more inequality than the wage distribution in the closed economy. This result holds independently of whether the opening of trade affects expected worker income (ω), because ω affects the lower limit of the actual open economy wage distribution (and hence the lower limit of the counterfactual wage distribution), but does not affect the comparison of levels of inequality between the two distributions.

Proposition 3 *(i) Sectoral wage inequality in the open economy when some but not all firms export is strictly greater than in the closed economy; and (ii) Sectoral wage inequality in the open economy when all firms export is the same as in the closed economy.*

Proof. The proof follows from the discussion above, as shown formally in the web-based technical appendix. ■

[24] In order to generate Figures 1-3, we set the parameters of the model to match some of the salient features of the data. For details see Helpman, Redding and Itskhoki (2008b).

[25] Note that the actual and counterfactual distributions can intersect either above the wage at the most productive non-exporter, $w\left(\theta_x^-\right)$, as shown in Figure 2, or below it. In both cases, the actual and counterfactual distributions have the properties discussed in the text.

Proposition 3 holds for asymmetric countries and irrespective of which of the model's parameters are the source of the asymmetry across countries. While for simplicity we focus on the case of two countries, extending the analysis to a world of many countries is straightforward. The proposition identifies an alternative mechanism for trade to influence wage inequality from the Stolper-Samuelson Theorem of traditional trade theory. While the Stolper-Samuelson theorem emphasizes reallocations of resources across sectors that change the relative rewards of skilled and unskilled workers, the changes in wage inequality in Proposition 3 arise from changes in wages and employment across firms within sectors. This prediction that the opening of trade can increase wage inequality for asymmetric countries, the emphasis on reallocation across firms within sectors, and the focus on residual wage inequality find support in the recent empirical literature on trade and wage inequality reviewed in Goldberg and Pavcnik (2007).

While the opening of closed economies to trade raises wage inequality, it also increases average wages conditional on being employed (in terms of the numeraire). Under the conditions discussed in Section 6, expected worker income (ω) is constant in general equilibrium, and hence so are search costs (b) and the lower limit of the wage distribution (w_d). As a result, the discrete increase in wages at the productivity threshold for exporting implies that the open economy wage distribution first-order stochastically dominates the closed economy wage distribution, as can be seen from (24). To the extent that expected worker income (ω) is increased by the opening of trade, as discussed in Section 6, this raises the lower limit of the open economy wage distribution (w_d) and further reinforces the first-order stochastic dominance result.

Since sectoral wage inequality when all firms export is the same as in the closed economy, but sectoral wage inequality when only some firms export is higher than in the closed economy, the relationship between sectoral wage inequality and the fraction of exporters is non-monotonic. An increase in the share of firms that export can either raise or reduce sectoral wage inequality depending on the initial share of firms that export (ρ^z), which in turn depends on the relative productivity cutoffs (ρ). As $\rho \to 0$, no firm exports, and a small increase in the share of firms that export raises sectoral wage inequality, because of the higher wages paid by exporters. As $\rho \to 1$, all firms export, and a small reduction in the share of firms that export increases sectoral wage inequality, because of the lower wages paid by domestic firms. Therefore the model points to the initial level of trade openness as a relevant control in examining the empirical relationship between wage inequality and trade openness.

While fixed and variable trade costs (f_x and τ, respectively) both influence sectoral wage inequality, they do so through slightly different mechanisms, because they have different effects on the extensive and intensive margins of trade openness (ρ and Υ_x, respectively). This can be seen most clearly for symmetric countries, where the intensive margin depends on variable trade costs alone ($\Upsilon_x = 1 + \tau^{\frac{-\beta}{1-\beta}}$), and changes in the fixed costs of exporting affect only the extensive margin (ρ). More generally, for asymmetric countries, the intensive margin depends on variable trade costs and relative sectoral demand levels ($\Upsilon_x = 1 + \tau^{\frac{-\beta}{1-\beta}} \left(\frac{A^*}{A}\right)^{\frac{1}{1-\beta}}$), and fixed and variable trade costs affect both margins of trade openness.

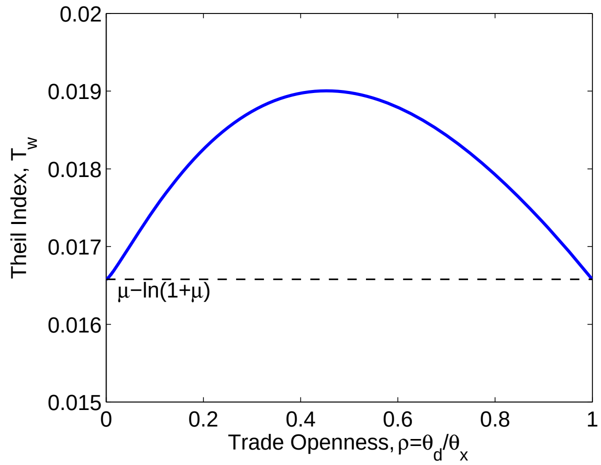

Figure 3: Theil index of sectoral wage inequality

To illustrate the non-monotonic relationship between sectoral wage inequality and trade openness, Figure 3 graphs the variation in the Theil Index of wage inequality with symmetric countries as we vary the fixed costs of exporting (f_x) and hence the extensive margin of trade openness (ρ). Similar non-monotonic relationships are observed as we vary variable trade costs (τ) and for other measures of wage inequality such as the Gini Coefficient.

4 Sectoral Unemployment

The presence of labor market frictions generates equilibrium unemployment. Workers can be unemployed either because they are not matched with a firm or because their match-specific ability draw is below the screening threshold of the firm with which they are matched. Therefore the sectoral unemployment rate u can be expressed as one minus the product of the hiring rate σ and the tightness of the labor market x:

$$u = \frac{L - H}{L} = 1 - \frac{H}{N}\frac{N}{L} = 1 - \sigma x, \tag{28}$$

where $\sigma \equiv H/N$, H is the measure of hired workers, N is the measure of matched workers, and L is the measure of workers seeking employment in the sector.

The sectoral tightness of the labor market (x) in (14) depends on the search friction parameter (α_0) and expected worker income (ω). Therefore the tightness of the labor market is not directly affected by trade openness and is only indirectly affected in so far as trade openness influences ω. While in this section we examine the comparative statics of unemployment for a given value of ω, in Section 6 we determine its value in general equilibrium. As part of that analysis, we provide conditions under which ω is unaffected by trade openness, and examine how the comparative statics of unemployment change when it responds to trade openness.

In contrast, the sectoral hiring rate (σ) depends directly on trade openness, which influences firm revenues and hence screening ability thresholds. Using the Pareto productivity distribution, the sectoral hiring rate can be expressed as a function of the extensive and intensive margins of trade openness (ρ and Υ_x respectively), the sufficient statistic for wage inequality (μ), and other parameters, as shown in the web-based technical appendix:

$$\sigma = \varphi(\rho, \Upsilon_x) \cdot \frac{1}{1+\mu} \cdot \left[\frac{\Gamma}{\beta(1-\gamma k)} \frac{c a_{\min}^{\delta}}{f_d} \right]^{k/\delta}, \tag{29}$$

where the term in square parentheses is the hiring rate of the least productive firm (h_d/n_d) and:

$$\varphi(\rho, \Upsilon_x) \equiv \frac{1 + \left[\Upsilon_x^{\frac{(1-\beta)(1-k/\delta)}{\Gamma}} - 1 \right] \rho^{z-\beta(1-k/\delta)/\Gamma}}{1 + \left[\Upsilon_x^{\frac{(1-\beta)}{\Gamma}} - 1 \right] \rho^{z-\beta/\Gamma}}.$$

Evidently, we have $\varphi(0, \Upsilon_x) = 1$ and $0 < \varphi(\rho, \Upsilon_x) < 1$ for $0 < \rho \leq 1$, since $\Upsilon_x > 1$ and $\delta > k$.

4.1 Sectoral Unemployment in the Closed Economy

The closed economy hiring rate can be obtained by taking the limit $\rho \to 0$ in (29); it depends solely on model parameters for a given value of expected worker income (ω). The hiring rate depends on the screening cost (c) but not on the search friction parameter (α_0), and it depends on both the dispersion of firm productivity (z) and the dispersion of worker ability (k). Combining the closed economy hiring rate (σ) from (29) with labor market tightness (x) from (14), we can examine the determinants of the sectoral unemployment rate (u). This yields

Proposition 4 *Let ω be constant. Then the closed economy sectoral unemployment rate u is increasing in the search friction α_0, decreasing in the screening cost c, increasing in the dispersion of firm productivity (lower z), and can be either increasing or decreasing in the dispersion of worker ability (lower k).*

Proof. The proof follows immediately from equations, (14), (27), (28) and (29). ■

It is clear from this proposition that search and screening costs have quite different effects on sectoral unemployment. As the search cost (b) rises in response to a rise in α_0, the sectoral tightness of the labor market (x) falls, which increases the sectoral unemployment rate. In contrast, as the screening cost (c) increases, firms screen less intensively, which increases the sectoral hiring rate (σ), and thereby reduces the sectoral unemployment rate.

It is also clear that dispersion of firm productivity has a different effect on sectoral unemployment from the dispersion of worker ability. Since more productive firms screen more intensively, an increase in the dispersion of firm productivity (lower z) reduces the sectoral hiring rate (σ), which increases sectoral unemployment. In contrast, an increase in the dispersion of worker ability (lower k) has an ambiguous effect on the sectoral hiring rate (σ) and hence on the sectoral unemployment rate. On the one hand, more dispersion in worker ability increases the probability of being hired conditional on being sampled ($[a_{\min}/a_c(\theta)]^k$) for a given screening threshold ($a_c(\theta) > a_{\min}$), which reduces sectoral unemployment. On the other hand, more dispersion in worker ability induces firms to screen more intensively (lower k raises $a_c(\theta)$ from (23)), which increases sectoral unemployment.[26] Like sectoral wage inequality, the sectoral unemployment rate also depends on other product and labor market parameters that influence workforce composition (β, γ and δ, which enter Γ and μ).

4.2 Open Versus Closed Economy

For a given value of expected worker income (ω), the opening of trade only affects the sectoral unemployment rate (u) through the hiring rate (σ). Furthermore, the open economy hiring rate (29) equals the closed economy hiring rate times the fraction $\varphi(\rho, \Upsilon_x)$, which depends on both the extensive and intensive margins of trade openness. This fraction is strictly less than one in an equilibrium where some firms export ($0 < \rho \leq 1$), and hence the sectoral hiring rate (σ) is strictly lower in the open economy than in the closed economy. We therefore have

Proposition 5 *Let ω be invariant to trade. Then the sectoral unemployment rate u is strictly higher in the open economy than in the closed economy.*

Proof. The proof follows immediately from equation (29). ■

The opening of trade results in an expansion in the revenue of exporters and a contraction in the revenue of non-exporters, which changes industry composition towards more productive firms that screen more intensively, and thereby increases sectoral unemployment. While the sectoral unemployment rate is higher in the open economy than in the closed economy, once the economy is open to trade, the relationship between sectoral unemployment and trade openness (like the relationship between sectoral wage inequality and trade openness) can be non-monotonic. In particular, the sectoral unemployment rate can be either monotonically decreasing in trade openness, or it can exhibit an inverted U-shape, where sectoral unemployment is initially increasing in trade openness before decreasing in trade openness, as discussed further in Helpman et al. (2008b).

As our analysis in this section considers the case where ω is invariant to trade, it focuses solely on changes in unemployment due to changes in firms' screening policies (σ). In our analysis of general equilibrium in Section 6 below, we show that the opening of trade can also affect ω and have offsetting effects on unemployment through labor market tightness (x).

[26] There is an additional compositional effect of greater dispersion in worker ability. From (23), lower k increases $n(\theta)$ for all firms, but has a larger effect for more productive firms. Since more productive firms screen more intensively, this change in sectoral composition increases sectoral unemployment.

5 Sectoral Income Inequality

The sectoral distribution of income depends on both the sectoral distribution of wages and the unemployment rate, where unemployed workers all receive the same income of zero. Since there is greater wage inequality and a higher unemployment rate in the open economy than in the closed economy, it follows that there is also greater income inequality. As shown in the web-based technical appendix, the Theil Index of income inequality ($\mathcal{T}_\iota$) can be expressed as the following function of the Theil Index of wage inequality ($\mathcal{T}_w$) and the unemployment rate (u),

$$\mathcal{T}_\iota = \mathcal{T}_w - \ln(1-u). \tag{30}$$

A similar result holds for the Gini Coefficient of income inequality ($\mathcal{G}_\iota$), which can be expressed in terms of the Gini Coefficient of wage inequality ($\mathcal{G}_w$) and the unemployment rate:[27]

$$\mathcal{G}_\iota = (1-u)\,\mathcal{G}_w + u. \tag{31}$$

5.1 Sectoral Income Inequality in the Closed Economy

The comparative statics for sectoral income inequality in the closed economy follow from those for sectoral wage inequality and unemployment above.

Proposition 6 *Let ω be constant. In the closed economy sectoral income inequality, as measured by either the Theil Index or the Gini Coefficient, is increasing in the search friction α_0, decreasing in the screening cost c, increasing in the dispersion of firm productivity (lower z), and can be either increasing or decreasing in the dispersion of worker ability (lower k).*

Proof. The proposition follows immediately from Propositions 2 and 4 and the expressions for the Theil Index (30) and Gini Coefficient (31). ■

While a rise in the search friction α_0 (which raises the search cost b) or a reduction in the screening cost (c) leaves sectoral wage inequality unchanged, it raises sectoral unemployment and hence increases sectoral income inequality. On the other hand, a rise in the dispersion of firm productivity (lower z) increases sectoral income inequality through both higher wage inequality and higher unemployment. In contrast, a rise in the dispersion of worker ability (lower k) has an ambiguous effect on sectoral wage inequality, unemployment and income inequality. Furthermore, greater dispersion of worker ability can raise sectoral wage inequality while at the same time reducing sectoral income inequality (and vice versa) as shown in Helpman et al. (2008a), so that conclusions based on wage inequality can be misleading if the ultimate concern is income inequality.

[27] The Theil Index of inequality allows an exact decomposition of overall inequality into within and between-group inequality (Bourguignon 1979), where the groups are here employed and unemployed workers. In general, the Gini Coefficient does not allow such a decomposition, but in the present case all unemployed workers receive the same income of zero, which is strictly less than the lowest income of an employed worker. Therefore, a similar decomposition can be undertaken for the Gini Coefficient, as shown in the web-based technical appendix.

5.2 Open Versus Closed Economy

The effect of the opening of trade on sectoral income inequality also follows from its effects on sectoral wage inequality and unemployment above.

Proposition 7 *Let ω be invariant to trade. Then sectoral income inequality, as measured by the Theil Index or the Gini Coefficient, is higher in the open economy than in the closed economy.*

Proof. The proposition follows immediately from Propositions 3 and 5 and the expressions for the Theil Index (30) and Gini Coefficient (31). ■

The opening of trade raises sectoral income inequality through two channels. First, the partitioning of firms by productivity into exporters and non-exporters, and the discrete increase in wages at exporters relative to non-exporters, raises sectoral wage inequality. Second, the reallocation of employment towards more productive firms that screen more intensively reduces the hiring rate and increases sectoral unemployment.

While sectoral income inequality in the open economy is higher than in the closed economy, once the economy is open to trade, sectoral income inequality (like wage inequality and unemployment) has a non-monotonic relationship with trade openness. Therefore a further increase in trade openness can either increase or decrease sectoral income inequality depending on the initial level of trade openness.

6 General Equilibrium

Up to this point, we have analyzed sectoral equilibrium in the closed and open economy, taking as given expected worker income (ω), prices in other sectors ($\mathbf{P}_{-i}$) and aggregate income (Ω). In this section, we examine the determination of these variables in general equilibrium and the relationship between them.

We begin by assuming that workers are risk neutral and consider two alternative ways of closing the model in general equilibrium. First, we introduce an outside good, which is homogeneous and produced without search frictions. This approach is particularly tractable, as with risk neutrality expected income in the differentiated sector is pinned down by the wage in the outside sector when both goods are produced. Therefore expected worker income is invariant to the opening of trade in equilibria where both goods are produced.[28] Second, we consider a single differentiated sector and solve for endogenous expected worker income. While endogenizing expected worker income complicates the determination of general equilibrium, all of our results for sectoral wage inequality are unchanged, and we obtain a new general equilibrium effect for unemployment, since labor market tightness responds endogenously to the opening of trade.

[28] While we assume no search frictions in the outside sector, Helpman and Itskhoki (2009) show in a model without worker heterogeneity or screening that introducing search frictions in the outside sector generates an expected income ω_0 that is independent of features of the differentiated sector. Augmenting the model here to incorporate search frictions in the outside sector would generate a similar result.

Closing the model in general equilibrium also enables us to examine the effect of the opening of trade on workers' *ex ante* expected and *ex post* welfare. In the first two sub-sections, we characterize these effects under risk neutrality. In a final sub-section, we introduce risk aversion, which enables us to address the issue of globalization and income risk. We show that risk aversion introduces a new general equilibrium effect, which works against the expected welfare gains from the increase in average productivity induced by the opening of trade.

Individual workers in the differentiated sector experience idiosyncratic income risk as a result of the positive probability of unemployment and wage dispersion. In each of the alternative ways of closing the model, we assume that preferences are defined over an aggregate consumption index ($\mathcal{C}$) and exhibit Constant Relative Risk Aversion (CRRA):

$$\mathbb{U} = \frac{\mathbb{E}\mathcal{C}^{1-\eta}}{1-\eta}, \qquad 0 \leq \eta < 1,$$

where $\mathbb{E}$ is the expectations operator. Expected indirect utility is therefore:

$$\mathbb{V} = \frac{1}{1-\eta}\mathbb{E}\left(\frac{w}{\mathcal{P}}\right)^{1-\eta}, \tag{32}$$

where $\mathcal{P}$ is the price index of the aggregate consumption measure $\mathcal{C}$.

6.1 Outside Sector and Risk Neutrality

We begin closing the model using an outside sector under the assumption of risk neutrality ($\eta = 0$). The aggregate consumption index ($\mathcal{C}$) is defined over consumption of a homogeneous outside good (q_0) and a real consumption index of differentiated varieties (Q):

$$\mathcal{C} = \left[\vartheta^{1-\zeta} q_0^{\zeta} + (1-\vartheta)^{1-\zeta} Q^{\zeta}\right]^{1/\zeta}, \qquad 0 < \zeta < \beta,$$

where Q is modelled as in Section 2 above, and ϑ determines the relative weight of the homogeneous and differentiated sectors in consumer preferences.[29] While for simplicity we consider a single differentiated sector, the analysis generalizes in a straightforward way to the case of multiple differentiated sectors.

In the homogeneous sector, the product market is perfectly competitive and there are no labor market frictions. In this sector, one unit of labor is required to produce one unit of output and there are no trade costs. Therefore, as we choose the homogeneous good as the numeraire ($p_0 = 1$), the wage in this sector is equal to one in both countries.

To determine expected worker income in the differentiated sector, we use an indifference condition between sectors analogous to that in Harris and Todaro (1970), which equates the expected utility of entering each sector in an equilibrium where both goods are produced. Un-

[29] While in the analysis here we assume that workers have CRRA-CES preferences and experience income risk, Helpman et al. (2008a,b) consider an alternative specification with quasi-linear preferences and income insurance within families.

der risk neutrality, this Harris-Todaro condition implies that expected worker income in the differentiated sector equals the certain wage of one in the homogeneous sector (see (13)):

$$xb = \omega = 1, \tag{33}$$

where incomplete specialization can be ensured by appropriate choice of labor endowments ($\bar{L}$, $\bar{L}^*$) and relative preferences for the homogeneous and differentiated goods (ϑ). Positive unemployment occurs in the differentiated sector for a sufficiently large search friction α_0, such that $\alpha_0 > \omega = 1$ and hence $0 < x < 1$ in (14).

Given a certain wage of one in the outside sector and a positive probability of unemployment in the differentiated sector, worker indifference across sectors requires the average wage in the differentiated sector to be strictly greater than one. As a result, in this first specification of the model, there is a positive relationship across sectors between the unemployment rate and the average wage.[30] In contrast, in the second specification of the model with a single differentiated sector considered below, expected worker income is endogenous. Therefore, changes in parameters can induce either a positive or negative relationship between changes in the unemployment rate and average wage within the differentiated sector, because expected worker income (one minus the unemployment rate times the average wage) is no longer constant.

Given an expected income of one in each sector, each country's aggregate income is equal to its labor endowment:

$$\Omega = \bar{L}. \tag{34}$$

To determine the price index in the differentiated sector (P), we use the functional relationship (19) introduced above, which with CES preferences between the homogeneous and differentiated sector takes the following form:

$$A^{\frac{1}{1-\beta}} = \frac{(1-\vartheta)\, P^{\frac{\beta-\zeta}{(1-\beta)(1-\zeta)}}\, \Omega}{\vartheta + (1-\vartheta)\, P^{\frac{-\zeta}{1-\zeta}}}, \tag{35}$$

where the right-hand side is monotonically increasing in P. Therefore this relationship uniquely pins down P given the demand shifter (A) and aggregate income (Ω).

To determine general equilibrium, we use the conditions for sectoral equilibrium in Section 2 above (where (35) replaces (19)), and combine them with the Harris-Todaro condition (33) and aggregate income (34). Together these relationships determine the equilibrium vector (x, b, θ_d, θ_x, A, Q, P, M, L, ω, Ω). Having determined this equilibrium vector, the price index $\mathcal{P}$—dual to the aggregate consumption index $\mathcal{C}$—and consumption of the homogeneous good q_0 follow from CES demand. Finally, equilibrium employment in the homogeneous sector follows from labor market clearing ($L_0 = \bar{L} - L$, where incomplete specialization requires $L < \bar{L}$).

[30] This feature follows from our assumption that worker ability is match-specific and hence unknown prior to entering a sector. Extending the model to allow for additional worker characteristics that are known prior to entering a sector would affect this result if workers with different known characteristics sort non-randomly across sectors and differ in terms of their unemployment rate and average wage.

Having characterized general equilibrium, we are now in a position to examine the impact of the opening of trade on *ex ante* expected and *ex post* welfare. To characterize the impact on *ex ante* welfare, note that differentiated sector workers receive the same expected indirect utility as workers in the homogenous sector when both goods are produced:

$$\mathbb{V} = \frac{1}{\mathcal{P}} \quad \text{for } \eta = 0. \tag{36}$$

Therefore the change in expected welfare as a result of the opening of trade depends solely on the change in the aggregate price index ($\mathcal{P}$), which with our choice of numeraire depends solely on the change in the price index for the differentiated sector (P). These comparative statics are straightforward to determine. From the free entry condition (18), the opening of trade raises the zero-profit productivity cutoff (θ_d). Using the Harris-Todaro condition (33) and labor market tightness (14), search costs (b) remain constant as long as both goods are produced, because expected worker income equals one. Therefore, from the zero-profit cutoff condition (15), the rise in θ_d implies a lower value of the demand shifter (A). Given constant aggregate income (Ω) and a lower value of A, CES demand (35) implies that the opening of trade reduces the price index for the differentiated sector (P), which implies higher expected welfare in the open than in the closed economy.

While *ex ante* welfare is the same for all workers, the opening of trade has distributional consequences for *ex post* welfare. In the homogeneous sector, there is no uncertainty, and *ex post* and *ex ante* welfare are the same. In contrast, in the differentiated sector, the opening of trade raises the zero-profit productivity cutoff (θ_d) and induces selection into export markets ($\theta_x > \theta_d$), which from the solutions for firm-specific variables (23) implies higher wages in exporting firms and lower wages in domestic firms (in terms of the numeraire). Additionally, there is a higher unemployment rate in the differentiated sector in the open economy than in the closed economy, since expected worker income (ω) is invariant to the opening of trade as long as both goods are produced. To the extent that there are workers who are unemployed in the open economy, but would be employed in the closed economy, these workers experience lower income in the open economy than in the closed economy. Using these results for the incomes of employees of exporters, employees of domestic firms and the unemployed, as well as the lower aggregate price index in the open economy established above, we can compare welfare in the open and closed economies as follows:

Proposition 8 *Let $\eta = 0$. Then (i) Every worker's ex ante welfare is higher in the open economy than in the closed economy; (ii) A homogeneous sector worker's ex post welfare is higher in the open economy than in the closed economy; (iii) In the differentiated sector: (a) The ex post welfare of a worker employed by an exporting firm with productivity θ is higher in the open economy than in the closed economy; (b) The ex post welfare of workers who are unemployed in the open economy, but who would be employed in the closed economy, is lower than in the closed economy; (c) The ex post welfare of a worker employed by a domestic non-*

exporting firm with productivity θ can be either higher or lower in the open economy than in the closed economy.

Proof. The proposition follows from the indirect utility function, the free entry condition (18), the zero-profit cutoff condition (15), and CES demand (35), as shown in the web-based technical appendix. ■

As there is no unemployment or income inequality in the outside sector, aggregate unemployment and income inequality depend on the differentiated sector's share of the labor force as well as unemployment and income inequality within this sector. As a result, the opening of trade has additional compositional effects on aggregate unemployment (as discussed in Helpman and Itskhoki 2009) and aggregate income inequality (as discussed in Helpman et al. 2008a,b).

6.2 Single Differentiated Sector and Risk Neutrality

We next consider a single differentiated sector under the assumption of risk neutrality ($\eta = 0$). The aggregate consumption index ($\mathcal{C}$) is defined over consumption of a continuum of horizontally differentiated varieties:

$$\mathcal{C} = Q,$$

where Q again takes the same form as in Section 2 above. While for simplicity we again assume a single differentiated sector, the analysis generalizes in a straightforward way to the case of multiple differentiated sectors.

General equilibrium can be determined in the same way as sectoral equilibrium in Section 2, while also solving for expected worker income (ω) and aggregate income (Ω). We choose the dual price index (P) in one country as the numeraire, and assume for simplicity throughout this sub-section that countries are symmetric, which implies $P = P^* = 1$. Having normalized P, the differentiated sector's real consumption index (Q) follows immediately from the demand shifter (A) in (20): $Q = A^{1/(1-\beta)}$. To determine expected worker income (ω), we combine the zero-profit cutoff condition (15), the search technology (12) and expected worker income (13), which together yield the following upward-sloping relationship between Q and ω:

$$Q = \left(\frac{f_d}{\kappa_r} \frac{1+\beta\gamma}{\Gamma} \right)^{\frac{\Gamma}{1-\beta}} c^{\frac{\beta(1-\gamma k)}{(1-\beta)\delta}} \alpha_0^{\frac{\beta\gamma}{(1-\beta)(1+\alpha_1)}} \theta_d^{-\frac{\beta}{1-\beta}} \omega^{\frac{\beta\gamma}{1-\beta}\frac{\alpha_1}{1+\alpha_1}}. \tag{37}$$

A second upward-sloping relationship between Q and ω is provided by equilibrium labor payments (22), which with country symmetry can be written as:

$$\omega = \frac{1}{\bar{L}} \frac{\beta\gamma}{1+\beta\gamma} Q, \tag{38}$$

where we have used labor market clearing: $L = \bar{L}$.

Having determined the zero-profit productivity cutoff (θ_d) from the first bloc of equations (15), (16) and (18), the two equations (37) and (38) can be solved in closed form for Q and

ω. Having solved for ω, aggregate income is given by $\Omega = \omega \bar{L}$, and all remaining endogenous variables of the model can be solved for in closed form, as shown in the web-based technical appendix.[31]

Under the assumption of risk neutrality, and noting $P = P^* = 1$, *ex ante* expected welfare equals expected income (ω), which is now endogenous and responds to the opening of trade. We are therefore in a position to determine the comparative statics of opening closed economies to trade.

Proposition 9 *Let $\eta = 0$. Then in the one-sector economy the opening of trade: (i) Increases expected worker income (ω) and hence expected welfare; (ii) Increases labor market tightness (x) and search costs (b).*

Proof. See the web-based technical appendix for the formal derivation of these results. ■

The predictions of the model without the outside sector are similar to those of the model with the outside sector. The opening of trade increases *ex ante* expected welfare and has distributional consequences for *ex post* welfare depending on whether workers are employed or unemployed and depending on whether they are employed by exporters or domestic firms. One new general equilibrium effect is that the increase in average productivity in the differentiated sector following the opening of trade increases expected worker income (ω), which in turn increases the tightness of the labor market (x), and hence raises equilibrium search costs (b).

The model's predictions for sectoral wage inequality do not depend on expected worker income (ω) and search costs (b), and are therefore the same with or without the outside sector. In contrast, the endogenous determination of expected worker income (ω) opens up a new channel for trade to affect sectoral unemployment (28). As shown in Section 2, the opening of closed economies to trade raises sectoral unemployment for a given value of expected worker income (ω), because it reduces the hiring rate (σ). In the model without the outside sector, the opening of trade now also increases expected worker income (ω). This "income effect" reduces sectoral unemployment through increased labor market tightness (x). Depending on parameter values, this increase in labor market tightness can dominate the reduction in the hiring rate, so that sectoral unemployment can fall rather than rise following the opening of trade. Finally, in the model with a single differentiated sector, there are no changes in sectoral composition, so that our results for sectoral inequality and unemployment extend immediately to aggregate inequality and unemployment.

6.3 Outside Sector and Risk Aversion

To introduce risk aversion ($0 < \eta < 1$), we return to the model with the outside sector, where we can explore the implications of uncertainty for the allocation of resources between the riskless

[31] As discussed in the web-based technical appendix, the stability of the equilibrium requires $\frac{\beta\gamma}{1-\beta}\frac{\alpha_1}{1+\alpha_1} > 1$, which is satisfied for sufficiently convex search costs (sufficiently high α_1) and sufficiently high elasticities of substitution between varieties (β sufficiently close to but less than one).

homogeneous sector and risky differentiated sector.[32] Introducing risk aversion changes the equilibrium share of revenue received by workers in the bargaining game, but does not affect any of the comparative statics of sectoral equilibrium considered above.[33] General equilibrium can be determined in the same way as in Section 6.1, but with appropriate modifications for risk aversion to the Harris-Todaro condition (33) and aggregate income (34).

Under the assumption of risk aversion, the Harris-Todaro condition equates expected utility in the differentiated sector to the certain wage of one in the homogeneous sector, and therefore takes the following form:

$$x\sigma\mathbb{E}w^{1-\eta} = x\sigma\int_{w_d}^{\infty} w^{1-\eta}dG_w(w) = 1, \tag{39}$$

where expected utility in the differentiated sector equals the probability of being matched (x) times the probability of being hired conditional on being matched (σ) times expected utility conditional on being hired.[34] This condition can be expressed as:

$$\Lambda(\rho,\Upsilon_x)\frac{b^{1-\eta}x}{\phi_w^{\eta}(1+\mu\eta)} = 1, \tag{40}$$

where ϕ_w is a derived parameter defined in the web-based technical appendix and:

$$\Lambda(\rho,\Upsilon_x) \equiv \frac{1+\rho^{z-\frac{\beta(1-\eta k/\delta)}{\Gamma}}\left[\Upsilon_x^{\frac{(1-\beta)(1-\eta k/\delta)}{\Gamma}}-1\right]}{1+\rho^{z-\frac{\beta}{\Gamma}}\left[\Upsilon_x^{\frac{(1-\beta)}{\Gamma}}-1\right]}.$$

Evidently, we have $\Lambda(0,\Upsilon_x) = 1$ and $0 < \Lambda(\rho,\Upsilon_x) < 1$ for $0 < \rho \leq 1$, since $\Upsilon_x > 1$, $\delta > k$ and $0 < \eta < 1$.

There is income risk in the differentiated sector, because of unemployment and wage inequality, which imply that risk averse workers require a risk premium to enter this sector. To determine expected worker income in the differentiated sector ($\omega = xb$), we combine (40) with (12) to obtain:

$$\omega = (\alpha_0)^{\frac{\eta}{1+(1-\eta)\alpha_1}}\left[(1+\mu\eta)\phi_w^{\eta}\right]^{\frac{\alpha_1+1}{1+(1-\eta)\alpha_1}}\Lambda(\rho,\Upsilon_x)^{-\frac{1+\alpha_1}{1+(1-\eta)\alpha_1}}, \tag{41}$$

where a sufficiently large search friction (α_0) ensures positive unemployment ($0 < x < 1$ in (14)) and a positive risk premium in the differentiated sector ($\omega - 1 > 0$). Aggregate income is the

[32] Introducing risk aversion in the model with a single differentiated sector has little effect, because there is no riskless activity to or from which resources can move.

[33] In the web-based technical appendix, we derive the solution to the Stole and Zwiebel (1996a,b) bargaining game when workers are risk averse. We show that with CRRA-CES preferences the solution takes a similar form as when there are differences in bargaining weight between the firm and its workers.

[34] The terms in the price index ($\mathcal{P}$) and $1/(1-\eta)$ cancel from the Harris-Todaro condition equating expected indirect uility (32) in the two sectors.

sum of worker income in the homogeneous sector and the differentiated sector:

$$\Omega = \bar{L} + (\omega - 1) L. \tag{42}$$

As shown in the analysis of sectoral equilibrium in Sections 2–4 above, the opening of trade increases sectoral wage inequality and unemployment for a given value of ω. This increase in wage inequality and unemployment enhances income risk in the differentiated sector, which implies that risk averse workers require a higher risk premium to enter the differentiated sector. This "risk effect" raises expected worker income (ω) following the opening of trade (since $\Lambda(0, \Upsilon_x) = 1$ and $0 < \Lambda(\rho, \Upsilon_x) < 1$ for $0 < \rho \leq 1$ in (41)), which increases labor market tightness (x) and search costs (b). We are now in a position to state the following comparative statics for the opening of closed economies to trade.

Proposition 10 *Let $0 < \eta < 1$. Then the opening of trade: (i) Increases expected worker income (ω); (ii) Increases labor market tightness (x) and search costs (b).*

Proof. The proposition follows from the free entry condition (18), expected worker income (41) and labor market tightness (14), as shown in the web-based technical appendix. ■

Under risk aversion, the opening of trade has two counteracting effects on expected welfare. On the one hand, it raises the zero-profit productivity cutoff, which increases average productivity, expands the size of the differentiated sector and reduces the differentiated sector price index. On the other hand, it increases the risk premium in the differentiated sector, which increases search costs, contracts the size of the differentiated sector and increases the differentiated sector price index. In addition, there are distributional consequences of the opening of trade for *ex post* welfare depending on a worker's sector and firm of employment, as discussed in the case of risk neutrality above.

The predictions for sectoral wage inequality are unchanged by the introduction of risk aversion, because they do not depend on expected worker income (ω). In contrast, as in the model without the outside sector, the increase in expected worker income as a result of the opening of trade modifies the predictions for sectoral unemployment. While the reduction in the hiring rate (σ) established in Section 2 above increases unemployment, the increase in labor market tightness (x) induced by higher expected worker income reduces unemployment. As in the risk neutral case discussed above, aggregate inequality and unemployment depend on their sectoral values and sectoral composition.

7 Conclusion

The relationship between international trade and earnings inequality is one of the most hotly-debated issues in economics. Traditionally, research has approached this topic from the perspective of neoclassical trade theory with its emphasis on specialization across industries and changes in the relative rewards of skilled and unskilled labor. In this paper we propose a new framework that features variation in employment, wages and workforce composition across firms within industries, and equilibrium unemployment. These features are explained by firm heterogeneity, worker heterogeneity, search frictions and screening of workers by firms.

We characterize the distribution of wages across workers and the determinants of unemployment. In the closed economy, there is a single sufficient statistic for wage inequality, which is increasing in the dispersion of firm productivity, and can be either increasing or decreasing in the dispersion of worker ability. Opening closed economies to trade raises wage inequality, but once economies are open to trade, further increases in trade openness can either raise or reduce wage inequality. The unemployment rate depends on the fraction of workers that are matched (the tightness of the labor market) and the fraction of these matched workers that are hired (the hiring rate). While opening closed economies to trade reduces the hiring rate, it leaves labor market tightness unchanged except for general equilibrium effects through expected worker income. We provide conditions under which expected income remains constant in general equilibrium, in which case the opening of closed economies to trade raises income inequality through both greater wage inequality and higher unemployment.

Since trade affects wage inequality and unemployment, it influences both *ex ante* expected welfare and *ex post* welfare once firms and workers are matched. When workers are risk-neutral, welfare gains from trade are ensured. When workers are risk averse, the reduction in the consumer price index as a result of the productivity gains induced by the opening of trade is counterbalanced by greater income risk in the differentiated sector. As compensation for this greater income risk, workers receive higher expected income in the open economy than in the closed economy, which increases labor market tightness. As a result, the increase in unemployment from a lower hiring rate is offset by a reduction in unemployment from a tighter labor market.

Our model provides a framework which can be used to analyze the complex interplay between wage inequality, unemployment and income risk, and their relation to international trade. In emphasizing wage inequality across firms within industries, it is compatible with trade-related changes in income inequality, even in the absence of large observed reallocations of resources across sectors.

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