Trade Liberalization, Monitoring and Wages

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Abstract

This paper incorporates efficiency wages into a model of trade and technology adoption with heterogeneous firms. Worker effort is imperfectly observed by firms. How accurately workers are monitored depends on the monitoring technology a firm adopts. Firms have a binary choice between adopting a basic technology involving low monitoring accuracy and adopting an advanced one involving a higher monitoring accuracy. The most productive firms choose the advanced technology, while less productive firms choose the basic one. This mechanism potentially generates wage differentials across firms such that large firms pay higher wages than small firms. The effects of lower variable trade costs on unemployment and wages are investigated.

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1 Introduction

One of the stylized facts about labour markets is that large employers pay higher wages than small employers. Several empirical studies have confirmed the presence of such an employer size-wage premium, even after controlling for observed worker characteristics such as education levels and skills, and firm characteristics such as type of industry, capital-labour ratio, and labour productivity (Brown and Medoff, 1989; Idson and Oi, 1999; Troske, 1999; Bayard and Troske, 1999; Gibson and Stillman, 2009). This fits in with recent empirical studies which have reported a substantial wage inequality among workers with similar observed characteristics across firms within sectors (e.g., Akerman et al., 2013; Helpman et al., 2017; for a survey see Helpman, 2016.)

Among the explanations for why workers are better paid by large firms one is based on efficiency wages. Large firms, it is argued, face greater problems with monitoring worker effort than small firms. To motivate workers, they therefore pay them more, thus substituting higher pay for monitoring (Bulow and Summers, 1986). Originally, this argument rests on the assumption due to Shapiro and Stiglitz (1984) that workers only have a choice between one exogenously given level of effort or nothing. Mehta (1998) provides a variant of the view that increased difficulties with monitoring can firms lead to pay higher wages. He develops a hierarchy model in which managers can divide a fixed amount of time between monitoring workers, thereby preventing them from shirking, and coordinating them, thereby directly increasing output. Workers can choose their most preferred level of effort from a range of possible values. Mehta (1998) shows that when workers become more productive the firm wants to employ more of them in a production unit, which increases the span of control of managers. This requires more time for supervision, thus leaving managers less time for directly increasing output through coordination. In order to counteract this loss of output, the firm pays workers higher wages, thereby inducing them to work harder.

This paper further investigates the role of efficiency wages in generating wage differentials across firms among homogeneous workers. It introduces efficiency wages in a heterogeneous firm model of trade and technology adoption. Firms differ in their initial productivity drawn from a known distribution and have to incur fixed costs for entry, production and exporting, as in Melitz (2003). In addition, it is assumed that firms imperfectly observe worker effort. How accurately workers are monitored depends on the monitoring technology the firm adopts. Firms can choose between a basic technology involving low monitoring accuracy, and an advanced technology involving a higher monitoring accuracy. Regarding the binary technology adoption choice combined with firm heterogeneity, the paper builds on Bustos (2011a). In her model firms have a choice between using a general basic technology and upgrading it to an advanced one which entails an increase in productivity. In contrast to the present paper, however, Bustos (2011a), following Melitz (2003), considers a perfectly competitive labour market with all workers receiving a common wage. [1]

Worker effort is assumed to be a continuous variable. Correspondingly, its level is determined endogenously: given its monitoring technology, a firm chooses an effort standard so as to maximize its profit. [2] Firms that adopt the advanced monitoring technology can elicit more effort from their workers than firms using the basic monitoring technology. They also have lower wage costs per unit of effort, and hence make more variable profit for a given productivity. Furthermore, when the advanced technology is adopted, variable profits increase at a greater rate with firm productivity than when the basic technology is used. On the other hand, better monitoring requires additional fixed costs of production. As a result, there is a threshold of productivity (the innovation cutoff) above which variable profit from domestic and (potentially) export sales is high enough to cover the higher fixed cost involved by better monitoring. Thus, all firms with a productivity above that threshold adopt the advanced monitoring technology, whereas all firms with a productivity below the threshold use the basic monitoring technology.

This simple mechanism generates wage heterogeneity. Each of the two monitoring technologies a firm can choose from is associated with a specific wage rate that gives workers an incentive not to shirk. However, with effort varying continuously, in general it cannot be said which of the two wage rates is higher. This is because there are always two opposing effects from increasing monitoring accuracy. On the one hand, firms can offer a lower wage rate for workers to comply with the initial effort target, i.e., monitoring is substituted for pay. On the other hand, with a higher monitoring accuracy firms are induced to demand more effort, which requires a higher wage. [3] Which of these effects dominates, depends on how the cost of effort to workers responds to changes in the effort level. It is shown that for a broad class of cost of effort functions an increase in monitoring accuracy results in a higher wage rate. In that case firms adopting the advanced monitoring technology will not just demand more effort from their workers, they will also pay them higher wages. At the same time, firms practising more intensive monitoring are the most productive ones. They are also the largest ones in terms of revenue and employment. Thus, it may well happen that the largest firms pay higher wages, in accordance with the empirical evidence on the employer size-wage premium.

The model is used to study the effects of trade liberalization between two symmetric countries on unemployment and wages. Both effects depend on the changes in the three productivity cutoffs - for serving the domestic market, exporting and innovation - induced by freer trade.

[1] A binary technology adoption choice has also been used in heterogeneous firm models of trade with two types of labour: skilled and unskilled labour, whose endowments are fixed (Bustos, 2011b; Bas, 2012). Heterogeneous firms can choose between two production technologies that differ in efficiency and skill-intensity: a basic technology using less skilled relative to unskilled labour and a more efficient technology using more skilled relative to unskilled labour but requiring a higher fixed cost.

[2] For shirking models with continuously variable effort see, e.g., Walsh (1999) and Allgulin and Ellingsen (2002). Altenburg and Brenken (2008) introduce efficiency wages with continuously variable effort in a trade model with monopolistic competition and homogeneous firms.

[3] For a detailed analysis of this issue see Allgulin and Ellingsen (2002).

It is shown that regarding the determination of the productivity cutoffs the present model is isomorphic to Bustos (2011a). Correspondingly, the changes in the productivity cutoffs have the same unambiguous signs as in Bustos (2011a). Nevertheless, the effects on unemployment and wages in general cannot be signed. Both of these depend on the change in the share of better monitored jobs in the economy, which is a key variable of the model. This share can rise or fall because there are opposing effects. In addition, the effect on unemployment depends on whether high-technology firms leave their workers better or worse off (in terms of utility) than low-technology firms, which in general is ambiguous. Finally, the impact on wages additionally depends on the ranking of the two types of firms with regard to wages. As mentioned above, this in general cannot be predicted. The paper provides conditions under which the ambiguities are removed and sharp predictions are obtained.

The idea of introducing efficiency wages in a heterogeneous firm model is already present in earlier papers. However, the mechanisms developed in those papers differ from the here presented one. Davis and Harrigan (2011) combine a variant of Shapiro and Stiglitz (1984) efficiency wages with Melitz (2003)-style firm heterogeneity to study the impact of trade liberalization on job loss and the aggregate composition of jobs. Yet there are important differences. First, the model of Davis and Harrigan (2011) features two dimensions of random firm heterogeneity instead of one: productivity (as in Melitz, 2003) and monitoring ability. Second, they retain the assumption of the Shapiro and Stiglitz model that workers have a binary choice between providing one exogenous positive level of effort and zero effort. As mentioned above, that assumption entails an inverse relationship between monitoring ability and no-shirking wages: firms with closer monitoring pay lower wages, whereas firms with poorer monitoring pay higher wages. Therefore, as firm size decreases with marginal cost, for a given level of productivity it is the smallest firms that pay the highest wages, which is at variance with empirical evidence. To resolve this problem, Davis and Harrigan (2011) use the two sources of firm heterogeneity. Due to random variation of both wages and productivity, jobs at low-productivity firms that pay low wages can coexist with jobs at high-productivity firms that pay high wages. For the same reason high-wage as well as low-wage jobs can be lost through trade.

Like the present paper, Wang and Zhao (2015) assume that worker effort is a continuous variable. However, in their model worker effort does not affect the firms' productivity. Rather, it is linked to their choice of product quality: higher quality requires more effort. Furthermore, the single dimension of random firm heterogeneity is "management talent", which has no impact upon productivity. Regarding worker utility, Wang and Zhao (2015) follow Davis and Harrigan (2011) in assuming that it takes a multiplicative functional form which is similar to that used in the present paper. A further parallel is that monitoring accuracy is an endogenous variable. But instead of considering a binary technology choice of firms, Wang and Zhao (2015) allow for a continuum of monitoring technology (i.e., monitoring accuracy) choices. Better monitoring produces higher effort and hence higher quality, which enables firms to charge higher prices and generate higher revenues. On the other hand there is a monitoring cost, assumed to be increasing in monitoring accuracy and decreasing in management talent. After its draw of management talent a firm chooses its monitoring accuracy so as to maximize its profit, taking into account its monitoring cost. Assuming a special functional form of monitoring cost, Wang and Zhao (2015) get the result that monitoring accuracy increases with management talent. In contrast to the present model, theirs yields an unambiguous relationship between monitoring accuracy and wages. Firms with better monitoring always pay higher wages. This is due to their assumption that the cost of effort to workers is a linear function of product quality. Like the present paper, the model of Wang and Zhao (2015) thus provides an explanation for a positive size-wage correlation based on efficiency wages, though the underlying mechanisms are different.

The paper is also related to the literature that introduces other forms of labour market frictions in trade models with heterogeneous firms and homogeneous workers. All these models are used to explain wage differentials across firms and how these wage differentials are affected by trade. The labour market frictions dealt with are fair wages (Egger and Kreickemeier, 2009; Amiti and Davis, 2012), and search and matching (Helpman, Itskhoki, and Redding, 2010, among others; for a survey see Helpman, 2016).

The remainder of the paper is structured as follows. Section 2 develops the model. Section 3 characterizes the equilibrium. The effects of trade liberalization on unemployment and wages are studied in Section 4. Section 5 provides a numerical illustration of the model and Section 6 concludes.

2 Setup of the Model

I consider a model with two symmetric countries pursuing trade liberalization. Symmetry implies that in equilibrium all aggregate variables take the same values in both countries. It therefore suffices to describe an equilibrium for one of them, say the home country.

2.1 Workers

In each country there is a fixed mass L of identical workers, each supplying one physical unit of labour. Workers are infinitely-lived, risk-neutral, and maximize their expected present-discounted lifetime utility. Time is continuous. The analysis is confined to steady states. At each instant of time a worker is either employed or unemployed, and when employed can be either working or shirking.

A worker's instantaneous utility U takes the following multiplicative form

$$U(w,e) = \begin{cases} \frac{w}{1+C(e)} & \text{if employed} \\ 0 & \text{if unemployed,} \end{cases} \tag{1}$$

where w is the real wage (in units of a final good introduced shortly) and e the level of effort a worker exerts on the job. In contrast to Shapiro and Stiglitz (1984), worker effort is taken to be continuously variable with $e \geq e_{\min} \geq 0$, where $e_{\min}$ is some minimum level of effort.

The function $C(e)$ captures the cost of effort (its disutility) to the worker. [4] It is assumed that $C(e) > 0$, $C'(e) > 0$, $C''(e) \geq 0$ for $e > e_{\min} \geq 0$ and $C(e_{\min}) = 0$. Usually, the minimum level of effort is normalized to zero. Permitting $e_{\min} > 0$ allows for cases in which there is some exogenous bliss level of effort: workers exert it voluntarily because it does not cause any disutility of effort. An example is provided by a cost of effort function of the form $C(e) = \frac{(e-e_{\min})^2}{2}$ (see Rebitzer and Taylor, 2011). An unemployed worker is assumed to receive no income and incur no cost of effort so that his instantaneous utility is zero.

When employed, a worker is asked by his employer to exert effort at a level which for a moment is taken as fixed. As a worker is only imperfectly monitored, he can shirk, i.e., provide less than the required effort level. If a worker does not shirk, i.e., does exert the required level of effort, he will keep his job until the firm in which he works is hit by a bad shock, forcing it to close down production so that all its workers lose their jobs. This job break-up occurs at rate δ per unit time, affecting all firms and workers alike.

If the worker shirks, he faces an additional risk of being separated from his job for being caught shirking and fired. The detection of shirking occurs at rate q per unit time. The detection rate can differ across firms because they have a choice between two monitoring technologies each of which involves a specific detection rate. Both the common parameter δ and the firm specific parameter q are the rates of two independent Poisson processes. For a shirker it is then optimal to provide the minimum effort level, while a nonshirker's best choice is to perform exactly up to the required effort standard e. Concerning workers' transition from unemployment to employment, it is assumed that unemployed workers and firms that are seeking to hire workers meet completely at random.

Let ρ be the discount rate and let V_N and V_S denote the expected present discounted lifetime utility of a worker employed who exerts effort and who shirks, respectively, and V_U the expected present discounted lifetime utility of an unemployed. Then V_N and V_S satisfy the following asset equations:

$$\begin{aligned} \rho V_N &= \frac{w}{1+C(e)} + \delta[V_U - V_N], \\ \rho V_S &= w + (\delta + q)[V_U - V_S]. \end{aligned} \tag{2}$$

For an employee to choose not to shirk at given values of q, e, and V_U, the firm has to pay a wage high enough so that $V_N \geq V_S$ (no-shirking condition). Using (2), this implies that

$$w \geq \widetilde{w}(e, V_U, q) \equiv \left(\frac{q[1+C(e)]}{q-(\rho+\delta)C(e)} \right) \rho V_U. \tag{3}$$

It gives the minimum real wage $\widetilde{w}(\cdot)$ a firm with monitoring ability q must pay its workers to induce them to provide a given level of effort e. The macro variable V_U is taken by agents as

[4] A similar functional form of a worker's utility has been used by Davis and Harrigan (2011) and Wang and Zhao (2015). Davis and Harrigan (2011) dubbed this form "iceberg cost of effort". It departs from the more common additive specification, $U = w - e$, due to Shapiro and Stiglitz (1984).

exogenously given. Since there is no need to pay a wage higher than $\widetilde{w}(\cdot)$, the firm chooses the wage so that (3) holds with equality, implying that $V_N = V_S \equiv V$.

2.2 Production and Firms

The structure of production in a country is as follows. There is a single non-traded final good that can be consumed and used as fixed input in production and exporting. The final good is produced with a continuum of differentiated intermediate inputs that can be traded between the countries. [5] The production function of the final good sector has the usual CES form: [6]

$$Y = \left[\int_{i \in I} y(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1, \tag{4}$$

where Y is final output, $y(i)$ the quantity of intermediate input i, I the set of available input varieties, and σ the elasticity of substitution between input varieties. The final good is produced under conditions of perfect competition and is chosen as numéraire.

Cost minimization in the final good sector implies that the demand for an input variety is

$$y(i) = Y \left(\frac{p(i)}{P} \right)^{-\sigma}, \tag{5}$$

where $p(i)$ denotes the price of intermediate input i and

$$P = \left[\int_{i \in I} p(i)^{1-\sigma} di \right]^{\frac{1}{1-\sigma}} \tag{6}$$

is the price of the final good, being equal to its unit cost. With the final good chosen as the numéraire, we have $P = 1$.

Intermediate goods are produced under monopolistic competition, with each variety produced by a single firm. An intermediate good producer who wants to enter the market pays a fixed entry cost of f_e units of final output, which is sunk. Thereafter the firm draws its initial productivity φ from a continuous cumulative distribution $G(\varphi)$ with density $g(\varphi)$ and support over $(0, \infty)$. [7] After observing their productivity φ, intermediate goods producers decide whether to exit or stay and start production. Intermediate goods are produced by using only labour.

A firm's output y depends on the number of workers ℓ it employs, the level of effort e exerted by its workers, and the level of its initial productivity φ. The firm's output is assumed to be given by $y = \varphi e \ell$. Each intermediate good producer bears a fixed production cost in units of final output. Its amount depends on which monitoring technology he adopts. He can choose

[5] Similar production structures have been considered in Matusz (1996), Altenburg and Brenken (2008), Egger and Kreickemeier (2009) and Bas (2012).

[6] Egger and Kreickemeier (2009) and Bas (2012) use a special variant of CES function.

[7] Most of the results in Section 4 hinge on the assumption that productivity is Pareto distributed. That distribution will also be used for the numerical illustration of the model in Section 5.

between two monitoring technologies, a basic technology l, represented by a detection rate q_l, and an advanced technology h, represented by a higher detection rate $q_h > q_l$. When the firm chooses technology l, it bears a fixed cost f, and when it adopts technology h, it bears the higher fixed cost ηf with $\eta > 1$. The benefit of choosing technology h is that it allows a firm to demand a higher level of effort from its workers than by using technology l, thereby increasing labour productivity and variable profits, as will be shown below. If an intermediate good producer serves only the domestic market, f or ηf are the only fixed production costs to bear. However, if he chooses to export, he faces additional fixed costs of f_x units of final output. In addition, there are melting-iceberg trade costs: $\tau > 1$ units must be shipped for one unit to arrive abroad.

2.3 Decisions of Intermediate Goods Producers

The decisions an intermediate good producer makes at any moment of time have no impact on his profit at another moment of time. Therefore, facing the no-shirking condition (3) and the intermediate good demand (5), a firm with productivity φ and monitoring accuracy q chooses its producer price p and its effort target e to maximize its instantaneous profit. In doing so, it takes Y and V_U as given. The first-order conditions imply

$$p(\varphi) = \frac{\sigma}{\sigma - 1}\frac{w}{\varphi e}, \tag{7}$$

$$\frac{w}{e} = \frac{\partial \widetilde{w}(\cdot)}{\partial e}. \tag{8}$$

In the present setting a firm's marginal cost equals the wage cost per efficiency unit of labour, $w/\varphi e$. Equation (7) is thus the common pricing rule according to which the profit maximizing producer price of an intermediate good is a constant mark-up over marginal cost. Equation (8) is a kind of Solow condition for the firm's subproblem of choosing e to minimize the cost per efficiency unit of labour (the effective labour cost), hence, as φ is given, the wage cost per unit of effort, w/e (Solow, 1979). Note that productivity φ does not enter into the Solow condition (8). Using the no-shirking condition (3), the Solow condition implies

$$[q - (\rho + \delta)C(e)][1 + C(e)] - (q + \rho + \delta)eC'(e) = 0. \tag{9}$$

For given parameters equation (9) implicitly defines the profit maximizing effort level as a function $e(q)$ of the detection rate q alone. [8] This function allows us to determine the profit maximizing level of effort associated with each of the two fixed detection rates, q_l and q_h, which have been assumed to be the only ones available to firms. By implicitly differentiating equation (9) and using the assumption that the cost of effort function, $C(e)$, is increasing and convex,

[8] This is a consequence of the assumption that workers have multiplicative preferences. Things would become more complicated if continuously variable effort and firm heterogeneity were instead introduced in a model with the more common additive form of worker utility. In that case the profit maximizing effort depends not just on q but also on the firm wage and thus, the value of being unemployed, V_U, a macro variable.

it can be shown that worker effort is monotonically increasing in the detection rate q, i.e., $\partial e(q)/\partial q > 0$. [9] Thus the profit maximizing level of worker effort associated with the advanced monitoring technology h is higher than the level associated with technology l: $e(q_h) > e(q_l)$.

To induce workers to provide the respective effort level, a firm must pay them a wage that satisfies the no-shirking condition (3). The wages associated with the two monitoring technologies are obtained by substituting q_s and $e(q_s)$ with $s = l, h$ into (3) and solving for w. However, in general it cannot be said whether the wage $w(q_h)$ needed to induce workers to exert the higher level of effort, $e(q_h)$, is higher or lower than the wage $w(q_l)$ necessary for workers to provide the lower level $e(q_l)$. To see this, consider the function $w(q)$ defined by (3) combined with the function $e(q)$ implicitly defined by (9). Differentiating $w(q)$ gives [10]

$$\frac{\partial w(q)}{\partial q} = \frac{\rho V_U}{[q-(\rho+\delta)C(e)]^2}\left[q(q+\rho+\delta)C'(e)\frac{\partial e(q)}{\partial q} - (\rho+\delta)[1+C(e)]C(e)\right]. \tag{10}$$

Equation (10) shows that the response of the firm's wage to a variation in q is in general ambiguous because there are two opposing effects. On the one hand, there is a negative substitution effect, corresponding to the second term in brackets on the right-hand side of (10): holding e constant, a higher q lowers the wage needed to induce workers to exert the initial level of effort, i.e., monitoring is substituted for pay. On the other hand, with a higher q a firm wishes to elicit more effort ($\partial e(q)/\partial q > 0$). This requires more pay to compensate workers for their increased cost of effort. That effect is represented by the first term in brackets on the right-hand side of (10). [11]

A sufficient condition for firms with higher q to pay higher wages (hence for $w(q_h) > w(q_l)$) can be derived by using the elasticity of the cost of effort function, $\varepsilon(e) \equiv eC'(e)/C(e)$. It can be shown that for $\partial w(q)/\partial q > 0$ it is sufficient that the elasticity of the cost of effort is non-increasing ($\varepsilon'(e) \leq 0$). Clearly, this condition is satisfied when the cost of effort function has constant elasticity. In that case it can be written as $C(e) = e^\gamma/\gamma$ with $\varepsilon(e) = \gamma \geq 1$. An example is the quadratic cost of effort function, which has often been used in agency theory. A further functional form guaranteeing a positive relationship between q and w is $C(e) = (e - e_{\min})^2/2$ for $e \geq e_{\min} > 0$, where $e_{\min}$ can be interpreted as a fixed bliss level of effort (see Rebitzer and Taylor, 2011). A shirking worker would now choose an effort level $e = e_{\min}$ so that his

[9] Differentiate (9) to get

$$\frac{\partial e(q)}{\partial q} = \frac{1 + C(e) - eC'(e)}{2(\rho+\delta)[1+C(e)]C'(e) + (q+\rho+\delta)eC''(e)}.$$

Moreover, (9) implies that $1 + C(e) > eC'(e)$ (see (A3) in the Appendix). From the assumption that the cost of effort function, $C(e)$, is increasing and convex ($C'(e) > 0$ and $C''(e) \geq 0$) we have that $\partial e(q)/\partial q > 0$.

[10] To avoid notational clutter, here and in footnote 9 I have omitted the argument q of $e(q)$ in the function $C(e(q))$ and its derivatives.

[11] This second effect is similar to what Allgulin and Ellingsen (2002) dubbed "scale effect". Equation (10) illustrates the contrast to models with one fixed positive effort level such as the Shapiro and Stiglitz (1984) model. There a higher monitoring intensity always enables firms to pay lower wages because the negative substitution effect is the only one to occur.

cost of effort again equals zero. In that case the elasticity of the cost of effort monotonically decreases with e ($\varepsilon'(e) < 0$ for $e_{\min} < e < \infty$). The following lemma summarizes the main result regarding the variation of wages.

Lemma 1. *Workers employed at firms using the advanced monitoring technology are paid a higher wage than workers employed at firms using the basic monitoring technology ($w(q_h) > w(q_l)$) if the elasticity of the cost of effort is non-increasing.*

Proof. See Appendix.

Intuitively, when the elasticity of the cost of effort is decreasing, workers become continually less averse to providing greater effort (despite the fact that the cost of effort may increase progressively with the level of effort). As a consequence, a higher q prompts firms to require more additional effort from their workers than under circumstances in which the elasticity of the cost of effort is increasing. This in turn requires more pay to such an extent that it outweighs the negative substitution effect. Thus the wage increases with monitoring intensity. [12]

A key variable on the production side of the model is the wage cost per unit of effort, w/e. In conjunction with productivity φ, it determines a firm's product price and hence its output, revenue and profit. Using (3), the expression for w/e can be written as

$$\frac{w(q)}{e(q)} = \frac{\rho V_U}{\psi(q)}, \tag{11}$$

where

$$\psi(q) = \frac{[q - (\rho + \delta)C(e(q))]e(q)}{[1 + C(e(q))]q}. \tag{12}$$

As the wage cost per unit of effort is essential to the present framework, so too is the measure $\psi(q)$. Henceforth it will be used throughout the analysis.

How does $\psi(q)$ respond to a change in q? Profit maximization by intermediate goods producers implies that for a given q they choose the effort target so as to minimize w/e or, equivalently, maximize worker effort per unit of wage. This in turn is equivalent to maximizing $\psi(q)$ because firms take V_U as exogenously given. Thus, for finding out how a firm's maximum worker effort per unit of wage varies with monitoring accuracy q, the envelope theorem can be applied. Accordingly, the effect of q on the maximum $\psi(q)$ (allowing e to adjust) is equal to the partial effect of q on $\psi(q)$, holding e fixed at the initial level. Using (12) yields

$$\frac{d\psi(q)}{dq} = \left.\frac{\partial\psi(q)}{\partial q}\right|_e = \frac{(\delta + \rho)eC(e)}{[1 + C(e)]q^2} > 0. \tag{13}$$

This leads to the following conclusion.

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[12] For a discussion of how the elasticity of the cost of effort influences the impact of better monitoring on wages see Walsh (1999), who considers the more common additive form of worker utility. In that case the condition for the wage to be increasing in q is slightly different. In particular, a constant elasticity implies that the wage remains unchanged, while in the present model it suffices for the wage to rise with q.

Lemma 2. *It holds that* $\psi(q_h) > \psi(q_l)$ *or, equivalently,* $w(q_h)/e(q_h) < w(q_l)/e(q_l)$, *i.e., firms using technology* h *have lower wage costs per unit of effort than firms using technology* l.

As a consequence, the profit maximizing prices set by an intermediate good producer with productivity φ differ depending on both the market he serves and the monitoring technology he uses. Substitution of (11) for w/e into (7) yields the following expression for the price p_{dl} set in the domestic market by a firm using technology l: $p_{dl}(\varphi) = (\sigma/(\sigma-1))(\rho V_U/\varphi\psi(q_l))$. In the foreign market the firm will charge the higher price $p_{xl} = \tau p_{dl}$. The prices set by a firm using technology h in the two markets are $p_{dh}(\varphi) = (\sigma/(\sigma-1))(\rho V_U/\varphi\psi(q_h))$ and $p_{xh} = \tau p_{dh}$. Because of $\psi(q_h) > \psi(q_l)$ the prices set by firms using technology h are lower in both markets. Revenues from domestic sales and exports of firms using technology l and technology h are, respectively,

$$\begin{aligned} r_{ds}(\varphi) &= Y\left(\frac{\sigma-1}{\sigma\rho V_U}\right)^{\sigma-1}[\psi(q_s)\varphi]^{\sigma-1}, \\ r_{xs}(\varphi) &= \tau^{1-\sigma} r_{ds}(\varphi), \qquad\qquad s = l, h, \end{aligned} \tag{14}$$

where use has been made of the demand function (5), the pricing rule (7), the expression (11) for w/e, and the fact that $p_{xs} = \tau p_{ds},\ \ s = l, h$.

To decide which monitoring technology to use and whether to enter the export market, an intermediate good producer with productivity φ compares the total profit earned from each of the possible choices, which parallel those in the Bustos (2011a) model. Let $\pi_{dl}(\varphi)$ and $\pi_{dh}(\varphi)$ denote the firm's profit earned from domestic sales and let $\pi_{xl}(\varphi)$ and $\pi_{xh}(\varphi)$ be the firm's profit earned from export sales when it uses technology l and technology h, respectively. Profits earned exclusively from domestic sales when using technology l are

$$\pi_{dl}(\varphi) = \frac{r_{dl}(\varphi)}{\sigma} - f,$$

and profits earned exclusively from domestic sales when using technology h are

$$\pi_{dh}(\varphi) = \frac{r_{dh}(\varphi)}{\sigma} - \eta f = \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\frac{r_{dl}(\varphi)}{\sigma} - \eta f.$$

Total profit earned from both domestic and export sales when using technology l is

$$\pi_{dl}(\varphi) + \pi_{xl}(\varphi) = (1+\tau^{1-\sigma})\frac{r_{dl}(\varphi)}{\sigma} - f - f_x,$$

and total profit earned from both domestic and export sales when using technology h is

$$\begin{aligned} \pi_{dh}(\varphi) + \pi_{xh}(\varphi) &= (1+\tau^{1-\sigma})\frac{r_{dh}(\varphi)}{\sigma} - \eta f - f_x \\ &= (1+\tau^{1-\sigma})\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\frac{r_{dl}(\varphi)}{\sigma} - \eta f - f_x. \end{aligned}$$

The ratio of effort per unit of wage attainable with technology h to effort per unit of wage attainable with technology l, $\psi(q_h)/\psi(q_l) > 1$, is a measure of the relative advantage from better monitoring. The ratio of a firm's revenue when using technology h to its revenue when using technology l is given by $[\psi(q_h)/\psi(q_l)]^{\sigma-1}$.

Total variable profit from domestic and export sales increases at a greater rate with firm productivity φ than variable profit earned exclusively from domestic sales. Thus, there is a cutoff productivity level φ_x above which variable profit is high enough to cover the additional fixed cost of exporting, f_x. Similarly, with technology h adopted, total variable profit from domestic and (possibly) export sales increases at a greater rate with productivity φ than when technology l is used. Accordingly, there is also a cutoff productivity level φ_h above which variable profit is high enough to cover the increased fixed cost ηf of production so that all firms with $\varphi \geq \varphi_h$ adopt the advanced technology h. There can arise different kinds of equilibria involving different rankings of the export and high-technology (innovation) cutoffs φ_x and φ_h.

Referring to her own empirical findings, Bustos (2011a) has concentrated on equilibria in which firms sort into groups as follows. Let φ_d the cutoff productivity level above which low productivity firms have enough revenue to cover the fixed production cost and earn some positive profit. Then the least productive firms with $\varphi < \varphi_d$ exit because otherwise they would make losses. Firms with low productivity $\varphi \in [\varphi_d, \varphi_x)$ exclusively serve the domestic market and use technology l. Firms with medium productivity $\varphi \in [\varphi_x, \varphi_h)$ also use technology l but serve both the domestic and export market. The most productive firms with $\varphi \geq \varphi_h$ serve both the domestic and export market but adopt technology h. In what follows I will assume that this pattern of partitioning of firms by export and technology status also holds in the present framework. [13] It implies that in equilibrium the productivity cutoffs φ_d, φ_x, and φ_h satisfy the following conditions.

The domestic productivity cutoff φ_d is defined by the zero cutoff profit condition $\pi_{dl}(\varphi_d) = 0$, or equivalently

$$\frac{r_{dl}(\varphi_d)}{\sigma} = f. \tag{15}$$

As the marginal exporter uses technology l, the export cutoff φ_x is defined by $\pi_{xl}(\varphi_x) = 0$, or equivalently

$$\frac{r_{xl}(\varphi_x)}{\sigma} = f_x. \tag{16}$$

The zero cutoff profit conditions for domestic and export sales (15) and (16) together with (14) imply

$$\varphi_x = \tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} \varphi_d. \tag{17}$$

Thus, necessary and sufficient for $\varphi_x > \varphi_d$ is the condition $\tau(f_x/f)^{1/(\sigma-1)} > 1$. It is identical to its equivalents in the Melitz (2003) and Bustos (2011a) models.

Given that the marginal innovator is an exporter, the innovation cutoff φ_h is defined by

$$\pi_{dh}(\varphi_h) + \pi_{xh}(\varphi_h) - \pi_{dl}(\varphi_h) - \pi_{xl}(\varphi_h) \quad = \quad 0$$

[13] This pattern of partitioning is also considered in Bustos (2011b) and Bas (2012). Navas and Sala (2015) in addition dwell on the configuration where all exporters use technology h ($\varphi_h < \varphi_x$) and the limiting case in which firms either are both exporting and innovating or abstain from both activities ($\varphi_d < \varphi_x = \varphi_h$).

$$\Leftrightarrow \qquad \left[\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right](1+\tau^{1-\sigma})\frac{Y}{\sigma}\left(\frac{\sigma-1}{\sigma\rho V_U}\right)^{\sigma-1}[\psi(q_l)]^{\sigma-1}\varphi_h^{\sigma-1} \quad = \quad f(\eta-1). \quad (18)$$

The left-hand side of (18) is the increase in variable profits due to a switch to the advanced monitoring technology at the innovation cutoff φ_h. It is equal to the increase in fixed cost $f(\eta-1)$. The zero cutoff profit condition (15) implies that $(Y/\sigma)[(\sigma-1)/(\sigma\rho V_U)]^{\sigma-1}[\psi(q_l)]^{\sigma-1} = f\varphi_d^{1-\sigma}$. Substituting this into (18) gives φ_h as a function of φ_d, which is analogous to its equivalent in Bustos (2011a):

$$\varphi_h = \left[\frac{\eta-1}{(1+\tau^{1-\sigma})\left[\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right]}\right]^{\frac{1}{\sigma-1}} \varphi_d. \quad (19)$$

Using (17) in (19) yields:

$$\frac{\varphi_h}{\varphi_x} = \left[\frac{\tau^{1-\sigma}f(\eta-1)}{(1+\tau^{1-\sigma})\left[\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right]f_x}\right]^{\frac{1}{\sigma-1}} > 1. \quad (20)$$

Parameter conditions in favour of the ordering $\varphi_h > \varphi_x$ are low per-unit and fixed trade costs, a small relative advantage from better monitoring, as measured by $\psi(q_h)/\psi(q_l)$, and high additional fixed costs from adopting the advanced technology, $f(\eta-1)$.

The following proposition stating the main findings with regard to firm behaviour is immediate from the preceding discussion.

Proposition 1. *The most productive firms (with $\varphi \geq \varphi_h$) adopt the advanced monitoring technology. As a consequence, (i) these firms demand from their workers greater effort and (ii) have lower wage costs per unit of effort than the less productive firms (with $\varphi < \varphi_h$), which use the basic monitoring technology. (iii) If the elasticity of cost of effort is non-increasing, the most productive firms pay a higher wage than the less productive firms.*

The second part of Proposition 1 follows from Lemma 2 and its third part from Lemma 1. Notice that the most productive firms are at the same time the largest ones in terms of revenue and, as will become clear shortly, in terms of employment. Under the stated condition it is thus the largest firms that pay higher wages, which squares with the evidence on a positive correlation between firm size and wages.

3 Equilibrium

3.1 Productivity Cutoffs

An equilibrium in the intermediate goods markets is characterized by the domestic productivity cutoff φ_d defined by (15), the exporting cutoff φ_x defined by (16), and the innovation cutoff φ_h defined by (18). After eliminating Y and ρV_U by using (15) and (16), the three cutoff levels are determined by an equations system consisting of the relationship (17) between φ_d and φ_x, the relationship (19) between φ_d and φ_h, and the free entry condition

$$[1 - G(\varphi_d)]\frac{\overline{\pi}}{\rho + \delta} = f_e, \tag{21}$$

where $\overline{\pi}$ denotes the average profit conditional on successful entry. The free entry condition requires that the probability of successful entry, $1 - G(\varphi_d)$, times the present discounted value of the average profit conditional on successful entry, $\overline{\pi}/(\rho + \delta)$, equals the sunk entry cost, f_e. Average profit $\overline{\pi}$ can be written as $\overline{\pi} = \overline{\pi}_d + \chi\overline{\pi}_x$, where $\overline{\pi}_d$ and $\overline{\pi}_x$ are the average profit of active firms from domestic sales and the average profit of exporting firms from foreign sales, respectively, and $\chi \equiv [1 - G(\varphi_x)]/[1 - G(\varphi_d)]$ is the probability that an active firm exports, being equal to the ex-post fraction of exporting firms (see Melitz, 2003). The average profit of active firms from domestic sales is

$$\overline{\pi}_d = \int_{\varphi_d}^{\varphi_h} \pi_{dl}(\varphi)\frac{dG(\varphi)}{1 - G(\varphi_d)} + \int_{\varphi_h}^{\infty} \pi_{dh}(\varphi)\frac{dG(\varphi)}{1 - G(\varphi_d)},$$

and the average profit of exporting firms from foreign sales is

$$\overline{\pi}_x = \int_{\varphi_x}^{\varphi_h} \pi_{xl}(\varphi)\frac{dG(\varphi)}{1 - G(\varphi_x)} + \int_{\varphi_h}^{\infty} \pi_{xh}(\varphi)\frac{dG(\varphi)}{1 - G(\varphi_x)}.$$

The existence and uniqueness of an equilibrium domestic cutoff level φ_d can be shown in a similar way as for the Melitz (2003) model.

Proposition 2. *Suppose that initial productivity is drawn from a continuous distribution $G(\varphi)$ with support $(0, \infty)$ and the marginal exporter uses the basic technology l. Then there exists a unique equilibrium productivity cutoff φ_d.*

PROOF. See Appendix.

Once the domestic productivity cutoff φ_d is known, the exporting cutoff φ_x is determined by (17) and the innovation cutoff φ_h is determined by (19).

3.2 Unemployment

An equilibrium in the labour market can be characterized by the unemployment rate, denoted by u, and a worker's present discounted value of being unemployed, V_U. Given the equilibrium productivity cutoffs φ_d, φ_x, and φ_h, the equilibrium values of the unemployment rate and a worker's value of being unemployed can be determined sequentially. First, the solution for u can be found by using the asset equation for an unemployed. Second, with u determined, the labour market clearing condition (introduced below) is used for finding V_U.

As mentioned above, unemployed workers meet employers randomly. Depending on their initial productivity, firms choose either technology l or technology h to monitor their workers. Correspondingly, employed workers will end up in one of two possible jobs, each offering a specific wage and requiring a specific effort level. As a result, there are also two levels of the present discounted value of employment a non-shirking worker can arrive at by chance: $V(q_l)$ when hired by a firm using technology l and $V(q_h)$ when hired by a firm using technology h. Solving the first equation in (2) for V and substituting (3) for w gives

$$V(q_s) = \nu(q_s)V_U \quad \text{with} \quad \nu(q_s) = \frac{q_s - \delta C(e(q_s))}{q_s - (\rho + \delta)C(e(q_s))} > 1, \qquad s = l, h, \tag{22}$$

Whichever job offer an unemployed worker happens to receive, he will accept it because the utility he derives from the job always exceeds his utility when unemployed. In addition it is assumed that once committed to an employer, a worker cannot switch firms, i.e., there is no on-the-job search. Job changes can only occur through an intervening spell of unemployment, after the employer has been hit by a bad shock.

Since there is no unemployment income nor any inherent value of leisure, the instantaneous payoff of an unemployed is zero. Let a be the rate per unit time at which an unemployed gets a job and $\overline{V}$ the employment weighted average of the two possible values of being employed, $V(q_h)$ and $V(q_l)$. The weights are the fractions of jobs at high-technology and low-technology firms. [14] The asset equation for an unemployed is then

$$\rho V_U = a(\overline{V} - V_U). \tag{23}$$

Equation (23) says that the return to the asset of being unemployed, ρV_U, equals the expected capital gain from finding a job, $a(\overline{V} - V_U)$.

Using (22), the average value of being employed can be written as

$$\overline{V} = \Lambda_h V(q_h) + (1 - \Lambda_h)V(q_l) = [\Lambda_h \nu(q_h) + (1 - \Lambda_h)\nu(q_l)]V_U = \overline{\nu} V_U, \tag{24}$$

where Λ_h is the fraction of jobs at firms using technology h and $\overline{\nu} = \Lambda_h \nu(q_h) + (1 - \Lambda_h)\nu(q_l)$ the weighted average of the $\nu(q_s)$'s, $s = l, h$.

At each instant of time $\delta(1 - u)L$ employed workers become unemployed, while auL unemployed get employed. A steady state requires the flows into and out of unemployment to be equal: $\delta(1 - u)L = auL$. This implies that the steady state unemployment rate satisfies

$$a = \frac{\delta(1 - u)}{u}. \tag{25}$$

Inserting (24) and the flow equilibrium condition (25) into the asset equation (23), cancelling the V_U's, and solving for u yields the equilibrium unemployment rate

$$u = \frac{\delta(\overline{\nu} - 1)}{\rho + \delta(\overline{\nu} - 1)}. \tag{26}$$

As equation (26) shows, the equilibrium unemployment rate positively depends on the average ratio $\overline{\nu}$ of the $V(q_s)$'s to V_U, which in turn is determined by the $\nu(q_s)$'s and the fraction of jobs at firms using technology h, Λ_h. The former are determined by the firms' profit maximizing

[14] For a similar approach in a shirking model with two types of jobs see Acemoglu and Newman (2002).

choices of effort targets for given q_s. It remains to consider the determinants of the fraction of high-technology jobs.

The employment levels resulting from domestic sales and exports of firms using technology l and technology h are, respectively

$$\begin{aligned}
\ell_{ds}(\varphi) &= Y\left(\frac{\sigma-1}{\sigma\rho V_U}\right)^{\sigma}\frac{[\psi(q_s)]^{\sigma}}{e(q_s)}\varphi^{\sigma-1}, \\
\ell_{xs}(\varphi) &= \tau^{1-\sigma}\ell_{ds}(\varphi), \qquad\qquad s=l,h.
\end{aligned} \tag{27}$$

In deriving equations (27) use has been made of $\ell = y/\varphi e$, the demand function (5), the pricing rule (7), the expression (11) for w/e, and the fact that an exporting firm must produce $\tau > 1$ units of its product for one unit to be supplied in the foreign market. Equation (27) shows that a firm's employment level is monotonically increasing in its initial productivity φ. The impact of the detection rate q on the firm's employment level is captured by the term $[\psi(q_s)]^{\sigma}/e(q_s)$.

Let M denote the mass of intermediate goods producers. The fraction of high-technology jobs is then given by

$$\Lambda_h = \frac{\frac{M}{1-G(\varphi_d)}\left\{\int_{\varphi_h}^{\infty}[\ell_{dh}(\varphi)+\ell_{xh}(\varphi)]dG(\varphi)\right\}}{\frac{M}{1-G(\varphi_d)}\left\{\int_{\varphi_d}^{\varphi_h}\ell_{dl}(\varphi)dG(\varphi)+\int_{\varphi_x}^{\varphi_h}\ell_{xl}(\varphi)dG(\varphi)+\int_{\varphi_h}^{\infty}[\ell_{dh}(\varphi)+\ell_{xh}(\varphi)]dG(\varphi)\right\}}. \tag{28}$$

Using (27), equation (28) can be written as

$$\Lambda_h = \frac{\frac{[\psi(q_h)]^{\sigma}}{e(q_h)}(1+\tau^{1-\sigma})\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)}{\frac{[\psi(q_l)]^{\sigma}}{e(q_l)}\left[\int_{\varphi_d}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)+\tau^{1-\sigma}\int_{\varphi_x}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)\right]+\frac{[\psi(q_h)]^{\sigma}}{e(q_h)}(1+\tau^{1-\sigma})\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)}. \tag{29}$$

The ratios $[\psi(q_s)]^{\sigma}/e(q_s)$, $s = l, h$, are determined by the firms' profit maximizing choices of effort targets for given detection rates q_s. Given these ratios, the equilibrium fraction of high-technology jobs is determined by the equilibrium productivity cutoffs φ_d, φ_x, and φ_h. The exporting cutoff φ_x and the innovation cutoff φ_h can both be pinned down, once the domestic productivity cutoff φ_d is known. As already mentioned, the ratios of the value of being employed to the value of being unemployed, $\nu(q_s)$, $s = l, h$, too, are determined by the firms' profit maximizing choices of effort targets. Thus, given the firms' choices, the equilibrium unemployment rate is also determined by φ_d and parameters.

3.3 The Value of Being Unemployed

Whereas the level of effort is determined once the monitoring accuracy q is known, other firm-level variables such as wages, prices, and employment levels are influenced by the flow value to a worker of being unemployed, ρV_U. For finding out the equilibrium value of ρV_U (hence of V_U given that ρ is exogenous) the labour market clearing condition is used. It requires that aggregate employment, $(1-u)L$, equals aggregate labour demand of surviving firms, denoted

L_D. Aggregate labour demand of surviving firms is

$$L_D = \frac{M}{1-G(\varphi_d)}\left[\int_{\varphi_d}^{\varphi_h} \ell_{dl}(\varphi)dG(\varphi) + \int_{\varphi_h}^{\infty} \ell_{dh}(\varphi)dG(\varphi) \cdots \right.$$
$$\left. + \int_{\varphi_x}^{\varphi_h} \ell_{xl}(\varphi)dG(\varphi) + \int_{\varphi_h}^{\infty} \ell_{xh}(\varphi)dG(\varphi)\right]. \quad (30)$$

Substituting (27) for the firms' employment levels into (30) gives

$$L_D = \frac{MY}{1-G(\varphi_d)}\left(\frac{(\sigma-1)}{\sigma\rho V_U}\right)^{\sigma}\left\{\frac{[\psi(q_l)]^{\sigma}}{e(q_l)}\left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1}dG(\varphi) + \tau^{1-\sigma}\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1}dG(\varphi)\right] \cdots \right.$$
$$\left. + \frac{[\psi(q_h)]^{\sigma}}{e(q_h)}(1+\tau^{1-\sigma})\int_{\varphi_h}^{\infty} \varphi^{\sigma-1}dG(\varphi)\right\}. \quad (31)$$

For ascertaining the equilibrium ρV_U it is helpful to express aggregate labour demand L_D as a function of ρV_U and variables that only depend on the productivity cutoffs. To achieve this, final output Y and the mass of firms M must be eliminated from (31) (the derivation is detailed in the Appendix). To eliminate Y, use can be made of the zero cutoff profit condition (15), which together with (14) implies that

$$Y = f\varphi_d^{1-\sigma}[\psi(q_l)]^{1-\sigma}\sigma\left(\frac{\sigma-1}{\sigma\rho V_U}\right)^{1-\sigma}. \quad (32)$$

The mass of firms M can be eliminated from (31) by combining it with a relationship between M and ρV_U. This relationship is obtained by using the fact that aggregate revenue in the intermediate goods sector, denoted R, is related to M by $M\overline{r} = R$, where $\overline{r}$ is the average revenue per surviving intermediate good producer. Moreover, aggregate revenue of the intermediate goods sector equals final output so that $M\overline{r} = Y$. Inserting the expression for $\overline{r}$ into $M = Y/\overline{r}$ leads to

$$M = \left(\frac{\sigma}{\sigma-1}\frac{\rho V_U}{\widetilde{\varphi}}\right)^{\sigma-1}, \quad (33)$$

where

$$\widetilde{\varphi} \equiv \left\{\frac{1}{1-G(\varphi_d)}\left[[\psi(q_l)]^{\sigma-1}\left(\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1}dG(\varphi) + \tau^{1-\sigma}\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1}dG(\varphi)\right) \cdots \right.\right.$$
$$\left.\left. + [\psi(q_h)]^{\sigma-1}(1+\tau^{1-\sigma})\int_{\varphi_h}^{\infty} \varphi^{\sigma-1}dG(\varphi)\right]\right\}^{\frac{1}{\sigma-1}}. \quad (34)$$

is an index of aggregate productivity in the intermediate goods sector.

Let $\omega(q_s) \equiv w(q_s)/\rho V_U$ be the ratio of the wage paid by a firm using technology s to the flow value of being unemployed. From (11) we have $\omega(q_s) = e(q_s)/\psi(q_s)$. The ratio of the weighted average wage to ρV_U, denoted by $\overline{\omega}$, then is

$$\overline{\omega} = \Lambda_h\omega(q_h) + (1-\Lambda_h)\omega(q_l), \quad (35)$$

where the fraction of high-technology jobs, Λ_h, is given by (29). Combining equations (31), (32), and (33) and using (35) leads to

$$L_D = f(\sigma-1)\left(\frac{\sigma}{\sigma-1}\frac{1}{\psi(q_l)\varphi_d}\right)^{\sigma-1}\frac{(\rho V_U)^{\sigma-2}}{\overline{\omega}}. \quad (36)$$

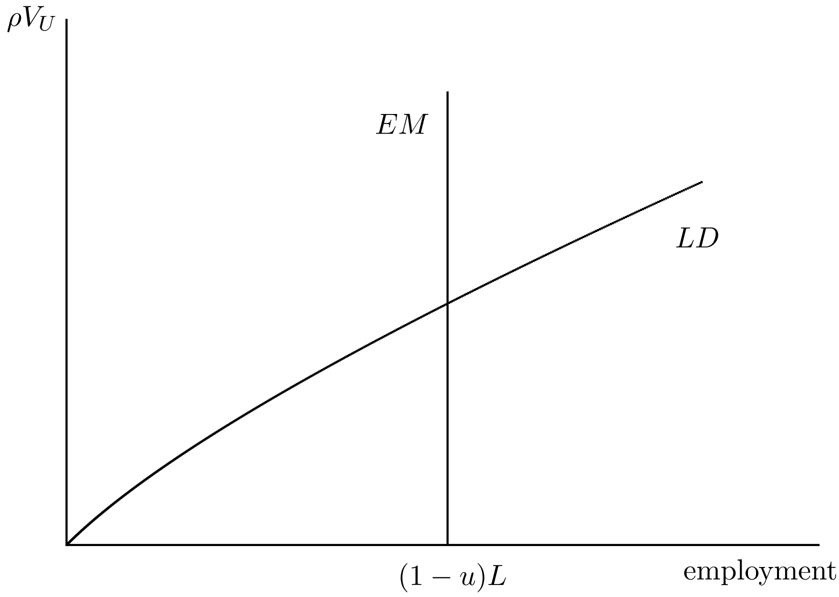

FIGURE 1. Determination of the flow value of unemployment

The condition for labour market clearing, $(1-u)L = L_D$, thus becomes

$$(1-u)L = f(\sigma-1)\left(\frac{\sigma}{\sigma-1}\frac{1}{\psi(q_l)\varphi_d}\right)^{\sigma-1}\frac{(\rho V_U)^{\sigma-2}}{\overline{\omega}}. \tag{37}$$

As (36) reveals, aggregate labour demand is decreasing in the ratio $\overline{\omega}$ of the average wage to ρV_U.

Given the firms' optimizing choices of effort levels, the equilibrium value of $\overline{\omega}$ is determined by the domestic productivity cutoff φ_d. Thus, given the domestic productivity cutoff and the firms' optimal choices, equation (36) defines aggregate labour demand as a function $L_D(\rho V_U)$ of the flow value of unemployment (provided that $\sigma \neq 2$). Its slope depends on the size of σ. Henceforward I assume that $\sigma > 2$. In view of the evidence on substitution elasticities this seems to be the more plausible case. [15] For $\sigma > 2$ aggregate labour demand is monotonically increasing in ρV_U, with $L_D(0) = 0$ and $\lim_{\rho V_U \to \infty} L_D(\rho V_U) = \infty$. As a consequence, in that case the labour market equilibrium condition (37) determines a unique equilibrium value of ρV_U, given the equilibrium value of the domestic productivity cutoff φ_d. [16] The determination of ρV_U can be illustrated by two curves in employment-ρV_U space, as depicted in Figure 1. The inverse of the aggregate labour demand function $L_D(\rho V_U)$ is shown as LD curve for $\sigma > 2$, in which case the curve slopes up. Aggregate employment (corresponding to the left-hand side of

[15] It is in line with the values of σ that have been used in simulations of existing heterogeneous firm models with monopolistically competitive sectors (see Bernard et al., 2003; Ghironi and Melitz, 2005; and Davis and Harrigan, 2011).

[16] In the alternative case $\sigma < 2$, (37) likewise determines a unique equilibrium value of ρV_U. The difference is that now aggregate labour demand is monotonically decreasing in ρV_U, with $\lim_{\rho V_U \to 0} L_D(\rho V_U) = \infty$ and $\lim_{\rho V_U \to \infty} L_D(\rho V_U) = 0$.

(37)) is shown as the vertical EM line at $(1-u)L$. The unique equilibrium flow value of being unemployed is given by the intersection of the LD curve and the EM line.

Once ρV_U is known, the distribution of all firm-level variables that depend on ρV_U can be pinned down. These include wages (eq. (3)), effective labour costs (eq. (11)), prices (eq. (7)), and employment levels (eq. (27)).

4 Trade Liberalization

Trade liberalization can occur through a decrease in variable trade costs, τ, and a decrease in fixed exporting costs, f_x. As in Bustos (2011a) here the focus will be on changes in the variable trade cost, τ. Owing to the structure of the model its comparative statics can be accomplished sequentially. The effects on the domestic, exporting, and innovation cutoffs are ascertained first. Subsequently, the impact on the fraction of jobs at innovating firms is dealt with. The change in the fraction of high-technology jobs is one of the factors that determine the impact of a decrease in trade costs on unemployment, discussed thereafter. With knowledge of the effect on unemployment it is possible to find out the effects on the flow value of being unemployed and wages.

4.1 Changes in the Productivity Cutoffs

Given their monitoring accuracy q, intermediate goods producers choose their effort targets so as to minimize the wage cost per unit of effort, w/e. This in turn determines the ratio of effort per unit of wage attainable with monitoring technology h to effort per unit of wage attainable with monitoring technology l, $\psi(q_h)/\psi(q_l)$. It represents the relative advantage from better monitoring. Once this relative advantage is known, the domestic, exporting, and innovation cutoffs are fixed by the free entry condition (21) and equations (17) and (19). These equations have the same form as in the Bustos (2011a) model. The difference is that in the present setting the relative productivity advantage of innovating firms results from optimizing behaviour of firms, while in Bustos (2011a) it is an exogenous parameter. Correspondingly, regarding the cutoff levels, the comparative static properties are the same as in Bustos (2011a). In the Appendix it is shown that these properties also hold for a general continuous distribution $G(\varphi)$ with support over $(0, \infty)$, not just for the case of Pareto-distributed productivity draws considered by Bustos (2011a). [17]

Proposition 3. *A decrease in variable trade costs raises the domestic productivity cutoff and reduces the productivity cutoffs for exporting and innovation in each country.*

Proof. See Appendix.

Intuitively, lower variable trade costs make foreign intermediate goods less expensive relative

[17] Navas and Sala (2015) who study a variant of the Bustos (2011a) model also use the assumption that firms draw their labour-per-unit-output coefficient from a general distribution.

to domestic ones. In each country this raises demand for foreign intermediate goods, thereby increasing revenues from exporting. With fixed export costs, f_x, this induces new firms to enter the export market (the export cutoff decreases). On the other hand, all firms experience a decline in revenue from domestic sales. As a result, firms that do not export see their profits decrease, and the least productive firms are forced to exit (the domestic cutoff rises). These effects are well-known from Melitz (2003). In addition, there is the effect on the innovation cutoff. Despite the loss of revenue from domestic sales the combined domestic and export revenues of exporting firms will increase when variable trade costs fall, which too is a characteristic of the Melitz (2003) model. [18] As the additional cost from innovation, $(\eta - 1)f$, is fixed, this induces more exporting firms to adopt the advanced monitoring technology (the innovation cutoff decreases).

4.2 The Change in the Fraction of High-Technology Jobs

The reduced exporting and innovation cutoffs and the increased domestic cutoff imply that the shares of exporting firms, $(1-G(\varphi_x))/(1-G(\varphi_d))$, and high-technology firms, $(1-G(\varphi_H))/(1-G(\varphi_d)$, both increase when variable trade costs fall. However, this does not in general entail that the fraction of high-technology jobs increases as well.

As the expression for Λ_h in (29) shows, a reduction in variable trade costs affects the share of high-technology jobs through four channels. First, there is a direct effect. The only portions of the fraction of high-technology jobs that are directly affected are those linked to exporting. With lower trade costs τ the export revenues of high- and low-technology exporters increase by the same percentage, which leads them to increase their employment levels. Since jobs linked to domestic sales are not directly affected, the direct effect of a reduction in τ will raise Λ_h. Second, the higher domestic cutoff causes the least productive firms to exit. Since these are low-technology firms, this too raises Λ_h. Third, the lower innovation cutoff induces more firms to adopt the advanced technology, thereby raising the share of high-technology jobs. Finally, with the reduced exporting cutoff some firms using the low technology begin to export and increase their employment levels. This reduces the share of high-technology jobs.

The latter effect works against the other three. That is why a reduction in variable trade costs can in general raise or lower the share of high-technology jobs. This ambiguity disappears

[18] From (14) and the zero cutoff profit condition (15),

$$r_{ds}(\varphi) = \left(\frac{\psi(q_s)}{\psi(q_l)}\right)^{\sigma-1} \left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} \sigma f, \quad s = l, h.$$

Thus, $r_{ds}(\varphi)$ decreases with a reduction in τ because of the increase in the domestic cutoff level φ_d. The combined domestic and export revenues of an exporting firm are

$$r_{ds}(\varphi) + r_{xs}(\varphi) = \frac{1+\tau^{1-\sigma}}{\varphi_d^{\sigma-1}} \left(\frac{\psi(q_s)}{\psi(q_l)}\right)^{\sigma-1} \varphi^{\sigma-1}\sigma f, \quad s = l, h.$$

In a similar way as in Melitz (2003) it can be shown that $\partial[(1+\tau^{1-\sigma})/\varphi_d^{\sigma-1}]/\partial\tau < 0$, i.e., the combined domestic and export revenues of an exporting firm increase with a reduction in τ.

if it is assumed that firms draw their initial productivity from a Pareto distribution, i.e., $G(\varphi) = 1 - (\varphi_{\min}/\varphi)^k$ for $\varphi > \varphi_{\min}$ with $k > \sigma - 1$. In this case the opposing effect through the change in the exporting cutoff is outweighed by the effect through the change in the domestic cutoff. This leads to the following result.

Proposition 4. *Suppose that the firms' initial productivity is Pareto-distributed with $k > \sigma - 1$. Then a reduction in variable trade costs increases the share of high-technology jobs in each country.*

Proof. See Appendix.

4.3 The Change in Unemployment

The direction of change in the equilibrium unemployment rate depends on the direction of change in the share of high-technology jobs and the ranking of a worker's two possible values of being employed relative to his value of being unemployed, $\nu(q_l)$ and $\nu(q_h)$ (see equation (26)). The latter, in turn, depends on whether the function $\nu(q) = [q - \delta C(e(q))]/[q - (\rho + \delta)C(e(q))]$ is increasing or decreasing in q. To see what determines the shape of $\nu(q)$, it is useful to rewrite the function as

$$\nu(q) = \frac{1 - \delta \frac{C(e(q))}{q}}{1 - (\rho + \delta)\frac{C(e(q))}{q}}. \tag{38}$$

Note that the function $C(e(q))$ is obtained by substituting the function $e(q)$ defined by (9) into the cost of effort $C(e)$. Correspondingly, $C(e(q))/q$ represents the average cost of effort per unit of detection rate q as a function of q. As (38) shows, $\nu(q)$ is increasing in $C(e(q))/q$. Thus, the shape of the function $\nu(q)$ reflects the shape of the average effort cost function: $\nu(q)$ increases (decreases) with q if and only if the average effort cost per unit of q increases (decreases) with q.

First, a sufficient condition is provided under which the average effort cost is decreasing in q, implying that workers employed at high-technology firms are worse off than workers with a job in low-technology firms. In deriving this condition again use is made of the elasticity of the cost of effort.

Lemma 3. *Workers employed at firms using the advanced monitoring technology are worse off than workers employed at firms using the basic monitoring technology (implying $\nu(q_h) < \nu(q_l)$) if the elasticity of the cost of effort is non-decreasing ($\varepsilon'(e) \geq 0$).*

Proof. See Appendix.

The condition $\varepsilon'(e) \geq 0$ is satisfied when the cost of effort function, $C(e)$, has constant elasticity. This functional form of $C(e)$ also satisfies the condition $\varepsilon'(e) \leq 0$, which according to Lemma 1 is sufficient for the wage to be increasing in monitoring intensity. As a consequence, when the cost of effort function is isoelastic, workers in high-technology firms are worse off, though they are paid higher wages.

The joint assumptions of a cost of effort with non-decreasing elasticity and a Pareto distribution of initial productivity yield a sharp prediction about the impact of trade liberalization on unemployment. Under Pareto-distributed productivity a reduction in variable trade costs increases the share of high-technology jobs in both countries. Under the assumption of a cost of effort function with non-decreasing elasticity workers with a job in high-technology firms are worse off. The average value of being employed relative to being unemployed, $\overline{\nu}$, therefore decreases when variable trade costs become smaller. From (26), the equilibrium unemployment rate depends positively on $\overline{\nu}$. Thus, equilibrium unemployment decreases when variable trade costs are reduced. To see the intuition behind the result, it is helpful to look again at the asset equation for an unemployed, (23). Dividing both sides by V_U gives $\rho = a(\overline{\nu} - 1)$. In this form the equation states that the (constant) rate of return to the asset of being unemployed equals the expected capital gain from finding a job relative to the value of being unemployed. As the average value of being employed relative to being unemployed, $\overline{\nu}$, decreases, the flow probability of getting a job, a, must rise. This implies that equilibrium unemployment falls.

Proposition 5. *Suppose that the firms' initial productivity is Pareto-distributed with $k > \sigma - 1$ and the cost of effort has a non-decreasing elasticity. Then a reduction in variable trade costs lowers unemployment in both countries.*

Next, I will turn to the case where it can happen that lower trade costs cause unemployment to rise. Under Pareto-distributed productivity lower trade costs result in a higher share of high-technology jobs. Thus, unemployment will rise if and only if workers in high-technology firms are better off than workers in low-technology firms ($\nu(q_h) > \nu(q_l)$). Necessary, though not sufficient, for $\nu(q)$ to increase with q is the condition that the elasticity of the cost of effort is decreasing ($\varepsilon'(e) < 0$). This is, at the same time, sufficient for the wage to rise with q. As noticed in Section 2.3, the condition $\varepsilon'(e) < 0$ is satisfied for a quadratic cost of effort function with a bliss level of effort, $C(e) = (e - e_{\min})^2/2$ with $e_{\min} > 0$. As a numerical computation using common values for ρ and δ shows, in that case the function $C(e(q))/q$ for small values of q increases with q, reaches a maximum, and thereafter decreases with q. Moreover, $C(e(q))/q$ approaches zero as q becomes large. As a result, $\nu(q)$ initially increases with q, reaches a maximum at the same value of q as $C(e(q))/q$, and thereafter decreases with q, approaching one as q becomes large (implying that $V(q)$ falls to V_U).

Thus, when the cost of effort is quadratic with a bliss level of effort, there exists an interval of small values of q, for which workers with superior-technology jobs both receive higher pay and are better off than workers with low-technology jobs. As a consequence, if the q's are in that interval, under Pareto-distributed productivity a decrease in trade costs causes unemployment to rise.

4.4 Changes in the Flow Value of Being Unemployed and Wages

The flow value of being unemployed, ρV_U, is determined by the condition (37) equating aggregate employment to aggregate labour demand. Solving it for ρV_U yields

$$\rho V_U = \left\{ \frac{(1-u)L}{f(\sigma-1)} \left[\frac{\sigma-1}{\sigma} \psi(q_l)\varphi_d \right]^{\sigma-1} \overline{\omega} \right\}^{\frac{1}{\sigma-2}}. \tag{39}$$

As mentioned above, here it is assumed that $\sigma > 2$. Under this assumption the factors that influence upon ρV_U have the following impact. As (39) shows, equilibrium ρV_U is decreasing in unemployment. On the demand side it is influenced through two channels: the domestic productivity cutoff φ_d and the average wage to ρV_U ratio, $\overline{\omega}$. Equilibrium ρV_U is increasing in both of these factors.

A decrease in variable trade costs always raises the domestic productivity cutoff φ_d (see Proposition 3). The least productive firms are forced to exit, and non-exporting firms cut their employment levels at a given ρV_U. Both of these effects reduce aggregate labour demand at a given ρV_U. Under the assumption $\sigma > 2$ this tends to raise the equilibrium ρV_U. As described above, the effect of a lower τ on unemployment is determined by its effect on the average wellbeing of employed relative to the wellbeing of unemployed workers. In general this effect cannot be signed because workers in high-technology firms may be better or worse off than workers in low-technology firms and the share of high-technology jobs may rise or fall. For similar reasons the impact of a lower τ on the ratio of the average wage to ρV_U in general cannot be signed either. It too depends on the change in the share of high-technology jobs. In addition, workers in high-technology firms may receive higher or lower pay than workers in low-technology firms.

The joint assumptions of Pareto-distributed productivity and a cost of effort function with constant elasticity remove the ambiguities from the effects of a lower τ on u and $\overline{\omega}$ and yield a clear-cut result regarding the overall effect of a reduction in variable trade costs on ρV_U and wages. With Pareto-distributed productivity the share of high-technology jobs becomes larger when variable trade costs are reduced (see Proposition 4). A constant-elasticity cost of effort implies that workers in high-technology firms receive higher pay (from Lemma 1) and are still worse off than workers in low-technology firms (from Lemma 3). First, these assumptions guarantee that in response to a decrease in τ the average value of being employed relative to the value of being unemployed falls, resulting in a lower unemployment rate (see Proposition 5). Second, the assumptions are sufficient for the ratio of the average wage to ρV_U, $\overline{\omega}$, to rise when variable trade costs are reduced. Thus, under the assumption $\sigma > 2$ all the effects of a reduction in τ (via φ_d, u, and $\overline{\omega}$) work towards an increase in ρV_U. According to (11), wages are linked to ρV_U by $w_s \equiv w(q_s) = e(q_s)/\psi(q_s)\rho V_U$, $s = l, h$. As a result, lower variable trade costs increase wages and ρV_U by the same percentage. These results are summarized in the following proposition.

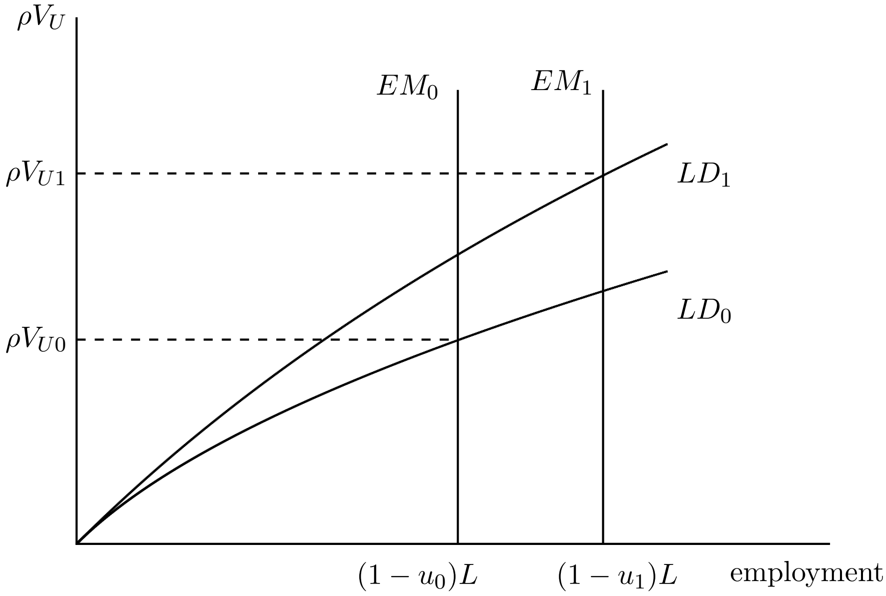

Figure 2. Impact of trade liberalization on ρV_U and employment

Proposition 6. *Suppose that $\sigma > 2$, the firms' initial productivity is Pareto-distributed with $k > \sigma - 1$, and the cost of effort has constant elasticity greater than or equal to one. Then a reduction in variable trade costs raises the flow value of being unemployed and wages in each country. Wages increase by the same proportion as ρV_U.*

Figure 2 illustrates the effects of a reduction in variable trade costs on the employment level and the workers' value of being unemployed in a country that occur under the conditions mentioned in Proposition 6. The initial employment level is represented by the vertical line EM_0 at $(1 - u_0)L$. Under the assumption that $\sigma > 2$ the curve LD_0 depicts the inverse of the aggregate labour demand function for the initial level of trade costs. The initial equilibrium flow value of being unemployed, ρV_{U0}, is given by the intersection of LD_0 with the line EM_0. The higher employment level following the reduction in τ is depicted by the vertical line EM_1 at $(1 - u_1)L$. The curve representing aggregate labour demand shifts up to LD_1. The intersection of the LD_1 curve with the line EM_1 gives the new equilibrium flow value of being unemployed, $\rho V_{U1} > \rho V_{U0}$.

In the present model ex-ante identical workers end up receiving different wages depending on whether they are employed in high- or low-technology firms. The model thus generates wage inequality. As there are only two wage rates, it is wage inequality in its simplest possible form. A simple measure of wage inequality is the ratio of the average to the minimum wage (mean to minimum ratio). [19] By using the weighted average wage $\overline{w} = \Lambda_h(w_h - w_l) + w_l$ the mean to

[19] The mean-min ratio has earlier been used by Egger and Kreickemeier (2009) in a heterogeneous firm model with fair wages. See also Hornstein et al. (2011) who use the measure for comparing wage dispersion in different search models.

minimum wage ratio becomes:

$$\frac{\overline{w}}{w_l} = \frac{w_h - w_l}{w_l}\Lambda_h + 1. \tag{40}$$

A change in τ leaves the relative wage gap, $(w_h - w_l)/w_l = [\psi(q_h)/e(q_h)]/[[\psi(q_h)/e(q_h)]] - 1$, unaltered. Differentiating (40) with respect to τ therefore yields

$$\frac{\partial\left(\frac{\overline{w}}{w_l}\right)}{\partial\tau} = \left(\frac{w_h - w_l}{w_l}\right)\frac{\partial\Lambda_h}{\partial\tau}. \tag{41}$$

Whether wage dispersion increases or decreases in response to lower variable trade costs, depends solely on the ranking of the two wage rates and the direction of change in the share of high-technology jobs. As stated in Proposition 4, under Pareto-distributed productivity a reduction in variable trade costs raises the share of high-technology jobs, Λ_h. From Lemma 1, a cost of effort function with non-increasing elasticity implies that high-technology firms pay the higher wage. Thus, under these assumptions trade liberalization raises the mean to minimum wage ratio. This leads to the following proposition.

Proposition 7. *Suppose that the firms' initial productivity is Pareto-distributed with $k > \sigma - 1$ and the cost of effort has non-increasing elasticity. Then a reduction in variable trade costs leads to greater wage inequality.*

How does a reduction in variable trade costs affect the utility of workers? On the one hand, there is the macro effect through the change in ρV_U, hence in V_U. It directly affects all the unemployed and, as the $V(q_s)$'s are proportional to V_U, all the employed as well. Under the conditions stated in Proposition 6 a reduction in variable trade costs raises V_U and thus benefits the unemployed and all workers that stay employed at firms that do not upgrade their monitoring technology. On the other hand, there are losses in utility that occur through the reallocation of labour across firms. The least productive firms are forced to exit so that all workers at these firms lose their jobs. This too happens to workers employed at firms that are hit by a bad shock. Additional job losses occur because non-exporting firms not only experience a loss of revenue but also cut their employment levels. [20] Furthermore, the lower innovation cutoff induces more firms to upgrade their monitoring technology. Under the assumption of an isoelastic cost of effort workers employed at these firms lose through the upgrade.

4.5 Numerical Illustration

In this section I simulate the model under the assumptions that the cost of effort has constant elasticity and the distribution of initial productivity is Pareto. The aim is to illustrate the main

[20] Using (14) and (27) yields $\ell_{ds}(\varphi) = [(\sigma-1)/\sigma\rho V_U][\psi(q_s)/e(q_s)]r_{ds}(\varphi)$. Using this together with the zero cutoff profit condition $r_{dl}(\varphi_d) = \sigma f$ leads to

$$\ell_{ds}(\varphi) = \frac{f(\sigma-1)}{\rho V_U}\frac{[\psi(q_s)]^\sigma}{e(q_s)}\left(\frac{\varphi}{\psi(q_l)\varphi_d}\right)^{\sigma-1}, \quad s = l, h.$$

Therefore, a decrease in τ reduces the employment levels of non-exporting firms if it raises ρV_U.

results and assess the magnitude of some of the effects triggered off by reductions in variable trade costs.

When choosing the range of possible values for the variable trade cost τ, one has to take into account that the equilibrium conditions apply only to the case where the innovation cutoff is not smaller than the exporting cutoff ($\varphi_h > \varphi_x$). The range of possible values of τ can be found by using equation (20). The ratio $\tau^{1-\sigma}/(1+\tau^{1-\sigma})$ takes its maximum value of 1/2 for $\tau = 1$. The percentage increase in fixed costs due to adopting technology h is $\eta - 1$, and the percentage increase in a firm's revenue entailed by switching to technology h is $(\psi(q_h)/\psi(q_l))^{\sigma-1} - 1$. The latter is the larger, the higher q_h is relative to q_l. Thus, for given values of fixed costs f and f_x, the ratio $(\eta-1)/[(\psi(q_h)/\psi(q_l)^{\sigma-1} - 1]$ must be sufficiently large for there to be a range of τ with $\varphi_h/\varphi_x > 1$. The values of τ must then satisfy [21]

$$\tau < \tau_{\text{sup}} = \left[\frac{(\eta-1)f}{\left[\left(\frac{\psi(q_h)}{\psi(q_l)} \right)^{\sigma-1} - 1 \right] f_x} - 1 \right]^{\frac{1}{\sigma-1}} . \tag{42}$$

The workers' cost of effort is assumed to be quadratic, having the form $C(e) = e^2/2$. This implies that the level of effort as a function of q , $e(q)$, is the relevant solution to a biquadratic equation defined by equation (9). [22]

Modeling the distribution of initial productivity as a Pareto distribution implies additional restrictions on the parameter choices. For the integrals in the free entry condition (21) and other equations to converge, the shape parameter k must satisfy $k > \sigma - 1$. Even with that condition satisfied there is no guarantee for an equilibrium to exist. In contrast to the case of a general form of a continuous productivity distribution with support $(0, \infty)$, in the case of Pareto-distributed productivity the existence of an equilibrium depends on the values of fixed costs. In particular, the fixed entry cost f_e must not be too large relative to the fixed costs of production, f, and exporting, f_x. In the subsequent example illustrated by Figure 3 the following parameters are used: $\varphi_{\min} = 1$, $k = 3.4$, $\sigma = 3.8$, $\rho = 0.04$, $\delta = 0.05$, $f = 1$, $f_x = 1.2$, $f_e = 40$, $q_l = 0.3$, $q_h = 0.6$, $\eta = 2.7$, and $L = 1$. The variable trade cost is lowered from 1.58 to 1.01. [23]

Panel (a) of Figure 3 shows the variation in the three cutoffs. Most strikingly, the change in the innovation cutoff φ_h is minimal: it falls from 2.05 to 2.02. By contrast, the domestic

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[21] The expression for τ_{sup} is obtained from (20) by setting $\varphi_h/\varphi_x = 1$ and solving for τ.

[22] It can be shown that

$$e(q) = \left\{ -\frac{q}{\rho+\delta} - 3 + \left[\left(\frac{q}{\rho+\delta} \right)^2 + \frac{10q}{\rho+\delta} + 9 \right]^{\frac{1}{2}} \right\}^{\frac{1}{2}} .$$

[23] The values of k and σ have been used in a number of simulations of Melitz-type models, e.g., in Ghironi and Melitz (2005) and Davis and Harrigan (2011).

Figure 3. Effects of trade liberalization

and exporting cutoffs exhibit considerable variation. The domestic cutoff, φ_d, rises from 1.21 to 1.4, while the exporting cutoff, φ_x, falls from 2.05 to 1.51. As a consequence, there is also substantial variation in the share of exporting firms, which under Pareto-distributed productivity is $(\varphi_d/\varphi_x)^k$. Panel (b) of Figure 3 shows that it increases roughly to three and a half times the initial value. The variation in the share of firms using the advanced monitoring technology, $(\varphi_d/\varphi_h)^k$, is shown in panel (c) of Figure 3. It rises from 0.17 to 0.29, an increase almost entirely generated by the increase in the domestic cutoff. The share of high-technology jobs is much higher than the share of high-technology firms, as revealed by panel (d) of Figure 3. This reflects the fact that high-technology firms are large, employing on average much more workers than low-technology firms. It should also be noticed that the increase in the share of high-technology jobs, Λ_h, is considerably smaller than the increase in the share of high-technology firms: Λ_h rises by roughly 5%, whereas the share of high-technology firms increases by 70%. This is due to the fact that the change in Λ_h is the result of four effects. One of them, a large one, is caused by the reduction in the exporting cutoff and works against the other three. This tends to reduce the share of high-technology jobs because more and more low-technology firms enter the export market.

Wages are proportional to the flow value of being unemployed, ρV_U. With the assumed isoelastic cost of effort, we have $w_h > w_l$. Both wage rates increase by the same percentage as ρV_U, as illustrated in panel (e) of Figure 3. In the numerical example the percentage increase is almost 25%. The variation in the mean to minimum wage ratio is shown in panel (f) of Figure 3. According to (40) the mean to minimum ratio is $\Lambda_h(w_h - w_l)/w_l + 1$. The relative wage gap, $(w_h - w_l)/w_l$ remains constant at about 4.5%. The share of high-technology jobs rises from 0.81 to 0.85. As a result, the mean to minimum ratio increases by only a small amount, from 1.0366 to 1.0384.

The response of the unemployment rate u to variations in τ is depicted in panel (g) of Figure 3. As can be seen from equation (26), u is increasing in $\overline{\nu}$, the ratio of the average value of being employed to the value of being unemployed. This ratio can be written as $\overline{\nu} = \Lambda_h[\nu(q_h) - \nu(q_l)] + \nu(q_l)$. The assumption of an isoelastic cost of effort implies that $\nu(q_h) < \nu(q_l)$. Since the share of high-technology jobs, Λ_h, rises when τ is reduced, $\overline{\nu}$ and hence unemployment will decrease. In the example the unemployment rate responds very little to changes in variable trade costs, falling only from 6.22% to 6.10%. This is because both the difference between the $\nu(q_s)$'s and the increase in Λ_h are small, implying that $\overline{\nu}$ decreases by a tiny 0.1%. On the other hand, as shown by panel (h) of Figure 3, final output increases by about 25%, which is similar to the percentage increase in wages. A key message therefore is that the substantial increase in final output and wages following trade liberalization is attributable to the reallocation of labour from less to more productive firms, not to a reduction in unemployment.

5 Conclusion

The model presented in this paper integrates efficiency wages into a framework of trade and technology adoption with heterogeneous firms. After their productivity draw from a known distribution firms can choose between a basic and an advanced monitoring technology. Worker effort is assumed to be a continuous variable. There is a link between firm productivity and adoption of monitoring technology. The most productive firms adopt the advanced monitoring technology, which enables them to monitor their workers more intensively. The binary choice of monitoring technology generates heterogeneous wages. Each of the monitoring technologies requires a specific wage rate that induces workers to exert the profit-maximizing level of effort. In general, however, it cannot be said which type of firm pays the higher wage. The reason is that there are always two opposing effects from higher monitoring accuracy: on the one hand, firms can offer a lower wage to induce workers to provide a given level of effort; on the other hand, with better monitoring firms wish to elicit more effort, which requires a higher wage. The sign of the total effect depends on the shape of the workers' cost of effort function. It is shown that if its elasticity is non-increasing, the most productive firms will pay a higher wage. A feature of Melitz (2003)-style models of firm heterogeneity is that the most productive firms are also the largest ones in terms of revenue or employment. Therefore, under the mentioned condition it is the largest firms that pay higher wages, in accordance with the evidence on an employer size-wage premium. However, large firms do not do so because they have more difficulties with monitoring their workers, as predicted by standard efficiency wage models. On the contrary, they can pay their workers higher wages because they use a superior monitoring technology, which makes it profitable to elicit more effort.

The model is used to study the effects of trade liberalization between symmetric countries on unemployment and wages. Trade liberalization occurs through a reduction in variable trade costs. It is shown that the response of both unemployment and wages hinges on the change in the share of better monitored jobs in the economy, which in general cannot be signed. The effect on unemployment additionally depends on which type of job leaves workers better off, which in general cannot be predicted either. The effects on wages in addition depend on the (generally ambiguous) ranking of firm wages. Conditions are provided under which the model still yields sharp predictions. Under those conditions a decrease in variable trade costs raises the share of better monitored jobs, lowers unemployment, and raises wages in both countries. It also leads to greater wage inequality. Furthermore, lower variable trade costs increase the utility of the unemployed as well as all workers who maintain employment at firms that do not upgrade their monitoring technology.

Appendix

Proof of Lemma 1

Implicit differentiation of (9) gives

$$\frac{\partial e(q)}{\partial q} = \frac{1 + C(e(q)) - eC'(e(q))}{2(\rho+\delta)[1 + C(e(q))]C'(e(q)) + (q+\rho+\delta)eC''(e(q))}. \tag{A1}$$

Inserting (A1) into (10) yields [24]

$$\begin{aligned}
\frac{\partial w(q)}{\partial q} &= \frac{\rho V_U}{[q-(\rho+\delta)C]^2 D}\Big[-(\rho+\delta)(q+\rho+\delta)C(1+C)eC'' - 2(\rho+\delta)^2(1+C)^2CC' + \cdots \\
&\quad + q(q+\rho+\delta)(1+C-eC')C'\Big] \\
&= \frac{\rho V_U}{[q-(\rho+\delta)C]^2 N}(\rho+\delta)^2\Big[-\frac{q+\rho+\delta}{\rho+\delta}C(1+C)eC'' - 2(1+C)^2CC' + \cdots \\
&\quad + \frac{q}{\rho+\delta}\frac{q+\rho+\delta}{\rho+\delta}(1+C-eC')C'\Big], \qquad (A2)
\end{aligned}$$

where $D \equiv 2(\rho+\delta)(1+C)C' + (q+\rho+\delta)eC''$. Dividing the Solow condition (9) by $\rho+\delta$ and solving for $q/(\rho+\delta)$ gives

$$\frac{q}{\rho+\delta} = \frac{C(1+C)+eC'}{1+C-eC'}, \tag{A3}$$

and

$$\frac{q+\rho+\delta}{\rho+\delta} = \frac{q}{\rho+\delta} + 1 = \frac{(1+C)^2}{1+C-eC'}. \tag{A4}$$

Substituting the expressions (A3) and (A4) into (A2) gives

$$\frac{\partial w(q)}{\partial q} = \frac{\rho V_U}{[q-(\rho+\delta)C]^2 D}\frac{(1+C)^2}{1+C-eC'}\left\{(1+C)\left[-CC' - eCC'' + e(C')^2\right] + eC(C')^2\right\}. \tag{A5}$$

Differentiating the elasticity of the cost of effort, $eC'(e)/C(e)$, with respect to e one obtains $\varepsilon' \equiv d\varepsilon(e)/de = \frac{1}{C^2}[C(C'+eC'') - e(C')^2]$. Using this and the fact that $1 + C > eC'$ (from (A3)) yields

$$\begin{aligned}
\text{sign}\left\{\frac{\partial w(q)}{\partial q}\right\} &= \text{sign}\left\{(1+C)[-CC' - eCC'' + e(C')^2] + eC(C')^2\right\} \\
&= \text{sign}\left\{(1+C)C^2(-\varepsilon') + eC(C')^2\right\}, \qquad (A6)
\end{aligned}$$

Thus, for $\partial w(q)/\partial q > 0$, hence for $w(q_h) > w(q_l)$, it is sufficient that the elasticity of the cost of effort is non-increasing ($\varepsilon'(e) \le 0$).

[24] To avoid notational clutter, in the expressions that follow I drop the argument $e(q)$ in the function $C(e(q))$ and its derivatives if appropriate.

Proof of Proposition 2

The proof of existence and uniqueness of the domestic cutoff φ_d can be provided along similar lines as for the Melitz (2003) model (see Melitz and Redding, 2014). Relative revenues of firms within the same market using the same technology are given by

$$\frac{r_{js}(\varphi_1)}{r_{js}(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}, \quad j = d, x; \quad s = l, h. \tag{A7}$$

Relative revenues of firms within the same market using different technologies are given by

$$\frac{r_{jh}(\varphi_1)}{r_{jl}(\varphi_2)} = \left(\frac{\psi(q_h)}{\psi(q_l)}\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}, \quad j = d, x. \tag{A8}$$

In terms of revenues from domestic and foreign sales the free entry condition (21) can be written as

$$[1 - G(\varphi_d)]\left\{\int_{\varphi_d}^{\varphi_h}\left[\frac{r_{dl}(\varphi)}{\sigma} - f\right]\frac{dG(\varphi)}{1 - G(\varphi_d)} + \int_{\varphi_h}^{\infty}\left[\frac{r_{dh}(\varphi)}{\sigma} - \eta f\right]\frac{dG(\varphi)}{1 - G(\varphi_d)} \cdots\right. \tag{A9}$$

$$\left. + \frac{1 - G(\varphi_x)}{1 - G(\varphi_d)}\left\{\int_{\varphi_x}^{\varphi_h}\left[\frac{r_{xl}(\varphi)}{\sigma} - f_x\right]\frac{dG(\varphi)}{1 - G(\varphi_x)} + \int_{\varphi_h}^{\infty}\left[\frac{r_{xh}(\varphi)}{\sigma} - f_x\right]\frac{dG(\varphi)}{1 - G(\varphi_x)}\right\}\right\} = (\rho + \delta)f_e.$$

Using (A7), (A8), the zero-profit condition (15) for domestic sales, and the zero-profit condition (16) for exports, (A9) can be rewritten as

$$f\left\{\int_{\varphi_d}^{\varphi_h}\left[\left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{\varphi_h}^{\infty}\left[\left(\frac{\psi(q_h)}{\psi(q_l)}\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - \eta\right]dG(\varphi)\right\} \cdots$$

$$+ f_x\left\{\int_{\varphi_x}^{\varphi_h}\left[\left(\frac{\varphi}{\varphi_x}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{\varphi_h}^{\infty}\left[\left(\frac{\psi(q_h)}{\psi(q_l)}\frac{\varphi}{\varphi_x}\right)^{\sigma-1} - 1\right]dG(\varphi)\right\} = (\rho + \delta)f_e.$$

or

$$f\left\{\int_{\varphi_d}^{\infty}\left[\left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{\varphi_h}^{\infty}\left[\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right)\left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - (\eta - 1)\right]dG(\varphi)\right\} \cdots$$

$$+ f_x\left\{\int_{\varphi_x}^{\infty}\left[\left(\frac{\varphi}{\varphi_x}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{\varphi_h}^{\infty}\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right)\left(\frac{\varphi}{\varphi_x}\right)^{\sigma-1}dG(\varphi)\right\}$$

$$= (\rho + \delta)f_e. \tag{A10}$$

Using the relationship (17) between φ_x and φ_d and the relationship (19) between φ_h and φ_d, equation (A10) becomes

$$f\left\{\int_{\varphi_d}^{\infty}\left[\left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{K_2\varphi_d}^{\infty}\left[\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right)\left(\frac{\varphi}{\varphi_d}\right)^{\sigma-1} - (\eta - 1)\right]dG(\varphi)\right\} \cdots$$

$$+ f_x\left\{\int_{K_1\varphi_d}^{\infty}\left[\left(\frac{\varphi}{K_1\varphi_d}\right)^{\sigma-1} - 1\right]dG(\varphi) + \int_{K_2\varphi_d}^{\infty}\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right)\left(\frac{\varphi}{K_1\varphi_d}\right)^{\sigma-1}dG(\varphi)\right\}$$

$$= (\rho + \delta)f_e, \tag{A11}$$

where $K_1 \equiv \tau(f_x/f)^{1/(\sigma-1)}$ and $K_2 \equiv \{(\eta-1)/\left[(1+\tau^{1-\sigma})\left((\psi(q_h)/\psi(q_l))^{\sigma-1}-1\right)\right]\}^{1/(\sigma-1)}$. Given the parameters, the left-hand side of (A11) is a function of the domestic cutoff φ_d alone. The left-hand side tends to infinity as φ_d tends to zero, and it tends to zero as φ_d tends to infinity. Differentiating the left-hand side, denoted $H(\varphi_d;\cdot)$, of (A11) with respect to φ_d and cancelling each of the terms $g(\varphi_d)$ and $g(\varphi_x)K_1$ we get

$$
\begin{aligned}
\frac{\partial H}{\partial \varphi_d} &= f\left\{(1-\sigma)\varphi_d^{-\sigma}\int_{\varphi_d}^{\infty}\varphi^{\sigma-1}dG(\varphi) + \left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}-1\right)\left[-K_2^{\sigma-1}g(\varphi_h)K_2 \cdots\right.\right.\\
&\quad + \left.\left.(1-\sigma)\varphi_d^{-\sigma}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right] + (\eta-1)g(\varphi_h)K_2\right\}\cdots\\
&\quad + f_x\left\{(1-\sigma)\varphi_x^{-\sigma}K_1 + \left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}-1\right)\left[-\left(\frac{K_2}{K_1}\right)^{\sigma-1}g(\varphi_h)K_2 \cdots\right.\right.\\
&\quad + \left.\left.(1-\sigma)\varphi_x^{-\sigma}K_1\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\right\}\\
&= (1-\sigma)\left\{\varphi_d^{-\sigma}f\left[\int_{\varphi_d}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\cdots\right.\\
&\quad + \left.\varphi_x^{-\sigma}K_1 f_x\left[\int_{\varphi_x}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\right\}, \qquad \text{(A12)}
\end{aligned}
$$

using the fact that in the first equation of (A12) the terms ending with $g(\varphi_h)K_2$ add up to zero. From $\sigma > 1$, the left-hand side of (A11) is monotonically decreasing in φ_d. Thus, the free entry condition (A11) determines a unique equilibrium value of the domestic cutoff φ_d.

Proof of Proposition 3

With τ being treated as a variable, equation (A11) implicitly defines φ_d as a function of τ: $H(\varphi_d,\tau) = (\rho+\delta)f_e$, where $H(\cdot)$ again stands for the left-hand side of (A11). The derivative of this function is $\partial\varphi_d/\partial\tau = -(\partial H/\partial\tau)/(\partial H/\partial\varphi_d)$. The partial derivative $\partial H/\partial\varphi_d$ is known from (A12). Differentiating $H(\cdot)$ with respect to τ and cancelling the $g(\varphi_x)\varphi_d(\partial K_1/\partial\tau)$'s gives

$$
\begin{aligned}
\frac{\partial H}{\partial \tau} &= f\left[-\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}-1\right)K_2^{\sigma-1}g(\varphi_h)\varphi_d\frac{\partial K_2}{\partial\tau} + (\eta-1)g(\varphi_h)\varphi_d\frac{\partial K_2}{\partial\tau}\right]\cdots\\
&\quad + f_x\left\{-\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}-1\right)\left(\frac{K_2}{K_1}\right)^{\sigma-1}g(\varphi_h)\varphi_d\frac{\partial K_2}{\partial\tau}\cdots\right.\\
&\quad + \left.(1-\sigma)\varphi_x^{-\sigma}\varphi_d\frac{\partial K_1}{\partial\tau}\left[\int_{\varphi_x}^{\infty}\varphi^{\sigma-1}dG(\varphi) + \left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}-1\right)\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\right\}\\
&= (1-\sigma)\varphi_x^{-\sigma}\varphi_d\frac{\partial K_1}{\partial\tau}f_x\left[\int_{\varphi_x}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right], \qquad \text{(A13)}
\end{aligned}
$$

using the fact that in the first equation of (A13) the terms ending with $g(\varphi_h)\varphi_d(\partial K_2/\partial\tau)$ add up to zero.

From (A12) and (A13),

$$\frac{1}{\varphi_d}\frac{\partial \varphi_d}{\partial \tau} = -\frac{1}{\tau\Delta} f_x \varphi_x^{1-\sigma}\left[\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right] < 0, \tag{A14}$$

$$\begin{aligned} \Delta \ \equiv\ & f\varphi_d^{1-\sigma}\left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right]\cdots \\ & + f_x\varphi_x^{1-\sigma}\left[\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right]. \end{aligned}$$

Differentiating (17) with respect to τ and using (A14) and (17) gives

$$\frac{1}{\varphi_x}\frac{\partial \varphi_x}{\partial \tau} = \frac{1}{\tau\Delta} f\varphi_d^{1-\sigma}\left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right] > 0. \tag{A15}$$

Differentiating (19) with respect to τ and using (A14) and (19) gives

$$\begin{aligned} \frac{1}{\varphi_h}\frac{\partial \varphi_h}{\partial \tau} \ =\ & \frac{1}{\tau\Delta(1+\tau^{1-\sigma})}\left\{\tau^{1-\sigma} f\varphi_d^{1-\sigma}\left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right]\cdots \right. \\ & \left. -f_x\varphi_x^{1-\sigma}\left[\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right]\right\}. \end{aligned}$$

From (17), $\tau^{1-\sigma} f\varphi_d^{1-\sigma} = f_x\varphi_x^{1-\sigma}$. Hence,

$$\begin{aligned} \frac{1}{\varphi_h}\frac{\partial \varphi_h}{\partial \tau} &= \frac{\tau^{1-\sigma} f\varphi_d^{1-\sigma}}{\tau\Delta(1+\tau^{1-\sigma})}\left(\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) - \int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi)\right) \\ &= \frac{\tau^{1-\sigma} f\varphi_d^{1-\sigma}}{\tau\Delta(1+\tau^{1-\sigma})}\int_{\varphi_d}^{\varphi_x} \varphi^{\sigma-1} dG(\varphi) > 0. \end{aligned} \tag{A16}$$

Derivation of Equation (36)

To see that aggregate revenue of the intermediate goods sector equals final output, i.e., $M\bar{r} = Y$, first note that the aggregate cost of the home final-good sector has two components: the aggregate value of home intermediate goods used in home production plus the aggregate value of imported intermediate goods. The former equals the aggregate revenue of the home intermediate goods sector from domestic sales. With iceberg per-unit trade costs the aggregate value of intermediate goods imported from the foreign country equals the aggregate revenue of the foreign intermediate goods sector from exporting. The final good is produced from home and foreign intermediate inputs with a constant returns to scale technology and the final-good sector is competitive. Therefore, the aggregate cost of the home final good sector equals its aggregate revenue, PY, and, from $P = 1$, its output Y. As the countries are symmetric, each of the aggregate variables takes on the same value in the home and the foreign country. This is also true of the aggregate revenue from domestic sales and exporting in both countries. This implies that $Y = R = R^* = Y^*$. [25]

Using (14) and (34), average revenue can be written as

$$\bar{r} = Y \left[\frac{\sigma - 1}{\sigma} \frac{\widetilde{\varphi}}{\rho V_U} \right]^{\sigma - 1}. \tag{A17}$$

Substituting (A17) for $\bar{r}$ into $M = Y/\bar{r}$ and canceling Y yields (33). Combining equations (31), (32), and (33) leads to

$$L_D = f(\sigma - 1) \left(\frac{\sigma}{\sigma - 1} \frac{1}{\psi(q_l)\varphi_d} \right)^{\sigma - 1} \frac{\lambda}{\widetilde{\varphi}^{\sigma - 1}} (\rho V_U)^{\sigma - 2}, \tag{A18}$$

where

$$\begin{aligned} \lambda \quad \equiv \quad & \frac{1}{1 - G(\varphi_d)} \left\{ \frac{[\psi(q_l)]^\sigma}{e(q_l)} \left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) + \tau^{1 - \sigma} \int_{\varphi_x}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) \right] \cdots \right. \\ & \left. + \frac{[\psi(q_h)]^\sigma}{e(q_h)} (1 + \tau^{1 - \sigma}) \int_{\varphi_h}^{\infty} \varphi^{\sigma - 1} dG(\varphi) \right\}. \end{aligned} \tag{A19}$$

and $\widetilde{\varphi}$ is given by (34).

A final step is to show that

$$(1 - \Lambda_H)\omega(q_L) + \Lambda_H \omega(q_H) = \frac{\widetilde{\varphi}^{\sigma - 1}}{\lambda}. \tag{A20}$$

Using (29) together with the definitions of $\widetilde{\varphi}$ in (34) and λ in (A19) gives

$$\begin{aligned} & (1 - \Lambda_h)\omega(q_l) + \Lambda_h \omega(q_h) \\ = \quad & \frac{1}{[1 - G(\varphi_d)]\lambda} \left\{ \frac{e(q_l)}{\psi(q_l)} \frac{[\psi(q_l)]^\sigma}{e(q_l)} \left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) + \tau^{1 - \sigma} \int_{\varphi_x}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) \right] \cdots \right. \\ & \left. + \frac{e(q_h)}{\psi(q_h)} \frac{[\psi(q_h)]^\sigma}{e(q_h)} (1 + \tau^{1 - \sigma}) \int_{\varphi_h}^{\infty} \varphi^{\sigma - 1} dG(\varphi) \right\} \\ = \quad & \frac{1}{[1 - G(\varphi_d)]\lambda} \left\{ [\psi(q_l)]^{\sigma - 1} \left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) + \tau^{1 - \sigma} \int_{\varphi_x}^{\varphi_h} \varphi^{\sigma - 1} dG(\varphi) \right] \cdots \right. \\ & \left. + [\psi(q_h)]^{\sigma - 1} (1 + \tau^{1 - \sigma}) \int_{\varphi_h}^{\infty} \varphi^{\sigma - 1} dG(\varphi) \right\} \\ = \quad & \frac{[1 - G(\varphi_d)]\widetilde{\varphi}^{\sigma - 1}}{[1 - G(\varphi_d)]\lambda} = \frac{\widetilde{\varphi}^{\sigma - 1}}{\lambda}. \end{aligned}$$

Using (A20) in (A18) yields (36).

---

[25] This result also holds in other models which share with the present one a similar production structure, e.g., in Egger and Kreickemeier (2009).

Proof of Proposition 4

Using the partial derivatives of Λ_h with respect to τ, φ_d, φ_x, and φ_h, the total effect of a change in τ on the share of high-technology jobs can be written as

$$\frac{d\Lambda_h}{d\tau} = \frac{\partial\Lambda_h}{\partial\tau} + \frac{\partial\Lambda_h}{\partial\varphi_d}\frac{\partial\varphi_d}{\partial\tau} + \frac{\partial\Lambda_h}{\partial\varphi_x}\frac{\partial\varphi_x}{\partial\tau} + \frac{\partial\Lambda_h}{\partial\varphi_h}\frac{\partial\varphi_h}{\partial\tau}. \tag{A21}$$

Differentiating (29) with respect to τ, φ_d, φ_x, and φ_h yields

$$\frac{d\Lambda_h}{d\tau} = \frac{1}{\Gamma^2}(1-\sigma)\tau^{-\sigma}\frac{[\psi(q_l)]^\sigma}{e(q_l)}\frac{[\psi(q_h)]^\sigma}{e(q_h)}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\int_{\varphi_d}^{\varphi_x}\varphi^{\sigma-1}dG(\varphi)\ < 0,$$

$$\frac{d\Lambda_h}{d\varphi_d} = \frac{1}{\Gamma^2}\frac{[\psi(q_l)]^\sigma}{e(q_l)}\frac{[\psi(q_h)]^\sigma}{e(q_h)}(1+\tau^{1-\sigma})\varphi_d^{\sigma-1}g(\varphi_d)\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\ > 0,$$

$$\frac{d\Lambda_h}{d\varphi_x} = \frac{1}{\Gamma^2}\frac{[\psi(q_l)]^\sigma}{e(q_l)}\frac{[\psi(q_h)]^\sigma}{e(q_h)}\tau^{1-\sigma}(1+\tau^{1-\sigma})\varphi_x^{\sigma-1}g(\varphi_x)\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\ > 0,$$

$$\frac{d\Lambda_h}{d\varphi_h} = -\frac{1}{\Gamma^2}\frac{[\psi(q_l)]^\sigma}{e(q_l)}\frac{[\psi(q_h)]^\sigma}{e(q_h)}(1+\tau^{1-\sigma})\varphi_h^{\sigma-1}g(\varphi_h)\left(\int_{\varphi_d}^{\infty}\varphi^{\sigma-1}dG(\varphi)+\tau^{1-\sigma}\int_{\varphi_x}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right)\ < 0,$$

where

$$\Gamma \equiv \frac{[\psi(q_l)]^\sigma}{e(q_l)}\left(\int_{\varphi_d}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)+\tau^{1-\sigma}\int_{\varphi_x}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)\right)+\frac{[\psi(q_h)]^\sigma}{e(q_h)}(1+\tau^{1-\sigma})\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi).$$

Next combine the partial derivatives of Λ_h with respect to φ_d, φ_x, and φ_h with the changes in the cutoffs given by (A14) to (A16) to obtain: $(\partial\Lambda_h/\partial\varphi_d)(\partial\varphi_d/\partial\tau) < 0$, $(\partial\Lambda_h/\partial\varphi_x)(\partial\varphi_x/\partial\tau) > 0$, and $(\partial\Lambda_h/\partial\varphi_h)(\partial\varphi_h/\partial\tau) < 0$. Since $\partial\Lambda_h/\partial\tau < 0$, a sufficient condition for $d\Lambda_h/d\tau < 0$ is that

$$\frac{\partial\Lambda_h}{\partial\varphi_d}\frac{\partial\varphi_d}{\partial\tau} + \frac{\partial\Lambda_h}{\partial\varphi_x}\frac{\partial\varphi_x}{\partial\tau} \leq 0.$$

Using (A14), (A15), and (17) yields

$$\begin{aligned}
&\frac{\partial\Lambda_h}{\partial\varphi_d}\frac{\partial\varphi_d}{\partial\tau} + \frac{\partial\Lambda_h}{\partial\varphi_x}\frac{\partial\varphi_x}{\partial\tau} = \\
&\quad\frac{1}{\tau\Gamma^2\Delta}\frac{[\psi(q_l)]^\sigma}{e(q_l)}\frac{[\psi(q_h)]^\sigma}{e(q_h)}(1+\tau^{1-\sigma})f_x\varphi_x^{1-\sigma}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi) \\
&\quad\times\left\{-\varphi_d^\sigma g(\varphi_d)\left[\int_{\varphi_x}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)+\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\cdots\right. \\
&\quad\left.+\varphi_x^\sigma g(\varphi_x)\left[\int_{\varphi_d}^{\varphi_h}\varphi^{\sigma-1}dG(\varphi)+\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1}\int_{\varphi_h}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\right\}.
\end{aligned} \tag{A22}$$

For a general distribution of productivity the sign of $(\partial\Lambda_h/\partial\varphi_d)(\partial\varphi_d/\partial\tau)+(\partial\Lambda_h/\partial\varphi_x)(\partial\varphi_x/\partial\tau)$ is ambiguous because the expression in curly brackets in (A22) cannot be signed. Under the assumption of Pareto-distributed productivity this expression becomes

$$
\begin{aligned}
&-\varphi_d^{\sigma} g(\varphi_d)\left[\int_{\varphi_x}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right] \cdots \\
&+ \varphi_x^{\sigma} g(\varphi_x)\left[\int_{\varphi_d}^{\varphi_h} \varphi^{\sigma-1} dG(\varphi) + \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \int_{\varphi_h}^{\infty} \varphi^{\sigma-1} dG(\varphi)\right] \\
&= \frac{(k\varphi_{\min}^k)^2}{\sigma-1-k}\left[-\varphi_d^{\sigma-1-k}\left(\varphi_h^{\sigma-1-k} - \varphi_x^{\sigma-1-k} - \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \varphi_h^{\sigma-1-k}\right) \cdots \right. \\
&\left. + \varphi_x^{\sigma-1-k}\left(\varphi_h^{\sigma-1-k} - \varphi_d^{\sigma-1-k} - \left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} \varphi_h^{\sigma-1-k}\right)\right] \\
&= \frac{(k\varphi_{\min}^k)^2}{\sigma-1-k}\left(\left(\frac{\psi(q_h)}{\psi(q_l)}\right)^{\sigma-1} - 1\right) \varphi_h^{\sigma-1-k}\left(\varphi_d^{\sigma-1-k} - \varphi_x^{\sigma-1-k}\right). \qquad \text{(A23)}
\end{aligned}
$$

The fact that $\varphi_d < \varphi_x$ and the assumption that $k > \sigma - 1$ imply that $\varphi_d^{\sigma-1-k} > \varphi_x^{\sigma-1-k}$. As a consequence, the expression in (A23) is negative. Hence, $d\Lambda_h/d\tau < 0$.

Proof of Lemma 3

From equation (38), $\text{sign}\{\partial\nu(q)/\partial q\} = \text{sign}\{\partial[C(e(q))/q]/\partial q\}$. Differentiating $C(e(q))/q$ and substituting (A1) for $\partial e(q)/\partial q$ gives

$$
\begin{aligned}
\frac{\partial[C(e(q))/q]}{\partial q} &= \frac{1}{q^2}\left(qC'\frac{\partial e(q)}{\partial q} - C\right) \\
&= \frac{1}{q^2 D}\left[qC'(1+C-eC') - 2(\rho+\delta)(1+C)CC' - (q+\rho+\delta)eCC''\right], \qquad \text{(A24)}
\end{aligned}
$$

where $D \equiv 2(\rho+\delta)(1+C)C' + (q+\rho+\delta)eC''$. Multiply the Solow condition (9) by C' to obtain

$$
-(\rho+\delta)(1+C)CC' = (q+\rho+\delta)e(C')^2 - q(1+C)C'.
$$

Using this in (A24) yields

$$
\frac{\partial[C(e(q))/q]}{\partial q} = \frac{1}{q^2 D}\left[(q+\rho+\delta)(e(C')^2 - eCC'') + (\rho+\delta)e(C')^2 - q(1+C)C'\right],
$$

and after subtracting and adding $(q+\rho+\delta)CC'$ on the right-hand side of the equation,

$$
\begin{aligned}
\frac{\partial[C(e(q))/q]}{\partial q} &= \frac{1}{q^2}\left\{(q+\rho+\delta)[e(C')^2 - eCC'' - CC'] \cdots \right. \\
&\left. + (q+\rho+\delta)CC' + (\rho+\delta)e(C')^2 - q(1+C)C'\right\} \\
&= \frac{1}{q^2 D}\left\{-(q+\rho+\delta)C^2\varepsilon' + (\rho+\delta)C'\left[eC' - \left(\frac{q}{\rho+\delta} - C\right)\right]\right\}, \qquad \text{(A25)}
\end{aligned}
$$

using the fact that the derivative of the elasticity of $C(e)$ is $\varepsilon' \equiv d\varepsilon(e)/de = \frac{1}{C^2}[C(C' + eC'') - e(C')^2]$.

The Solow condition (9) can be rewritten as

$$\begin{aligned} eC' &= \frac{(1+C)[q-(\rho+\delta)]}{q+\rho+\delta} \\ &= \frac{1+C}{1+\frac{q}{\rho+\delta}}\left(\frac{q}{\rho+\delta}-C\right). \end{aligned} \tag{A26}$$

From (3) (as well as (9)), $q-(\rho+\delta)C>0$ or, equivalently, $q/(\rho+\delta)-C>0$. Hence, from (A26), $eC'<q/(\rho+\delta)-C$. Thus, from (A25), $\partial[C(e(q))/q]/\partial q<0$, hence $\partial\nu(q)/\partial q<0$ if $\epsilon'\geq 0$.

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