Skill-biased heterogeneous firms, trade liberalization and the skill premium

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Abstract. We propose a theory that rising globalization and rising wage inequality are related because trade liberalization raises the demand facing highly competitive skill-intensive firms. In our model, only the lowest-cost firms participate in the global economy exactly along the lines of Melitz (2003). In addition to differing in their productivity, firms differ in their skill intensity. We model skill-biased technology as a correlation between skill intensity and technological acumen, and we estimate this correlation to be large using firm-level data from Chile in 1995. A fall in trade costs leads to both greater trade volumes and an increase in the relative demand for skill, as the lowest-cost/most-skilled firms expand to serve the export market while less skill-intensive non-exporters retrench in the face of increased import competition. This mechanism works regardless of factor endowment differences, so we provide an explanation for why globalization and wage inequality move together in both skill-abundant and skill-scarce countries. In our model countries are net exporters of the services of their abundant factor, but there are no Stolper-Samuelson effects because import competition affects all domestic firms equally.

Résumé. Firmes hétérogènes à différentes intensité d'habileté, libéralisation du commerce, et prime à l'habileté. On propose une théorie qui suggère que mondialisation croissante et inégalité croissante des salaires sont co-reliées parce que la libéralisation du commerce accroît la demande des firmes hautement compétitives et à forte intensité d'habileté. Dans le modèle qu'on propose, seules les firmes aux coûts les plus faibles participent à l'économie mondiale, ainsi que le suggère Melitz (2003). En plus de différer par leur productivité, les firmes diffèrent aussi par l'intensité d'utilisation de l'habileté. On caractérise la technologie à intensité d'habileté comme une corrélation entre intensité d'habileté et sagacité technologique, et on estime que cette corrélation est grande en utilisant des données au niveau de la firme pour le Chili en 1995. Une baisse des coûts du commerce entraîne à la fois une croissance du volume du commerce et de la demande relative d'habileté, à proportion que les firmes à plus faibles coûts et utilisant plus intensivement l'habileté prennent de l'expansion pour servir le marché d'exportation, alors qu'il déclin des firmes non-exportatrices et utilisant moins intensément l'habileté face à la concurrence accrue des importations. Ce mécanisme est en opération quelle que soit les différences dans la dotation des facteurs, et fournit une explication de pourquoi mondialisation et inégalité des salaires vont de pair à la fois dans les pays où l'habileté est abondante et là où il y a

We thank the Bankard Fund for Political Economy at the University of Virginia for support. We thank John McLaren, Maxim Engers, Eric Young, Latchezar Popov, Çağlar Özden and seminar audiences in North America and Europe for helpful comments and suggestions.
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Canadian Journal of Economics / Revue canadienne d'économique, Vol. 48, No. 3
August 2015. Printed in Canada / Août 2015. Imprimé au Canada

0008–4085 / 16 / 1024–1066 /

rareté. Dans le modèle proposé, les pays sont exportateurs nets des services de leur facteur abondant, mais il n'y a pas d'effet Stolper-Samuelson, la concurrence de l'importation affecte toutes les firmes domestiques également.

JEL classification: F1, F16, J3, J31

1. Introduction

Two of the most striking trends in the global economy since 1970 are globalization and increasing wage inequality. For example, in the United States, the premium that college graduates earn over high school graduates grew by 35 percentage points between 1971 and 2005 (Autor et al. 2008). Over the same period, the ratio of trade to GDP in the US grew 15 percentage points.[1] Similar trends are apparent around the world, including in many developing countries (Goldberg and Pavcnik 2007). This raises an important but difficult question for applied economics: has increased globalization contributed to growing wage inequality? More precisely, have reductions in the costs of cross-border transactions led to both greater globalization and increased wage inequality?

There is a large, fascinating and inconclusive literature on this question. The primary alternative hypothesis to globalization is technological: skill-biased technological change, especially when embodied in information and communications technology investment (see, for example, Autor et al. 2003), has led to an increased relative demand for more educated workers.

In this paper we revisit this question using a model that combines skill-biased technology, heterogenous firms and factor endowment differences across countries. Our model is designed to be consistent with salient facts about firm heterogeneity and exporting activity. The first facts are that on average, exporters are larger and more skill intensive than non-exporters (see, for example, Bernard et al. 2007). More broadly, our model matches the correlation between size and skill intensity across firms. In addition, our model is designed to match the distribution of skill intensity across firms, as well as the overlap in this distribution for exporters and non-exporters. As we demonstrate below, these last two features are key components of the mechanism of how trade liberalization affects relative factor prices: inequality rises with trade liberalization, regardless of factor abundance. Despite this, and despite the fact that factor prices are not equalized, we find that factor abundance does predict net factor content of trade.

In our model, firms participate in the global economy exactly along the lines of Melitz (2003), namely only the most competitive, low-cost firms export. In addition to heterogeneity in their productivity, firms differ in their skill intensity. We model the skill bias of technology as a correlation between the skill share α and technological acumen φ. While the model accommodates any correlation, we focus on the empirically relevant case of a positive correlation, a specification

1 Our calculations, from United States National Accounts.

strongly supported by both data (ours and others') and theory.[2] Owing to this correlation, in equilibrium the most competitive firms are also the most skill-intensive, on average, despite the fact that skilled workers are more expensive (given realistic factor endowments).

Now consider trade liberalization. A fall in trade costs leads to both greater trade volumes and an increase in the relative demand for skill, as the most competitive, lowest-cost/high-skill firms expand to serve the export market while less competitive, less skill-intensive non-exporters retrench in the face of increased import competition. Since competitiveness comes together with higher demand for skill (on average), the changing composition of firms, together with changes in their sizes increase aggregate demand for skill and thus, the skill premium.

As long as productivity and skill intensity are positively correlated around the world, this mechanism works regardless of factor endowment differences. Thus, we provide an explanation for why globalization and wage inequality move together in both skill-abundant and skill-scarce countries. In our numerical analysis, we use plant-level data from Chile in 1995 to estimate a positive correlation between skill share and productivity. Using the numerical model, we show how multilateral trade liberalization raises average productivity and real GDP, and also increases the skill premium in both skill-abundant and skill-scarce countries, while net factor contents of trade reflect differences in factor abundances.

Some other models also predict that trade liberalization may increase the skill premium globally, including Feenstra and Hanson (1985), Acemoglu (2003), Zhu and Trefler (2005) and Burstein and Vogel (2012). What is new in our model is the interaction between skill intensity, factor endowment differences and firm heterogeneity with free entry. This means that our model is consistent with the evidence on firm-level heterogeneity and exporting (see Bernard et al. 2007 for a lucid discussion of this evidence) and is appropriate for long-run general equilibrium analysis. Free entry is important for determining the set of firms that operate in equilibrium and, as a consequence, affects the equilibrium joint distribution of skill, productivity and size—which is particularly important in the asymmetric country case.

Our paper builds on a large theoretical and empirical literature in international trade and labour economics. Two recent papers are most closely related to ours. Bernard et al. (2007) connect the Melitz model to the classic $2 \times 2 \times 2$ Heckscher-Ohlin-Samuelson model, and thereby integrate factor endowment differences with firm-level productivity and factor intensity differences. The model of Bernard et al. (2007) delivers a Stolper-Samuelson-like theorem and, as such,

2 There is a large body of work that indicates that throughout the 20th century newer and more efficient technologies have typically demanded more skilled (or better-educated) workers; see Goldin and Katz (2008) and references therein. Acemoglu (2002) provides a theoretical framework to explain this phenomenon, as well as the acceleration in the bias in favour of skilled labour post-1979 in the US. New technologies are embodied in new goods, and Xiang (2005) shows that new goods have higher skill intensity. Abowd et al. (2007) find a strong positive correlation between advanced technology and skill (both measured in various ways) in a cross-sectional analysis of US firms.

does not predict that relative factor prices will move in the same direction in both trading countries—a feature that is counterfactual. Burstein and Vogel (2012) develop a quantitative trade model that has a role for firm heterogeneity, and their treatment of skill-biased technology and its interaction with factor proportions offers an explanation for the rising skill premium in the North and the South that is similar to our explanation. However, since the model of Burstein and Vogel (2012) assumes Bertrand competition with no free entry, they do not address many of the margins of adjustment that we focus on below.

Other related papers are Yeaple (2005), Bustos (2011) and Vannoorenberghe (2011). These models of firm heterogeneity and trade feature skilled and unskilled workers and find that trade liberalization raises the relative demand for skill and thus the skill premium. The mechanism in Yeaple (2005) operates purely within firms, and thus rules out the empirically important between-firm compositional effects that we study. As our model does, the model in Vannoorenberghe (2011) features a relationship between firm-level skill intensity and productivity.[3] Vannoorenberghe's model does not allow for entry, and thus is not appropriate for long-run general equilibrium analysis, although Vannoorenberghe (2011) shows numerically that allowing for entry has a minimal effect on his results. Most importantly, the models in these papers analyze trade between identical countries only and thus do not address the effects of factor endowment differences that are a key feature of our model and of the global economy.

Our model treats each firm's production technology as fixed, with the factor market effects of trade liberalization due to a composition effect: high-skill firms gain market share globally at the expense of less skill-intensive firms. A complementary mechanism, which is not incorporated in our model, is that highly productive firms increase their skill intensity when faced with new export opportunities. This channel has been studied by Bas (2012) and by Bustos (2011), who finds that Argentinian exporters invested in skill-upgrading in response to liberalized trade with Brazil, with liberalization leading to about a two percentage point increase in the skill share for big relative to small firms.[4] Verhoogen (2008) finds that peso devaluation raised within-plant wage inequality in Mexican manufacturing and that this effect was stronger for initially more productive firms. Verhoogen (2008) plausibly interprets this result as support for within-plant quality and skill upgrading. A closely related general equilibrium theory of exporters endogenously adopting more skilled technologies is developed by Yeaple (2005). As noted above, however, both Yeaple's and Bustos's models consider only trade between *identical* countries and thus do not address the interactions between technology, trade and factor endowment differences that are our concern.

Other empirical studies have failed to find large effects of trade liberalization on firm-level or plant-level skill upgrading. In their influential early work, Bernard and Jensen (1997, 1999) find that the export-related skill-upgrading of US manufacturing was predominantly due to employment shifts that favour skill-intensive

3 The same is true of the model by Bas (2012), though her model takes the skill premium as fixed.
4 We refer here to the author's discussion in the first paragraph of section 4.2.2 of Bustos (2011).

plants, rather than differentially rapid skill-upgrading by exporters. Moreover, Bernard and Jensen (1997) show that most of these employment shifts are accounted for by exporters and are induced by demand-side factors (not technology), which is exactly the mechanism that our model highlights. Similarly, Trefler (2004) finds that more skilled Canadian manufacturing plants expanded their relative employment shares after trade liberalization with the United States, but did not engage in skill upgrading. We show below that more skilled Chilean manufacturing plants are more likely to be exporters, but their skill intensity is not affected by the export decision. Haltiwanger et al. (2007) show that firm-level heterogeneity is very persistent over time. This empirical evidence for the United States, Canada and Chile is consistent with the mechanism in our model.

Incorporating the mechanisms in Bustos (2011) and Verhoogen (2008) into our general equilibrium framework would render our model intractable, so in what follows we focus exclusively on between-firm rather than within-firm effects of trade liberalization on relative skill demand. It is clear that within-firm skill upgrading in response to trade liberalization will have effects on the equilibrium skill premium that are complementary to the channel we analyze.

Before developing the model, we illustrate the key empirical facts that provide the basis for the theory, using data from Chile. After the theory section, we return to these data in order to calibrate the model. This serves to illustrate its workings, with a focus on the effects of trade liberalization on the skill premium. In the final section, we offer concluding remarks.

2. Size, skill intensity and exporting

In this section, we make three points that jointly underpin our main modelling assumptions about productivity and skill intensity, using Chilean plant-level data. When we turn to numerical exercises in section 4, we calibrate key parameters of our model to match these facts.

First, there is a positive, but not perfect, correlation between size and skill intensity. Second, while exporters are more skill intensive on average, the distribution of skill intensity of exporters overlaps that of non-exporters. The third fact is that we do not find evidence of *exporting-induced* increases in skill intensity. While skill-biased technological change within plants may be taking place, exporting plants in our data do not differentially increase their skill intensity—either when they start exporting, before they start exporting, or while exporting—relative to non-exporting plants. This is in line with findings of Bernard and Jensen (1997) and Trefler (2004) for the US and Canada, respectively. At the same time we do find that size is associated with exporting along these dimensions in Chilean plants (when they start, before they start and while exporting), which is consistent with findings of Bernard and Jensen (1999) for the US.

These findings support our decision to model skill intensity as a parameter that is drawn from a primitive distribution jointly with productivity, where there is a positive correlation between the two. As mentioned above, this assumption simplifies the analysis and allows general equilibrium analysis. These findings also indicate that the Chilean plant-level data are a reasonable source of information for calibrating some of the key parameters of our model in section 4.

Our data source is the Annual National Industrial Survey of Chile, or ENIA (Encuesta Nacional Industrial Annual).[5] The ENIA is conducted annually by the Chilean government statistical office (Instituto Nacional de Estadistica) and covers the universe of Chilean manufacturing plants with 10 or more workers. Pavcnik (2002) indicates that in 1979–1986 more than 90% of Chilean manufacturing firms had only one plant, so the distinction between plants and firms is unlikely to be very important. Our concept of a skilled worker is captured in the ENIA by white-collar workers.[6] For each of these plants, we construct the following variables:

- Log revenue
- Export intensity = export revenue / total revenue
- Log average wage
- White-collar employment share
- White-collar wage bill share
- Export status (= 1 if export revenue > 0)

Standard regression-based methods (such as Olley-Pakes) of computing plant-level total factor productivity (TFP) are not applicable here. The reason is simple: regression-based TFP calculations need to assume that factor shares are constant across all plants. This is both empirically false (as we show immediately below) and contradicts the mechanism of our theory. The absence of plant-level TFP is not a drawback for our purposes, since in our model revenue is a sufficient statistic for productivity.

2.1. Cross-section evidence

In 1995, a total of 5,112 plants were surveyed. We eliminated 163 plants that did not report positive revenues. We also eliminated 346 plants that had either white-collar employment share or white-collar wage bill share equal to 0 or 1 (these coincide 93% of the times). These plants account for 5.3% of total revenue in the sample and are 30% smaller on average, but their distribution of revenues is not very dissimilar from the rest, so that this elimination does not affect much the overall distribution of revenues. However, only 4.6% of these plants export, compared to 24.3% of the other plants. Thus, we use a cross section of 4,603 plants in 1995, of which 24.3% are exporters.

5 We thank James Tybout for generously providing us with this data.
6 Proxying skill by "white collar" is problematic, though it is (by necessity) common practice in studies that plant-level data. Berman et al. (1994) show that for the United States, the production/non-production worker classification is a good proxy for skilled and unskilled workers.

TABLE 1
Descriptive statistics for Chilean plants, 1995

	Mean	Median	Std. dev.	Skew
Log revenue				
All	13.2	13	1.62	0.575
Domestic	12.7	12.6	1.36	0.643
Exporters	14.7	14.6	1.47	0.216
Log wage				
All	7.63	7.6	0.581	0.283
Domestic	7.51	7.49	0.536	0.305
Exporters	8	8	0.563	0.026
White-collar employment share				
All	0.233	0.2	0.151	1.2
Domestic	0.222	0.189	0.145	1.28
Exporters	0.268	0.236	0.164	0.96
White-collar wage bill share				
All	0.356	0.33	0.197	0.577
Domestic	0.326	0.3	0.185	0.696
Exporters	0.448	0.434	0.205	0.182

NOTES: Sample size is 4,603 total manufacturing plants, of which 3,485 (76%) are non-exporters and 1,118 (24%) are exporters. Units for revenue and wages are 1000s of pesos.
SOURCE: Annual National Industrial Survey of Chile, 1995.

Table 1 shows that exporting plants are larger and more skill-intensive than non-exporters. The distribution of log revenues for exporters is less skewed to the right, i.e., the largest exporters are closer to their respective mean than the largest firms that do not export. As with log revenues, we see that the distribution of the skill employment and wage bill shares for exporters are less skewed to the right. Figure 1 shows the wage bill shares for white-collar workers among exporters and non-exporters. The most interesting aspect of figure 1 is not the difference in median skill shares (which is well known) but the variability: many exporters have low skill shares, and conversely for non-exporters. In fact, the variation of the skill share within the exporter/non-exporter categories is essentially the same as the overall variation.[7] Table 2 shows that the overall correlation between log revenues and the white-collar wage bill share is positive, at 0.4. This correlation is slightly stronger so for non-exporters versus exporters. Figure 2 illustrates this relationship, and the variability in this figure motivates the key feature of our model: the positive but imperfect correlation between skill intensity and size. We

7 The overall standard deviation of the skill share is 0.197. Within exporters the standard deviation is 0.205, while within non-exporters it is 0.185. The R^2 of a regression of the skill share on an indicator for export status is just 0.07.

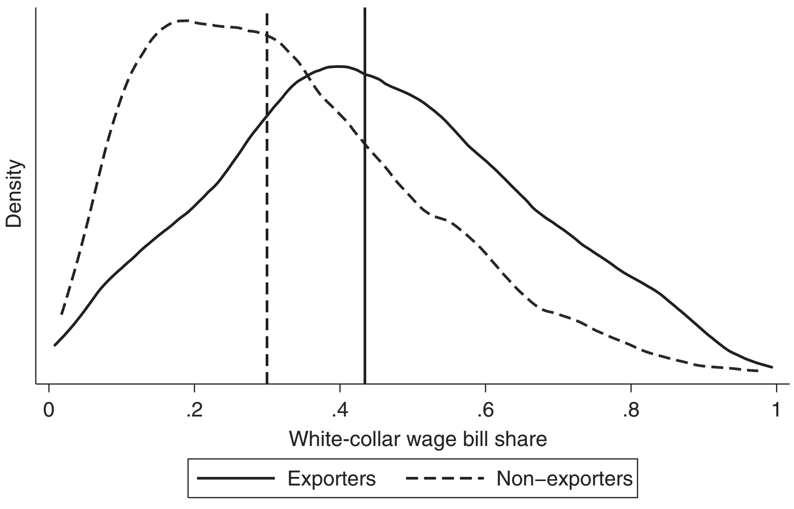

FIGURE 1 Distribution of white-collar wage bill shares kernel density plots, vertical lines at medians
NOTES: Data are white-collar employment shares in Chilean manufacturing plants in 1995, Annual National Industrial Survey of Chile. The sample includes 4,603 plants, of which 24% export.

TABLE 2
Correlations across Chilean plants, 1995

All plants ($N = 4{,}603$)	Log revenue	Log wage	Skill emp share
Log wage	0.65	1	
Skill emp share	0.23	0.43	1
Skill wage bill share	0.39	0.54	0.82
Non-exporting plants ($N = 3{,}485$)			
Log wage	0.58	1	
Skill emp share	0.18	0.35	1
Skill wage bill share	0.32	0.47	0.82
Exporting plants ($N = 1{,}118$)			
Log wage	0.57	1	
Skill emp share	0.24	0.58	1
Skill wage bill share	0.27	0.56	0.83

NOTES: All correlations are statistically significant at p-value of 0.01.
SOURCE: Annual National Industrial Survey of Chile, 1995.

exploit these differences when calibrating the joint distribution of skilled labour share and productivity in the model.

In addition, the firm-level skill share varies both within industries and across industries, but the within variation is much larger: between 4-digit ISIC indus-

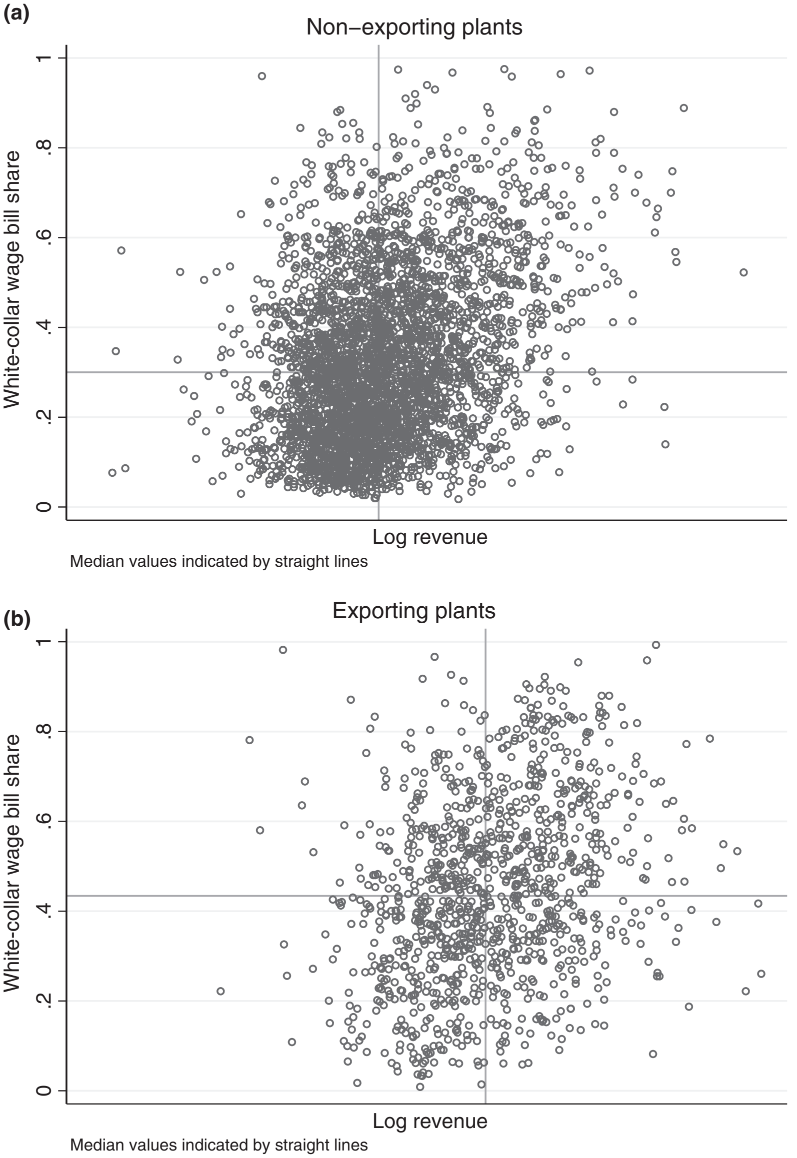

FIGURE 2 Skill share and log revenue, Chilean plants 1995
NOTE: See notes to table 1.

tries, the standard deviation of the skill share is 0.11, while within industries the standard deviation is more than half again as big, at 0.17. Dunne et al. (2004) find the exact same difference in US data. Therefore, it is not surprising that controlling for industry fixed effects does not alter the message of figures 1 and 2.

These findings support our decision to use a positive but imperfect correlation between skill share and productivity.

2.2. Exporting and skill intensity over time

There are at least two mechanisms that can account for a correlation between export status and skill intensity: skill-intensive plants select into exporting, or exporters choose to become more skill intensive. These mechanisms are not mutually exclusive. In our model, we focus on the first mechanism, though as noted in our introduction there is evidence in some data sets for the latter mechanism as well. In this subsection, we briefly investigate this question in our Chilean data.

Our tool is a series of simple panel regressions with plant and year fixed effects, along with indicators of export status:

$$y_{it} = \alpha_i + \alpha_t + \beta' \mathbf{x}_{it} + \varepsilon_{it},$$

where y_{it} is an outcome of interest (log revenue or wage bill share of skilled workers), $\mathbf{x}_{it}$ is a vector of export participation indicators and ε_{it} is interpreted simply as the prediction error from a linear projection.

We fit these regressions on three different samples. The first is all available plants and the second includes only plants that survive the entire sample. The third sample further restricts the second sample by keeping only exporters that export continuously for at least two years and never stop exporting once they start (i.e., the last year of exporting is invariably 1995). In each sample, we use a simple export participation indicator (=1 is plant exports in given year), and then we add indicators for plant-years before exporting starts for the first time and for plant-years after exporting commences. Estimation is by OLS with standard errors clustered by plant.

Table 3 shows our results. Panel A tells a simple and utterly unsurprising story: entering into exporting leads to big increases in revenue; revenue increases before starting to export and continues after that. Panel B, which investigates within-plant variation in the skill share over time, shows no statistically significant evidence of skill upgrading when plants enter into exporting. The firm fixed effects absorb virtually all the variation in skill intensity.[8] We obtain the same results when the regressand is the skilled employment share. As noted above, this is consistent with the evidence for the US and Canada. This supports our decision to model the skill share as a parameter that is drawn from a primitive distribution jointly with productivity and that does not respond to export opportunities.

8 Our results contrast with those of Bas (2012), who also analyzes the Chilean plant-level data, and find an effect of exporting on skill upgrading. We conjecture that the reason for the difference in findings is that Bas's specification excludes time fixed effects. Since both skill shares and export participation are trending up in the Chilean data, Bas's results may be conflating the effect of exporting and the omitted time trends.

TABLE 3
Chilean plant characteristics and exporting, 1990–1995

	(1)	(2)	(3)	(4)	(5)	(6)
A. Dependent variable: Log revenue						
4 years before export		−0.261***		−0.196***		–
		(0.059)		(0.059)		–
3 years before export		−0.151***		−0.106**		−0.187***
		(0.042)		(0.042)		(0.060)
2 years before export		−0.137***		−0.100***		−0.096***
		(0.031)		(0.031)		(0.034)
1 years before export		−0.079***		−0.055**		−0.064***
		(0.026)		(0.022)		(0.022)
Export dummy	0.168***	0.096***	0.130***	0.064***	0.214***	0.090***
	(0.018)	(0.020)	(0.015)	(0.016)	(0.022)	(0.022)
Export year 2		0.061***		0.040***		0.046***
		(0.014)		(0.012)		(0.013)
Export year 3		0.085***		0.049***		0.049***
		(0.017)		(0.016)		(0.018)
Export year 4		0.096***		0.044**		0.048**
		(0.020)		(0.019)		(0.021)
Export year 5		0.133***		0.101***		0.099***
		(0.021)		(0.021)		(0.023)
Export year 6		0.158***		0.149***		0.152***
		(0.026)		(0.027)		(0.028)
Year effects	No	Yes	No	Yes	No	Yes
R2, within	0.009	0.020	0.008	0.037	0.010	0.038
Observations	26,817	26,817	17,820	17,820	15,468	15,468
Number of plants	6,077	6,077	2,970	2,970	2,578	2,578
Number of exporters	1,698	1,698	1,056	1,056	664	664
B. Dependent Variable: Wage bill share of skilled workers						
4 years before export		0.0130		0.0155		–
		(0.018)		(0.018)		–
3 years before export		−0.0050		−0.0038		0.0010
		(0.012)		(0.012)		(0.018)
2 years before export		0.0040		0.0075		−0.0035
		(0.009)		(0.009)		(0.012)
1 years before export		0.0032		0.0060		0.0012
		(0.006)		(0.007)		(0.010)
Export dummy	0.0005	0.0013	0.0019	0.0029	0.0067	0.0057
	(0.004)	(0.004)	(0.004)	(0.005)	(0.008)	(0.008)
Export year 2		−0.0008		0.0001		−0.0004
		(0.004)		(0.004)		(0.005)
Export year 3		−0.0008		0.0012		−0.0011
		(0.004)		(0.005)		(0.005)
Export year 4		0.0031		0.0000		−0.0001
		(0.005)		(0.005)		(0.006)
Export year 5		−0.0001		−0.0050		−0.0056
		(0.006)		(0.006)		(0.007)
Export year 6		−0.0023		−0.0038		−0.0056
		(0.007)		(0.007)		(0.008)

TABLE 3
(Continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Year effects	No	Yes	No	Yes	No	Yes
R2, within	0.000	0.000	0.000	0.001	0.000	0.001
Observations	26,817	26,817	17,820	17,820	15,468	15,468
Number of plants	6,077	6,077	2,970	2,970	2,578	2,578
Number of exporters	1,698	1,698	1,056	1,056	664	664

NOTES: All regressions include plant fixed effects. Standard errors with clustering at the plant level are reported in parentheses. ***p< 0.01, **p< 0.05, *p< 0.1. In columns 1 and 2, we include all available plants. In columns 3 and 4, we restrict the sample to plants that survive the entire sample. In columns 5 and 6, we further restrict the sample by keeping only exporters that export continuously for at least two years and never stop exporting once they start (i.e., the last year of exporting is invariably 1995).
SOURCE: Annual National Industrial Survey of Chile 1990–1995. See text for more details.

3. Theory

In the Melitz model, there is one factor of production, and firms are identical up to a Hicks neutral productivity parameter φ that shifts marginal cost. In an important paper, Bernard et al. (2007) combine the Melitz model with the classic $2 \times 2 \times 2$ Heckscher-Ohlin-Samuelson model, which yields rich interactions between firm heterogeneity and factor proportions differences across sectors and countries. Our model takes a different approach to combining firm heterogeneity with factor proportions differences: we assume that firms differ continuously in *two* dimensions, productivity and the share of skilled labour in total cost (henceforth, "skill share"). Just as Melitz's assumption of heterogeneous firm productivity was motivated by the evidence, our assumption of heterogeneity in the skill share is motivated by the fact that skill intensity varies at least as much within conventionally-defined industries as it does between. Dunne et al. (2004) find this for the US (see their figure 1), and we find it in our Chilean firm dataset (see below).

In this section, we first develop the basic structure of our model and then analyze equilibrium in two cases. The first case considers trade between two identical countries, and the second introduces differences in aggregate factor endowment across countries.

3.1. Skill-biased heterogeneous firms

As in Melitz (2003), firms in our model must incur a sunk cost before discovering their variable cost function. Production requires both skilled and unskilled labour, which are paid s and w, respectively. We assume that variable cost functions are Cobb-Douglas and differ in two dimensions, the skill share in marginal cost α and productivity in marginal cost φ:

$$c_v(\alpha,\varphi,s,w)=s^{\alpha}w^{1-\alpha}\varphi^{-1}. \tag{1}$$

Applying Shepard's lemma, it follows that skilled labour demand in variable cost per unit output is:

$$h_v\left(\alpha,\varphi,\frac{s}{w}\right)=\alpha\left(\frac{s}{w}\right)^{\alpha-1}\varphi^{-1}. \tag{2}$$

Similarly, unskilled labour demand in variable cost per unit output is:

$$l_v\left(\alpha,\varphi,\frac{s}{w}\right)=(1-\alpha)\left(\frac{s}{w}\right)^{\alpha}\varphi^{-1}. \tag{3}$$

Because φ is a Hicks-neutral productivity shifter, factor intensity in variable cost does not depend on productivity:

$$\frac{h}{l}\left(\alpha,\frac{s}{w}\right)=\frac{\alpha}{1-\alpha}\left(\frac{w}{s}\right).$$

Inverse marginal cost, which we will refer to as "competitiveness" is:

$$\phi(\alpha,\varphi,s,w)=\frac{\varphi}{s^{\alpha}w^{1-\alpha}}. \tag{4}$$

The technology parameters α and φ are drawn simultaneously from a joint distribution function $G(\alpha,\varphi)$. As will be seen below, firms that have the same value of ϕ but differ in α will be alike in almost every respect (revenue, profitability, export status, etc.) except for their factor demands. Thus, while in Melitz (2003) and Bernard et al. (2007) firms within an industry are indexed only by their productivity φ, in our model the relevant index will in most settings be competitiveness ϕ.[9]

There are three fixed cost activities in our model: entry, production for domestic sale and exporting. While factor intensity in variable costs differ across firms in our model, we assume that factor intensity in fixed costs are common across firms. The fixed cost functions are:

$$c_{f_e}(s,w)=\omega(s,w)f_e, \tag{5}$$

$$c_f(s,w)=\omega(s,w)f, \tag{6}$$

$$c_{f_x}(s,w)=\omega(s,w)f_x, \tag{7}$$

where f_e, f and f_x denote fixed costs associated with entry, domestic production and exporting, respectively. The factor cost term $\omega(s,w)$ is the same for all firms and fixed cost activities. Furthermore, we assume that the factor intensity of fixed costs is constant and equal to the economy's overall factor abundance:

$$\omega(s,w)=\beta s+(1-\beta)w, \tag{8}$$

9 In the Greek alphabet, the symbols ϕ and φ are simply different representations of the same letter, pronounced "phi." The reader may find it useful to mentally pronounce the symbol ϕ as "phi" and the symbol φ as "var-phi."

$$\frac{\beta}{1-\beta}=\frac{H}{L}, \tag{9}$$

where H and L are the economy's inelastic aggregate supplies of skilled and unskilled workers, respectively. An implication of (8) is that the average wage in fixed cost activities is the economy's average wage. Because we want to restrict the heterogeneity of firms to differences in their variable costs, we assume that α and φ do not affect productivity in fixed costs. As will be seen below, the fixed factor proportions assumption neutralizes the effect of variations in entry on aggregate relative factor demands.

3.2. Demand

Preferences are given by a standard symmetric CES utility function with elasticity of substitution $\sigma > 1$. The assumed market structure is monopolistic competition. As is well-known for this setup, firms charge a price p, which is a constant markup over marginal cost. Marginal cost is $1/\phi$ for sales in the domestic market d and τ/ϕ for sales in the export market x, where $\tau > 1$ is an iceberg transport cost factor, so:

$$p_d(\phi)=\frac{1}{\rho\phi}, \tag{10}$$

$$p_x(\phi)=\frac{\tau}{\rho\phi}, \tag{11}$$

where $\rho=\frac{\sigma-1}{\sigma}\in(0,1)$.

Our assumptions on demand imply that consumer preferences over goods have no connection to the factor intensity of goods' production. This is a natural specification, since preferences and production techniques are logically separate concepts, and there is no particular empirical reason to think that they are linked. However, this assumption is in sharp contrast to the Heckscher-Ohlin tradition in trade theory. In the canonical $2\times2\times2$ model, the two homogeneous goods differ in their factor intensity, there is a finite elasticity of substitution between the goods and an infinite elasticity of substitution across "varieties" within goods. In their integration of monopolistic competition into the $2\times2\times2$ model, Helpman and Krugman (1985) maintain this ranking of elasticities of substitution in less extreme form: there is a finite elasticity of substitution $\sigma > 1$ across varieties produced with a given factor intensity and a smaller elasticity of substitution across varieties produced with different factor intensities. The same assumptions on preferences are made by Bernard et al. (2007). Like our model, the model of Romalis (2004) features monopolistic competition and Cobb-Douglas production where the factor cost shares vary continuously. Following Dornbusch et al. (1980), Romalis identifies goods with their factor intensity and assumes that the elasticity of substitution across goods is one while the elasticity across varieties within goods is greater than one. As will become clear in what follows, our decision to break with this Heckscher-Ohlin tradition and sever the link between preferences and production technology has major implications for how factor markets respond to trade liberalization.

3.3. *Equilibrium with identical countries*

In this section, we consider trade between two countries that are identical in every way, including their factor endowments H and L and the distribution $G(\alpha, \varphi)$ from which entering firms draw their technology.[10] Generalizing our analysis to more than two symmetric countries is trivial. Entering firms must pay a fixed cost $\omega(s, w) f_e$ to learn their technology, a fixed cost $\omega(s, w) f$ if they wish to sell in the domestic market and a fixed cost $\omega(s, w) f_x$ if they wish to export. Much of this section is based closely on Melitz (2003), so we move quickly.

3.3.1 Firm behaviour

With monopolistic competition and CES preferences, firm-level demand depends on aggregate nominal income R and the aggregate price index P. Since prices depend only on each firm's competitiveness ϕ, revenue and sales will differ across two firms if and only if they differ in ϕ. Standard computations show that the associated sales revenue r and profits π from domestic sales d and exporting x are:

$$r_d(\phi) = R(\rho P)^{\sigma-1} \phi^{\sigma-1}, \tag{12}$$

$$r_x(\phi) = \tau^{1-\sigma} r_d(\phi), \tag{13}$$

$$\pi_d(\phi) = \frac{r_d(\phi)}{\sigma} - \omega(s, w) f, \tag{14}$$

$$\pi_x(\phi) = \frac{r_x(\phi)}{\sigma} - \omega(s, w) f_x. \tag{15}$$

Note that we have defined $\pi_x(\phi)$ as the profit from exporting only. If a firm sells in both export and domestic markets, then its aggregate profits will be $\pi_d(\phi) + \pi_x(\phi)$.

Firms will sell in a market only if profits from doing so are non-negative. Thus, equations (14) and (15) implicitly define the minimum levels of ϕ for which firms will choose to sell at home and abroad:

$$r_d(\phi^*) = \sigma\omega(s, w) f, \tag{16}$$

$$r_x(\phi_x^*) = \sigma\omega(s, w) f_x. \tag{17}$$

Dividing (17) by (16) and substituting using (12) and (13) implies:

$$\phi_x^* = \phi^* \tau \left(\frac{f_x}{f} \right)^{\frac{1}{\sigma-1}}. \tag{18}$$

10 We assume that $G(\alpha, \varphi)$ is twice continuously differentiable over its support $[0, 1] \times \mathbb{R}_+^1$.

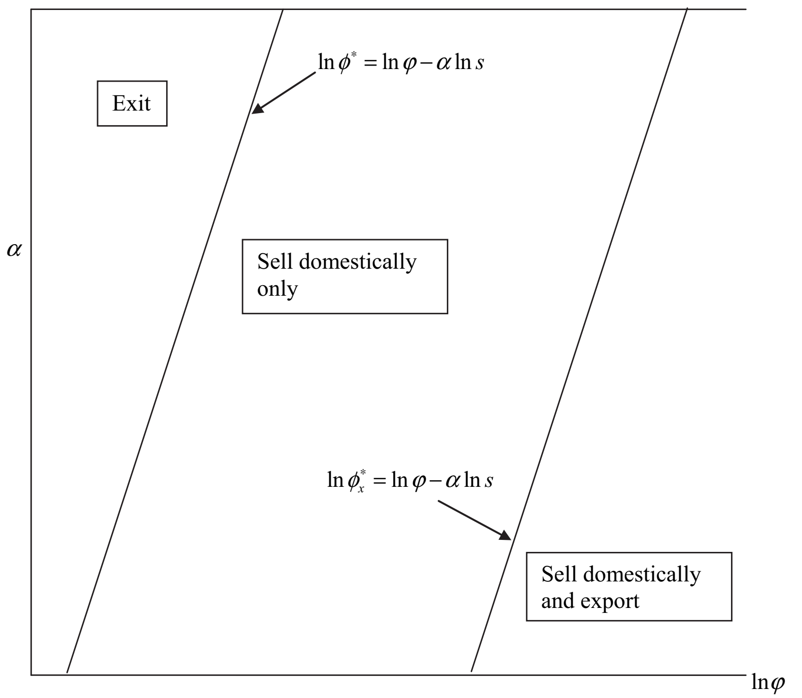

FIGURE 3 Sorting and the technology space
NOTES: Log inverse unit cost is $\ln\phi = \ln\varphi - \alpha \ln s$, $s > 1$ (for the purpose of these figures, we choose the unskilled wage w as our numeraire). The survival cutoff $\phi*$ and the export cutoff ϕ_x^* partition the space into three regions: technology draws where costs are too high to survive in equilibrium, cost draws low enough for profitable domestic sales but too high for exporting and cost draws low enough for profitable exporting.

As long as $\tau(f_X/f)^{\frac{1}{\sigma-1}} > 1$, then $\phi_x^* > \phi^*$. This implies that all exporting firms will also sell domestically and the highest cost surviving firms will not export. We will maintain this realistic parameter restriction in all of what follows.

The cutoffs ϕ^* and ϕ_x^* define regions in the (α, φ) space:

$$D\left(\phi^*, s, w\right) = \left\{(\alpha, \varphi) \in [0,1] \times \mathbb{R}_+^1 : \phi^* \leqslant \frac{\varphi}{s^\alpha w^{1-\alpha}}\right\}, \tag{19}$$

$$X(\phi_x^*, s, w) = \left\{(\alpha, \varphi) \in [0,1] \times \mathbb{R}_+^1 : \phi_x^* \leqslant \frac{\varphi}{s^\alpha w^{1-\alpha}}\right\}. \tag{20}$$

All firms with $(\alpha, \varphi) \in D$ are active in equilibrium while firms with $(\alpha, \varphi) \in X$ are also exporters, where $X \subset D$. These regions are illustrated in figure 3. After paying the entry fixed cost and before discovering its technology, the ex ante probability that a potential firm is active and/or an exporter is the probability that it draws a technology (α, φ) in D or X, respectively:

$$\chi_d = \Pr[(\alpha, \varphi) \in D] = \iint\limits_{(\alpha,\varphi)\in D} g(\alpha, \varphi)\, d\alpha d\varphi, \tag{21}$$

$$\chi_x = \Pr[(\alpha, \varphi) \in X] = \iint\limits_{(\alpha,\varphi)\in X} g(\alpha, \varphi)\, d\alpha d\varphi, \tag{22}$$

where $g(\alpha, \varphi) = \partial^2 G/\partial\alpha\partial\varphi$ is the joint density associated with $G(\alpha, \varphi)$. Conditional on selling domestically, the probability of being an exporter is $\chi = \chi_x/\chi_d < 1$.

3.3.2 Free entry

There is an unbounded mass of risk-neutral potential entrants. Free entry implies that in equilibrium the expected value of entry is equal to the fixed entry cost. To develop this free entry condition, we follow Bernard et al. (2007), who simplify the treatment of free entry in Melitz (2003).

The weighted average competitiveness of all active firms and exporters, respectively, are:

$$\tilde{\phi}(\phi^*) = \left[\chi_d^{-1} \iint\limits_{(\alpha,\varphi)\in D} \phi(\alpha, \varphi)^{\sigma-1} g(\alpha, \varphi)\, d\alpha d\varphi \right]^{\frac{1}{\sigma-1}}, \tag{23}$$

$$\tilde{\phi}_x(\phi_x^*) = \left[\chi_x^{-1} \iint\limits_{(\alpha,\varphi)\in X} \phi(\alpha, \varphi)^{\sigma-1} g(\alpha, \varphi)\, d\alpha d\varphi \right]^{\frac{1}{\sigma-1}}. \tag{24}$$

The average firm will make variable profits $\pi_d(\tilde{\phi})$, while the average exporter will make additional variable profits $\pi_x(\tilde{\phi}_x)$. Thus, the expected profit conditional on entry is:

$$\bar{\pi} = \pi_d(\tilde{\phi}) + \chi \pi_x(\tilde{\phi}_x). \tag{25}$$

The average entrant will earn $\bar{\pi}$ until death, which arrives at rate δ. With no discounting, the expected value of entry is then $\chi_d \bar{\pi}/\delta$, so the free entry condition is:

$$\frac{\bar{\pi}}{\delta} \chi_d = \omega(s, w) f_e. \tag{26}$$

Using the cutoff conditions (16) and (17) together with the fact that $r_d(\phi') = r_d(\phi)(\phi'/\phi)^{\sigma-1}$ and the definitions of profit, the free entry condition (26) can be rewritten as:

$$f \int\int_{(\alpha,\varphi)\in D} \left[\left(\frac{\phi(\alpha,\varphi)}{\phi^*} \right)^{\sigma-1} - 1 \right] g(\alpha,\varphi) d\alpha d\varphi + \\ f_x \int\int_{(\alpha,\varphi)\in X} \left[\left(\frac{\phi(\alpha,\varphi)}{\phi_x^*} \right)^{\sigma-1} - 1 \right] g(\alpha,\varphi)\, d\alpha d\varphi = \delta f_e. \tag{27}$$

Although the factor cost terms $\omega(s,w)$ associated with the fixed costs do not appear in (27), factor prices do enter the equation because they help determine the boundaries of the sets D and X. Thus, unlike Bernard et al. (2007), it is necessary to solve for factor prices jointly with the cutoff ϕ^*.

3.3.3 Labour market equilibrium

The labour market equilibrium conditions in our model are quite different from the corresponding conditions in Melitz (2003) and Bernard et al. (2007). The reason is that in our model, each firm's demand for skilled and unskilled labour depends on its technology draw (α,φ) as well as factor prices. In particular, two firms that have the same level of ϕ, and thus the same prices, revenues, etc., may have different demands for labour.

From the expressions for inverse marginal cost, prices and revenue (equations equations 4, 10, 11, 12 and 13), we obtain total output for domestic sale and for export:

$$q_d(\alpha,\varphi) = R(P)^{\sigma-1} \left(\frac{\rho\varphi}{s^\alpha w^{1-\alpha}} \right)^\sigma, \tag{28}$$

$$q_x(\alpha,\varphi) = \tau^{1-\sigma} q_d(\alpha,\varphi). \tag{29}$$

Using (2) and (3) with (28) and (29), we can express each firm's demand for skilled and unskilled labour in variable cost. Labour demand per firm for domestic sales is, $\forall(\alpha,\varphi)\in D$:

$$\begin{aligned} H_{dv}(\alpha,\varphi,s,w) &= \rho^\sigma R P^{\sigma-1} \alpha s^{(1-\sigma)\alpha-1} w^{(1-\sigma)(1-\alpha)} \varphi^{\sigma-1} \\ &= \rho^\sigma R P^{\sigma-1} \times \tilde{H}_{dv}(\alpha,\varphi,s,w), \end{aligned} \tag{30}$$

$$\begin{aligned} L_{dv}(\alpha,\varphi,s,w) &= \rho^\sigma R P^{\sigma-1} (1-\alpha) s^{(1-\sigma)\alpha} w^{\sigma(\alpha-1)-\alpha} \varphi^{\sigma-1} \\ &= \rho^\sigma R P^{\sigma-1} \times \tilde{L}_{dv}(\alpha,\varphi,s,w). \end{aligned} \tag{31}$$

We have written labour demand per firm as the product of two terms, one which depends on the aggregates $RP^{\sigma-1}$ and one which depends on the firms technology (α,φ). Labour demand per firm for export sales is, $\forall(\alpha,\varphi)\in X$, a fraction $\tau^{1-\sigma}$ of domestic sales:

$$H_{xv}(\alpha,\varphi,s,w) = \tau^{1-\sigma} H_{dv}(\alpha,\varphi,s,w), \tag{32}$$

$$L_{xv}(\alpha,\varphi,s,w) = \tau^{1-\sigma} L_{dv}(\alpha,\varphi,s,w). \tag{33}$$

Total labour demand for exporters is the sum of labour used for domestic and export sales.

The mass of firms in the economy in equilibrium is M, and the mass of exporters is $M_x = \chi M$. To compute aggregate labour demand in variable cost, we integrate over the per-firm labour demands for all active firms and multiply by the mass of firms.[11] This gives aggregate labour demand:

$$H_v\left(s, w, \phi^*\right) = \chi_d^{-1} M \rho^\sigma R P^{\sigma-1} \times$$

$$\left[\iint\limits_{(\alpha,\varphi)\in D} \tilde{H}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi + \tau^{1-\sigma} \iint\limits_{(\alpha,\varphi)\in X} \tilde{H}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi \right], \tag{34}$$

$$L_v\left(s, w, \phi^*\right) = \chi_d^{-1} M \rho^\sigma R P^{\sigma-1} \times$$

$$\left[\iint\limits_{(\alpha,\varphi)\in D} \tilde{L}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi + \tau^{1-\sigma} \iint\limits_{(\alpha,\varphi)\in X} \tilde{L}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi \right]. \tag{35}$$

Dividing (34) by (35) gives aggregate relative skill demand in variable cost:

$$\frac{H_v(s, w, \phi^*)}{L_v(s, w, \phi^*)} = \frac{\iint\limits_{(\alpha,\varphi)\in D} \tilde{H}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi + \tau^{1-\sigma} \iint\limits_{(\alpha,\varphi)\in X} \tilde{H}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi}{\iint\limits_{(\alpha,\varphi)\in D} \tilde{L}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi + \tau^{1-\sigma} \iint\limits_{(\alpha,\varphi)\in X} \tilde{L}_{dv} g(\alpha,\varphi)\, d\alpha d\varphi}. \tag{36}$$

Next, we develop aggregate labour demand in fixed cost activities. Let the number of prospective new firms at each moment be M_e, of whom a fraction χ_d will produce after discovering their technology. In steady state equilibrium, the number of new firms per unit time equals the number of dying firms, $\chi_d M_e = \delta M$. Thus for each active firm, there are δ/χ_d entrants, of whom a fraction χ are also exporters. Using (5), (6) and (7) gives total fixed costs per active firm:[12]

$$\left[\beta s + \left(1-\beta\right) w\right] \left[\frac{\delta f_e}{\chi_d} + f + \chi f_x\right]. \tag{37}$$

By Shepard's lemma, skilled and unskilled labour demand in fixed cost activities are:

11 The densities for domestic and exporting firms equal $g(\alpha,\varphi)$ divided by the probabilities χ_d and χ_x, respectively.

12 See Baldwin (2005) for more on this treatment of fixed costs in the Melitz model.

$$H_f = M\beta\left[\frac{\delta f_e}{\chi_d} + f + \chi f_x\right], \tag{38}$$

$$L_f = M(1-\beta)\left[\frac{\delta f_e}{\chi_d} + f + \chi f_x\right]. \tag{39}$$

Dividing (38) by (39) gives aggregate relative skill demand in fixed cost activities as:

$$\frac{H_f}{L_f} = \frac{\beta}{1-\beta}. \tag{40}$$

By our parameterization of β in (9), it immediately follows that $H_f/L_f = H/L$. Thus variations in the level of fixed cost activities do not affect the aggregate relative skill supply available for variable cost production. This allows us to state the relative labour market clearing condition using (36) as:

$$\frac{H_v(s,w,\phi^*)}{L_v(s,w,\phi^*)} = \frac{H}{L}. \tag{41}$$

At this point, we choose the unskilled wage w as our numeraire, $w=1$, so s is the skill premium.[13] The relative labour market clearing condition (41) and the free entry condition (27) constitute a two equation system in two endogenous variables, s and ϕ^*. As will be seen in the next section, all the rest of the endogenous variables in the model are functions of ϕ^* and s, so equations (27) and (41) are the key equations for solving the symmetric country version of our model.

3.3.4 Aggregation and equilibrium

To close the model, we need to determine the aggregates M, R and P. Although w is our numeraire, we continue to write it out explicitly in what follows for clarity and to prepare for the analysis of the model with factor endowment differences in the next section.

As in Melitz (2003), the free entry condition implies that profits equal the expenditure on fixed costs, which in turn is paid to labour. Thus all revenue goes to labour, so:

$$R = sH + wL. \tag{42}$$

Revenue of the average firm is related to the profit of the average firm by $\bar{\pi} = \bar{r}/\sigma - \omega(s,w)(f + \chi f_x)$. Substituting from the free entry condition (26) gives:

$$\bar{r} = \sigma\omega(s,w)\left(f + \chi f_x + \frac{\delta f_e}{\chi_d}\right). \tag{43}$$

This allows us to determine the mass of firms:[14]

13 To ensure that $s \geqslant 1$, we assume that skilled workers can work as unskilled workers if they choose, but not vice versa.

$$M = \frac{R}{\bar{r}} = \frac{H+L}{\sigma\left(f + \chi f_x + \frac{\delta f_e}{\chi_d}\right)}. \tag{44}$$

The price index comes from the CES utility function and depends on the prices of domestically produced and imported goods. Using the pricing equations (10) and (11) in the standard formula for the CES price index gives:

$$P = \left[M\left(\rho\tilde{\phi}_d\right)^{\sigma-1} + \chi M\left(\frac{\rho}{\tau}\tilde{\phi}_x\right)^{\sigma-1}\right]^{\frac{1}{1-\sigma}}. \tag{45}$$

This completes the description of the model in the case of identical countries. Equations (27) and (41) solve for ϕ^* and s. Equation (18) then determines ϕ_x^*, which allows computation of $\tilde{\phi}_d$ and $\tilde{\phi}_x$ using (23) and (24). The aggregates R, M and P can then be computed using equations (42), (44) and (45). All firm-level variables are functions of s, R and P.

3.3.5 Trade liberalization and the skill premium

In our model, as in Melitz (2003), exporters are low cost firms. In the data, a common finding is that exporters are more skill intensive than non-exporting firms, even within industries. We will present data below that illustrates the skill bias of exporters for Chile, and the same is true for the United States (see, for example, table 3 in Bernard et al. 2007). In this section, we show the factor market consequences of trade liberalization in the empirically relevant case of skill-biased technology. We also analyze the case where there is no relationship between technology and the skill share.

Skill-biased technology. If the skill premium is positive ($s/w > 1$), then firms with higher skill shares will have higher costs, controlling for productivity φ. Therefore, in our model the only way for exporters to be more skill-intensive than the average is if skill share α and productivity φ are sufficiently positively correlated when firms draw their technology parameters. In such a case, a high skill share is on average associated with high competitiveness ϕ. For now, we simply assume such a correlation in the ex ante technology distribution $G(\alpha, \varphi)$, and we will calibrate the correlation in the numerical analysis below.

What does our model imply about the labour market effects of opening to trade? Holding factor prices fixed for the moment, our model works exactly like Melitz (2003) opening to trade reduces revenue in the domestic market because of import competition and creates opportunities for extra revenue in the export market. In the new equilibrium, the survival cutoff ϕ^* rises, and with costly trade, the export cutoff ϕ_x^* is higher than ϕ^*. For new exporters, labour demand rises, while for non-exporters labour demand falls. By our assumption on $G(\alpha, \varphi)$, the exporting firms are more skill intensive on average than the non-exporting firms, so the expansion of the former and the contraction of the latter means a shift

14 Here we use $\omega(s, w) = \frac{sH + wL}{H+L}$ to simplify.

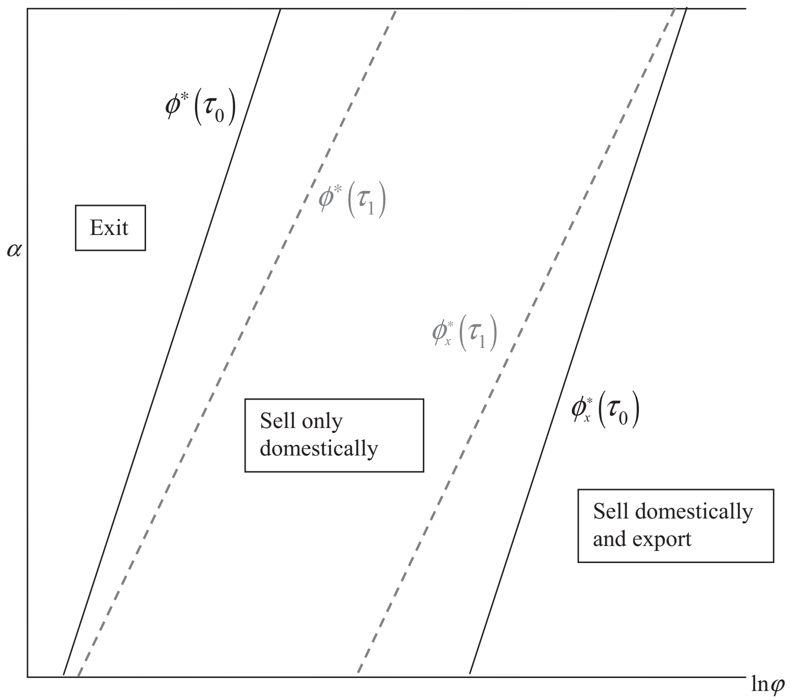

FIGURE 4 Trade liberalization
NOTE: The dotted lines show what happens when tarrif τ falls ($\tau_i < \tau_0$): survival cutoff rises, the export cutoff falls and the slope $\frac{1}{\ln s}$ gets flatter as the skill premium rises.

up in the relative demand for skill, equation (36). To satisfy the relative labour market clearing condition (41), the skill premium must rise. We thus have:

PROPOSITION 1 *Opening to trade between identical countries with skill-biased heterogeneous firms leads to a increase in the skill premium in both countries.*

Proof: See appendix A, available at cje.economics.ca.

The effects on the sets of surviving and exporting firms are illustrated in figure 4.

The result that trade liberalization may raise the skill premium appears in other models, as noted in our introduction. What is new in our model is the integration of relative labour demand effects with firm heterogeneity, as well as the ability of the model to match key moments in the data (see section 4, below).[15] Our model predicts that exporters are both more skill-intensive and more productive

15 Vannoorenberghe (2011) gets the same result in a closely related model, with one-dimensional firm heterogeneity and no free entry of firms. Vannoorenberghe (2011) does not move beyond the symmetric country case, however, which we do next.

than non-exporters, and it is this interaction that generates the increased skill premium with trade liberalization.

There are aggregate welfare gains from opening to trade in our model, but the factor price effects leave open the possibility that unskilled workers may see real wage losses from opening to trade. We investigate this issue in our numerical analysis below.

No skill bias in technology. We now consider the case where the skill share α and productivity φ are independent, so that the the ex ante technology distribution can be written as the product of the marginal distributions, $G(\alpha,\varphi) = G_\alpha(\alpha)G_\varphi(\varphi)$. There are no analytical results for this case in general. However, if the distribution of φ is Pareto and the distribution of α is uniform, we show in online appendix A that trade liberalization increases the survival cutoff for competitiveness ϕ^* and reduces the export cutoff ϕ^*_x but has no effect on the skill premium. The intuition for this result is straightforward: opening to trade has the standard pro-competitive effects, but the resulting changes in firm-level relative labour demand are not biased in favour of either skilled or unskilled labour. We also show that relative factor prices depend only on relative factor endowments. We collect these results in:

PROPOSITION 2 *When skill intensity α and productivity φ are independent, with φ distributed Pareto and α distributed uniform, and countries are identical, relative factor prices depend only on relative factor endowments. Trade liberalization raises the survival cutoff ϕ^* and reduces the export cutoff ϕ^*_x and has no effect on the skill premium.*

Proof: See online appendix A, available at cje.economics.ca.

Though proposition 2 holds only for particular choices for the distributions of α and productivity φ, in our numerical analysis below we show that trade liberalization between identical countries with no skill bias in technology has very close to zero effect on the skill premium. Propositions 1 and 2 together illustrate the point that it is skill-bias in technology that leads to factor market effects of trade liberalization in our model.

3.4. Equilibrium with factor endowment differences

In this section, we extend our model to consider trade between countries that differ in their relative factor endowments. We continue to assume that countries have the same cost functions and ex ante technology distributions $G(\alpha,\varphi)$. This is an interesting and relevant case, and the basic logic of the model is very similar to the identical country case. However, the need to keep track of two countries (who we denote by A and B superscripts) complicates the notation considerably. Where possible, we closely follow Bernard et al. (2007), who develop an elegant approach to analyzing non-identical countries in a Melitz-style model.

3.4.1 Firm behaviour and the entry and export cutoffs

Domestic revenue for a firm in country c depends only on the macro variables $R^c(P^c)^{\sigma-1}$ and inverse marginal cost:

$$r_d^c(\phi) = R^c(\rho P^c)^{\sigma-1}\phi^{\sigma-1}. \tag{46}$$

Variable profits from domestic sales are a fraction $1/\sigma$ of revenues, from which we subtract fixed costs to get profits in the domestic market, which defines the zero profit cutoff level of inverse marginal cost:

$$\pi_d^c(\phi) = \frac{r_d^c(\phi)}{\sigma} - \omega(s^c, w^c)f, \tag{47}$$

$$r_d^c(\phi^{*c}) = \sigma\omega(s^c, w^c)f. \tag{48}$$

Export revenue may differ from domestic market revenue for two reasons: transport costs τ and differences in $R^c(P^c)^{\sigma-1}$. Relative revenue in the home and export markets for firms located in the two countries are:

$$r_x^A(\phi) = \tau^{1-\sigma}\left(\frac{P^B}{P^A}\right)^{\sigma-1}\left(\frac{R^B}{R^A}\right) r_d^A(\phi) = \Upsilon^A r_d^A(\phi), \tag{49}$$

$$r_x^B(\phi) = \tau^{1-\sigma}\left(\frac{P^A}{P^B}\right)^{\sigma-1}\left(\frac{R^A}{R^B}\right) r_d^B(\phi) = \Upsilon^B r_d^B(\phi), \tag{50}$$

where r_x^c is export revenue for a firm located in c. The variable Υ^c is the relative size of c's export market compared to c's domestic market. This then defines the incremental profits from exporting and the export productivity cutoff:

$$\pi_x^c(\phi) = \frac{r_x^c(\phi)}{\sigma} - \omega(s^c, w^c)f_x, \tag{51}$$

$$r_x^c(\phi_x^{*c}) = \sigma\omega(s^c, w^c)f_x. \tag{52}$$

By relating the levels of domestic revenue at ϕ^{*c} and ϕ_x^{*c}, we can link the export cutoffs to the domestic cutoffs. A bit of algebra establishes:

$$\phi_x^{*A} = \tau\left(\frac{P^A}{P^B}\right)\left(\frac{R^A}{R^B}\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}\phi^{*A} = \Lambda^A\phi^{*A}, \tag{53}$$

$$\phi_x^{*B} = \tau\left(\frac{P^B}{P^A}\right)\left(\frac{R^B}{R^A}\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}\phi^{*B} = \Lambda^B\phi^{*B}. \tag{54}$$

It is instructive to compare these expressions to equation (18). Unlike in the identical country case, the endogenous variables R^c and P^c enter the relationship between ϕ^{*c} and ϕ_x^{*c}, so we can not ensure $\phi^{*c} < \phi_x^{*c}$ simply by a choice of parameters. Nonetheless, since exporters are generally found to be larger and more productive than non-exporters in the data, we will focus exclusively on equilibria where $\Lambda^c \geqslant 1$.

The cutoffs define regions of active and exporting firms as in equations (19) and (20), with c superscripts as appropriate. The same is true for the definitions of entry and export probabilities given by (21) and (22).

3.4.2 Free entry

The free entry condition in each country is virtually the same as in the identical country case. With appropriate c superscripts, the competitiveness averages $\widetilde{\phi}^c$ and $\widetilde{\phi}_x^c$ are defined as in equations (23) and (24), and the free entry conditions are given by (27). A complication relative to the identical country case is that the the aggregates R^c and P^c enter the free entry conditions, through equations (53) and (54).

3.4.3 Labour market equilibrium

In our development of the relative labour market clearing condition (41) in the identical country case, it was convenient that the aggregates R^c and P^c cancelled out when forming (41). This is no longer the case because of asymmetries in market sizes. In most instances the correct expressions can be obtained by replacing $\tau^{1-\sigma}$ with Υ^c.

With appropriate country superscripts on s, w, P and R, the equations relevant for labour market equilibrium are changed only slightly. Physical output for sale in the domestic market is as given by equation (28). Output for the export market is given by equation (29), except that $\tau^{1-\sigma}$ is replaced by Υ^c. The firm-level labour demand equations (30) and (31) are the same as before. Equations (32), (33), (34) and (35) are the same except that $\tau^{1-\sigma}$ is replaced by Υ^c. Because Υ^c now enters each aggregate labour demand equation, terms involving the aggregate variables R^c and P^c no longer cancel when dividing (34) by (35). The significance of this is that it is no longer possible to solve for factor prices separately from the aggregates R^c and P^c. Instead, factor market equilibrium requires setting labour demand in variable cost equal to labour supply minus labour used in fixed costs:

$$H_v^c(s^c, w^c, \phi^{*c}) = H^c - H_f^c, \tag{55}$$

$$L_v^c(s^c, w^c, \phi^{*c}) = L^c - L_f^c. \tag{56}$$

The treatment of labour used in fixed costs is unchanged, except that we introduce a technological difference across countries by letting the parameter $\beta^c = H^c/L^c$ be country specific. As in the identical country model, the purpose of this assumption is to neutralize any effects of entry on aggregate relative factor demand.

3.4.4 Aggregation and equilibrium

The determination of R and M follow equations (42) and (44), which are unchanged despite differences in factor endowments. For the price indices, we account for differences in $\tilde{\phi}^c$ and $\tilde{\phi}_x^c$, the mass of firms M^c and the conditional probability of exporting χ^c across countries:

$$P^A = \left[M^A \left(\rho\tilde{\phi}^A\right)^{\sigma-1} + \chi^B M^B \left(\frac{\rho}{\tau}\tilde{\phi}_x^B\right)^{\sigma-1}\right]^{\frac{1}{1-\sigma}}, \tag{57}$$

$$P^B = \left[M^B \left(\rho\tilde{\phi}^B\right)^{\sigma-1} + \chi^A M^A \left(\frac{\rho}{\tau}\tilde{\phi}_x^A\right)^{\sigma-1}\right]^{\frac{1}{1-\sigma}}. \tag{58}$$

This completes the description of the model with non-identical countries.

Although the underlying economics of the model is unchanged, solution is more challenging when countries are not identical because all the endogenous variables in both countries need to be solved simultaneously. The economics behind this complexity is that each country's per-firm demand shifter $R^c(P^c)^{\sigma-1}$ enters the other country's productivity cutoffs. We sketch our solution method here, with more details in online appendix B, available at cje.economics.ca.

Define the following vector of seven equilibrium variables:

$$\mu = (s^A, w^B, s^B, \phi^{*A}, \phi^{*B}, P^A, P^B),$$

where we set $w^A = 1$ as our numeraire. Given an arbitrary μ, the remaining equilibrium values can be determined as follows. First, we determine R^c from (42). Then, we can determine ϕ_x^{*c} by (53) and (54). Given all cutoffs and factor prices, we compute χ_d^c and χ^c using (21) and (22), as well as $\tilde{\phi}^c$ and $\tilde{\phi}_x^c$ using (23) and (24). Then, we can compute M^c from (44). μ is indeed an equilibrium if it satisfies seven equations: three factor market clearing conditions (equations (55) and (56) for each country, with one equation discarded as redundant), two free entry conditions (equation (27) for each country) and two price indices ((57) and (58)).

3.4.5 Trade liberalization and the skill premium

What effects do trade liberalization have in the asymmetric country version of our model? Full analysis can be done only numerically, but some insight can be gained through analytical reasoning. In all of what follows, we assume that country A ("North") is more skill abundant than country B ("South").

Consider the two countries in autarky. If skilled labour is sufficiently scarce, the skill premium will be positive in both countries and higher in B:

$$\left(\frac{s}{w}\right)^B > \left(\frac{s}{w}\right)^A > 1. \tag{59}$$

We consider two cases. The first is the "no skill bias" case, where φ and α are uncorrelated. The second, and empirically relevant, "skill biased" case is where φ and α are strongly positively correlated. Skill bias implies that unit costs and skill intensity are negatively correlated.

No skill bias in technology In the no bias case when (59) holds, in autarky there is a *negative* average relationship between unit costs and factor intensity, with more skill intensive firms having higher unit costs. In short, having a high skill share is bad news for a firm: it means that they have higher labour costs without, on average, any associated technological advantage.

Now consider an opening to costly trade. Holding factor costs fixed, this will lead to an expansion of the lower-cost firms in both countries and contraction or exit for higher cost firms. Because the low-cost firms are less skill intensive, this will lead to an increased relative demand for unskilled workers in both countries. So we have:

CONJECTURE 1 *If φ and α are uncorrelated and autarky skill premiums satisfy (59), then opening to costly trade leads to a fall in the skill premium in both countries.*

We are emphatically no longer in a Heckscher-Ohlin world. The reason is simple: in our model there is no connection between factor intensity and preferences. As a result, an increase in import competition in our model, whatever the skill content of the imported goods, affects demand for all domestically produced goods symmetrically. In models with a Heckscher-Ohlin structure, by contrast, an increase in import competition changes the relative demand for domestically produced goods. Because relative goods demand is directly linked to relative factor demands, Stolper-Samuelson type results follow. In our model, the factor price effects of opening to trade have nothing to do with demand and everything to do with supply: since skill-intensive firms have higher costs, opening to trade reduces the relative demand for skilled workers.

Skill-biased technology We now turn to the empirically relevant case, where skill intensity is associated with higher factor costs but also better technology on average. We focus on the case where the technology effect is dominant, so that on average more skill intensive firms have lower unit costs. Now consider an opening to costly trade. Holding factor costs fixed, this will lead to an expansion of the lower-cost firms in both countries and contraction or exit for higher cost firms. This will lead to an increase in the relative demand for skill in both countries. To restore factor market equilibrium, the skill premium must rise in both countries. We summarize this reasoning as:

CONJECTURE 2 *If productivity φ and α are strongly positively correlated, then opening to costly trade leads to a rise in the skill premium in both countries.*

We demonstrate below that conjectures 1 and 2 hold in our numerical simulations.

The insight that opening to trade raises the skill premium globally is similar to what we showed for identical countries in proposition 1, and the mechanism is the same here.

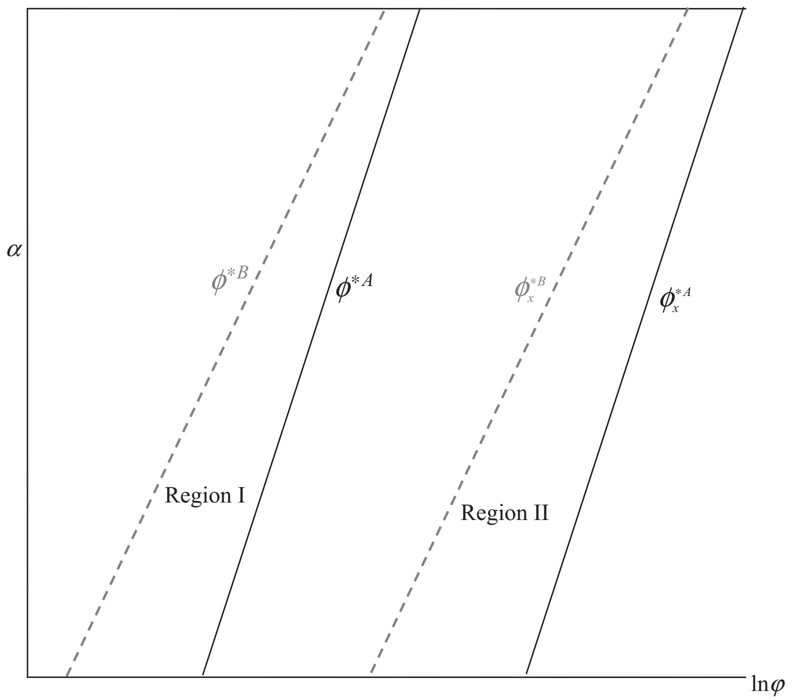

FIGURE 5 Specialization
NOTES: The solid lines are the survival and export cutoffs for country *A*, and the dashed lines are the survival and export cutoffs for country *B*. Region I contains non-exporters in *B* who would not survive in *A*, and Region II contains exporters in *B* who are non-exporters in *A*.

Trade patterns Although the factor price effects of opening to trade in our model are very different from what is found in Heckscher-Ohlin models, the trade patterns are broadly in line with Heckscher-Ohlin predictions, although the mechanism is different. Because the skill premium remains lower in *A* than in *B* after liberalization, *A* will have a comparative advantage in high skilled goods, and production in each country will shift toward comparative advantage goods. In our model, what we mean by comparative advantage is that high-skill exporters are more likely to come from *A*, while low-skill exporters are more likely to come from *B*. The specialization pattern is illustrated in figure 5, which is drawn on the assumption that the overall level of competition is less intense in *B* than in *A* (this is not essential, but it is what we find in our numerical analysis below).

Our model assumes two-dimensional heterogeneity in firms' technology, combined with symmetry in demand. Firms' revenue and profits are indexed by their inverse unit cost ϕ, and larger firms charge lower prices because they have lower unit costs (see equation equation 10). A way to summarize this is that in our model (as well as in the models of Melitz 2003, Bernard et al. 2007 and others) firms "compete on cost." This conflicts with evidence amassed by many authors, including Verhoogen (2008) and Baldwin and Harrigan (2011), that exporters more often "compete on quality," with more successful firms actually having higher costs and prices than less successful firms. In an earlier draft of this paper we showed that our model can easily be converted into a model of quality competition, with quality being positively correlated with skill intensity.[16] The punchline is simple: none of the implications of our model for trade, gains from trade, or factor prices are affected by rewriting it as a model of quality competition.

4. Numerical analysis

We use a numerical version of our model to illustrate its workings, with a focus on the effects of trade liberalization on the skill premium.

4.1. Modelling the correlation between skill intensity and productivity

A key innovation in our model is that we allow for positive but imperfect correlation between skill intensity α and productivity φ. This is motivated by the cross-sectional evidence that is vividly illustrated in figures 1 and 2. To implement this, we first specify the marginal distributions of α and φ and then model the correlation between them.

It is standard to model variation in productivity with a Pareto distribution, and we follow this practice here. Since the skill share lies in the unit interval, we model it as following a beta distribution, which is flexible enough to generate distributions as in figure 1. These densities are, respectively:

$$g_\varphi(\varphi) = k\varphi^{-k-1}, \tag{60}$$

$$g_\alpha(\alpha) = \frac{\alpha^{a-1}(1-\alpha)^{b-1}}{B(a,b)}. \tag{61}$$

For the Pareto distribution, we normalize the lower bound to one. For the beta distribution, $B(a,b) = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)}$, where $\Gamma(.)$ is the gamma function.

To flexibly allow correlation between φ and α while maintaining their marginal distributions, we apply the theory of copulas from mathematical statistics (the standard reference is Nelsen 2006).[17] The theory of copulas was first used in international trade theory by Davis and Harrigan (2011), also to accommodate two dimensions of heterogeneity in a Melitz-type model. Letting the marginal distribution functions for α and φ be $G_\alpha(\alpha)$ and $G_\varphi(\varphi)$, respectively, our parameterization of $G(\alpha,\varphi)$ uses the Plackett copula:

16 This correlation is exactly what Kugler and Verhoogen (2012) find for Colombia.
17 In the simplest case, a copula is a function that binds two marginal distribution functions to create a joint distribution function. In several copulas, as with the one used here, the degree of association between the marginal distributions governed by the parameter of the copula.

$$G\left(\alpha,\varphi\right)=\frac{P-\sqrt{P^{2}-4G_{\alpha}G_{\varphi}\left(\theta-1\right)}}{2\left(\theta-1\right)}, \tag{62}$$

$$P=\left[1+\left(\theta-1\right)\left(G_{\alpha}+G_{\varphi}\right)\right],$$

where the parameter $\theta>0$, $\theta\neq 1$ governs the correlation between φ and α. For $\theta=1$, φ and α are independent and $G(\alpha,\varphi)=G_{\alpha}G_{\varphi}$. For $\theta\neq 1$, the correlation between the values of the marginal distribution functions is:

$$Corr(G_{\alpha},G_{\varphi})=\frac{\theta^{2}-1-2\theta\log\theta}{(\theta-1)^{2}}.$$

This correlation has range $(-1,1)$ and is monotonically increasing in θ, with negative correlation when $\theta<1$ and positive correlation when $\theta>1$. There is no expression available for the correlation between φ and α. In our simulations, we use $\theta=11$, which gives $Corr(\alpha,\log\varphi)=0.6$.

4.2. *Estimation and calibration*

We use a minimum distance estimator to estimate four distributional parameters:

- k – the Pareto shape coefficient in (60)
- a, b – two parameters of the beta distribution in (61)
- θ – the Plackett copula association parameter in (62)

We hold constant all other parameters of the model. For comparability with the literature, we use the following parameters that are used by Bernard et al. (2007):

- $\sigma=3.8$ (estimated by Bernard et al. 2003)
- $f_e=20$
- $f=f_x=1$
- $\delta=0.025$

As discussed in appendix A.1 of Bernard et al. (2007), the choice of the fixed cost parameters f_e, f and f_x affect the scale of entry but otherwise have no substantial effect on the properties of the solutions.[18] The aggregate labour force is set at 100 workers, with skill abundance H/L as in the Chilean data: 0.26 (roughly 20% are skilled workers).

For the sake of estimating the remaining distributional parameters, we must calibrate the variable trade cost parameter τ as well. To do this, we exploit the fact that in the symmetric country model export intensity (ratio of export revenue to total revenue) is $\tau^{1-\sigma}/(1+\tau^{1-\sigma})$. The average export intensity in the Chilean

18 It would be preferable to choose the fixed cost parameters with reference to data on sunk and fixed costs of trade, but no such data exists to our knowledge. The well-known paper of Das et al. (2007) infers such costs but does not measure them.

data for 1995 is roughly 0.28. Given the parameterization of $\sigma = 3.8$, this gives roughly $\tau = 1.4$.

Estimation proceeds as follows. Given a guess of parameter values, we simulate the model for the symmetric open economy case and calculate a vector of moments, $\pi(k, a, b, \theta)$. We choose (k, a, b, θ) to minimize:

$$\left[\pi(k,a,b,\theta) - \pi^d\right]' W \left[\pi(k,a,b,\theta) - \pi^d\right],$$

where π^d are corresponding moments from the Chilean plant data and W is a weighting matrix.[19]

We use the following moments to estimate these parameters, with the model moments calculated by simulation:

- Overall correlation between log revenues and white-collar wage bill share (table 2). This moment largely identifies θ.
- The difference between average log revenues for exporters versus non exporters (table 1). This moment helps identifying θ and k, as well as a and b.
- Proportion of exporters (24%). This moment helps identifying k. Even though we have a functional relationship between ϕ^* and ϕ_x^*, it does not determine the percent of exporters, which is influenced by how fat the right tail of the Pareto distribution is.
- The 5, 25, 50, 75 and 95 percentiles of the white-collar wage bill share distribution, separately for exporters and non-exporters (10 separate moments, figure 1). These moments largely identify a and b and also help identify θ.

In order to specify the weighting matrix, we make some arbitrary choices: we multiply the deviations from the percent of exporters by four and we multiply the deviations from the empirical α percentiles by two. These weights are chosen to avoid a large spike in the distribution of α for firms who serve only the domestic market. Since we do not have a priori information about which moment is more important, this seems to be a reasonable choice.

The estimates are:

- $k = 3.6$
- $a = 2,\ b = 3.53$
- $\theta = 11$

We use these estimates in all numerical exercises below. We now briefly discuss them.

It is remarkable that simulation of the model using the estimates yields distributions of log revenue and the wage bill share that match the shape of the

19 See Cameron and Trivedi (2005) for the relevant econometric theory. Using simulation to calculate model moments introduces some additional error, in addition to sampling error. This error vanishes with the number of draws used to compute the moments. We use one million draws, so this type of error is likely to be very small. See Stern (1997) for a clear exposition of simulation based estimation.

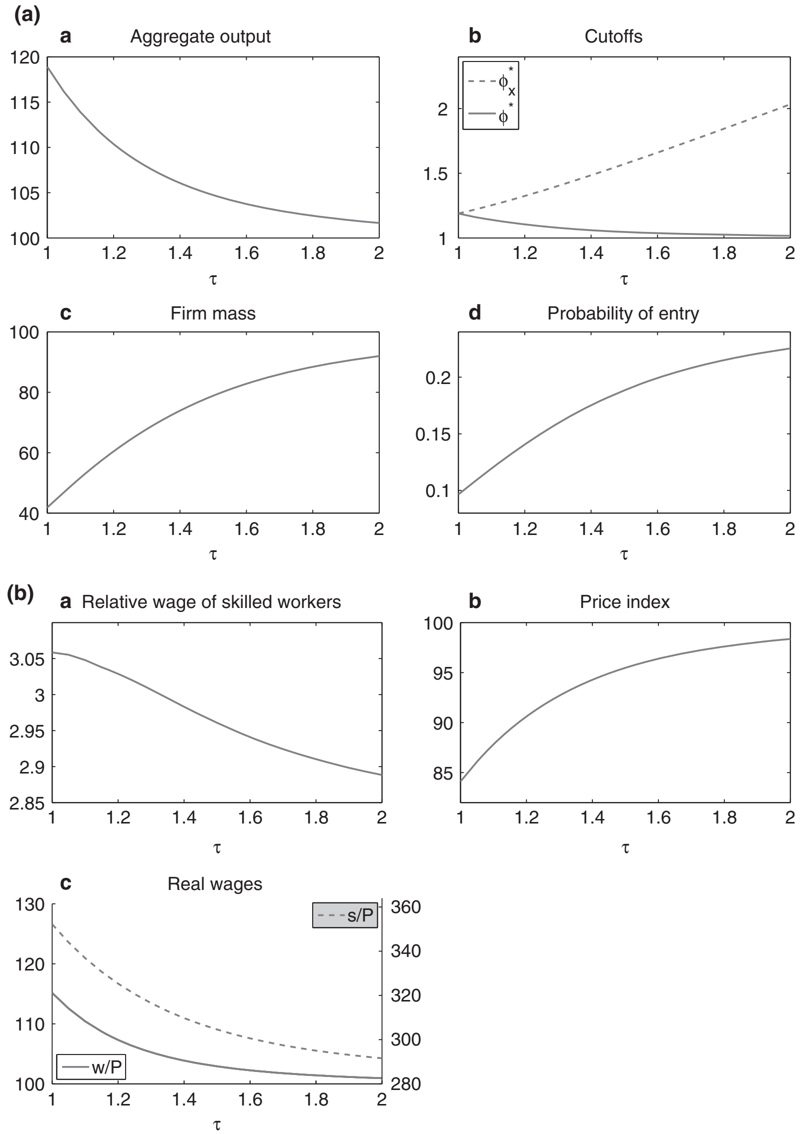

FIGURE 6 (a) Trade liberalization between identical countries: gains from trade and entry. (b) Trade liberalization between identical countries: prices
NOTES: 6(a): Real GDP and firm mass normalized to 100, and survival cutoff $\phi*$ normalized to one, in autarky. 6(b): Price index normalized to 100, and real unskilled wage normalized to 100, in autarky.

empirical distributions very closely, in particular figure 1. We note that the calibrated model exhibits a positive skill premium (see figure 6(b), at $\tau = 1.4$), despite not targeting this moment.

The estimates imply a primitive correlation of 0.6 between the skilled wage share α and $\log\varphi$ (0.48 between α and φ). The estimation procedure identifies the distribution of productivity and its correlation with skill intensity from moments of revenues. Therefore it is not surprising to find a stronger correlation of skill intensity with log productivity than with revenues in the data (0.4; see table 2): larger productivity differences for skill intensive firms are needed to overcome the cost of hiring more skilled workers when the skill premium is positive. Although firms with a high skill share α have higher factor costs (given a positive skill premium), we see relatively more such exporters versus non-exporters. The estimation captures this feature, because it assigns a positive correlation with productivity, $\theta = 11$.

The estimate $k = 3.6$ is not far from what Bernard et al. (2007) use, 3.4, and it obeys $k > \sigma - 1$, which is a requirement for convergence of integrals in Pareto-Melitz type models (see, for example, Baldwin 2005). Although the distribution of ϕ is not identically Pareto, it is rather close to Pareto, especially for exporters, i.e., in the upper tail of the ϕ distribution. The $\log\phi - \log(rank(\phi))$ scatter (not reported) is virtually a straight line for all active firms and for exporters. For strictly domestic firms, which have a much smaller (and bounded) range of ϕ, the influence of variation in α is much more important, and therefore the distribution of ϕ for this subset of active firms is far from Pareto: the $\log\phi - \log(rank(\phi))$ scatter is a curved line.

4.3. Equilibrium with identical countries

In this section, we simulate the identical country version of our model, using the parameters described above. Both countries have relative skill endowments of $H/L = 0.26$, and the exercise lowers variable trade costs from autarky, $\tau = \infty$, to costless trade, $\tau = 1$.[20] Results are illustrated in figure 6 and the first column of panel A in table 4.

The purely Melitz side of the model is illustrated in the four panels of figure 6(a). Trade liberalization leads to heightened competition, which is manifested in progressively higher survival cost cutoffs and lower export cost cutoffs. The result is less equilibrium entry, and the mass of firms is smaller. Unlike in Melitz (2003), the weighted average productivity of active firms is not a useful summary statistic, since it is unit cost, rather than productivity per se, that determines firm success in our model. Instead, we focus on real GDP (nominal GDP divided by the aggregate price index) as a summary of the economy-wide effects of trade liberalization. As expected, real GDP rises substantially as trade barriers are reduced, with the move from autarky to costless trade raising real GDP by 19%.

The novelty in our model comes from the factor market consequences of trade liberalization, which are illustrated in the three panels of figure 6(b). The skill premium rises substantially as trade barriers fall, from 2.84 in autarky to 2.98 for moderate trade costs ($\tau = 1.4$), an increase of 5%. Complete elimination of

20 We maintain fixed costs for exporting that are equal to the fixed costs of entering the home market throughout. For brevity, we say that trade is “costless” when variable trade costs are zero.

TABLE 4
Quantitative effects of opening to trade

A. Skill-biased technology, $\theta = 11$

	τ	Symmetric		Asymmetric		
		(H/L) = 0.26	(H/L) = 0.5	(H/L)_A = 0.5	(H/L)_B = 0.1	B/A
Real GDP	∞	100	100	100	100	1
	1.4	106	107	106	106	1
	1	119	120	119	117	0.98
Skill premium	∞	2.84	1.99	1.99	4.58	2.3
	1.4	2.98	2.04	2.03	4.84	2.39
	1	3.06	2.06	2.06	4.97	2.41
Real skilled wage	∞	284	199	199	357	1.79
	1.4	312	216	213	390	1.83
	1	352	243	242	441	1.82
Real unskilled wage	∞	100	100	100	78	0.78
	1.4	104	106	105	81	0.78
	1	115	118	117	89	0.75

B. No skill bias in technology, $\theta = 1$

	τ	Symmetric		Asymmetric		
		(H/L) = 0.26	(H/L) = 0.5	(H/L)_ A = 0.5	(H/L)_B = 0.1	B/A
Real GDP	∞	100	100	100	100	1
	1.4	107	107	107	107	1
	1	121	121	121	121	1
Skill premium	∞	1.64	1.06	1.06	3.12	2.94
	1.4	1.62	1.06	1.06	3.11	2.94
	1	1.62	1.06	1.06	3.11	2.94
Real skilled wage	∞	163	106	106	238	2.24
	1.4	175	114	114	255	2.24
	1	196	128	128	287	2.25
Real unskilled wage	∞	100	100	100	76.4	0.76
	1.4	108	108	107	82	0.76
	1	121	121	121	92.4	0.76

NOTES: Real GDP and real wages are normalized by real GDP of country A in autarky (=100) and by real wage of unskilled labour in country A in autarky (=100), respectively. Skill premium not normalized. In asymmetric case, country B's labour force is adjusted to so that A and B have the same autarky real GDP. In symmetric case normalization is by corresponding values of same (symmetric) country in autarky.

variable trade costs raises the skill premium by 7.7% compared to autarky. Real skilled wages rise by almost 10% in the move from autarky to moderate trade costs, while unskilled workers see more modest real wage increases of 4%. It is notable that all workers share in the gains from trade despite the rise in relative skill demand. The reason for this is the improvement in aggregate efficiency caused by trade liberalization, with high-cost low-skill firms exiting or contracting and low-cost, high-skill firms entering the export market.[21]

21 Bernard et al. (2007) find a similar result in their model: the aggregate efficiency effect implies that the scarce factor may gain in real terms from opening to trade. In their quantitative exercise they find that the real return to the scarce factor does indeed increase when trade opens.

The second column of panel A in table 4 summarizes how our results differ when we close to double skill abundance, from 0.26 (the level in our Chilean data set) to 0.5. The gains from trade are slightly higher, and the increase in the skill premium is much smaller, rising just 3.5% in the move from autarky to costless trade. The increase in real wages is 22% for skilled workers and 18% for unskilled workers. The explanation for this contrast is that skill bias puts a premium on skilled workers when trade is liberalized: when they are much more abundant, the economy as a whole gains more, with the gains from trade more evenly shared between skilled and unskilled workers.

4.4. Equilibrium with factor endowment differences

Next, we turn to trade liberalization between countries that differ in their factor endowments. The relative factor endowments are $(H/L)^A = 0.5$ and $(H/L)^B = 0.1$, and we scale country B's population so that real GDP is the same in both countries in autarky. These factor abundances are chosen to roughly match the skill abundance of the United States and low-income developing countries, respectively, and real GDP in autarky is equalized to neutralize market size effects. In all other respects the two countries are identical, most importantly in their ex ante skill-productivity distributions $G(\alpha, \varphi)$. As in the previous exercise, we lower variable trade costs from $\tau = \infty$ to $\tau = 1$. Results are illustrated in figure 7 and in the final three columns of panel A in table 4. In computing the equilibria, we choose global nominal GDP as our numeraire, so nominal values are in units of a common currency.

In this numerical exercise, we are not attempting to fully calibrate the model to any particular pair of countries or trade liberalization episode. By abstracting from differences in autarky country size and technology distributions, we isolate the mechanisms that are new to our model which are the interactions between trade liberalization, factor proportions differences, and skill-biased heterogeneous firms. Thus the quantitative results here should be interpreted as plausible numerical examples rather than estimates of the effects of an actual trade liberalization episode.[22]

The four panels of figure 7(a) illustrate the expected Melitz-type mechanisms: as trade is liberalized, entry becomes more difficult, the mass of firms falls and the share of exporters gets monotonically higher. Aggregate gains from trade are shown by rising real GDP in both countries. Country B is a somewhat less competitive market than A, which is seen in the higher cost cutoffs for A and the associated higher probability of entry in B. The reason for this is an interaction between skill bias and the higher skill premium in B: skill bias implies that the lowest cost firms are the most skill-intensive on average in both countries, but because of the higher skill premium in B, the cost advantage for the best firms is smaller in B than in A. This difference in the ex ante cost distributions in the two

22 The quantitative exercises in Burstein and Vogel (2012) and Bernard et al. (2007), for example, should in our view be interpreted in the same way.

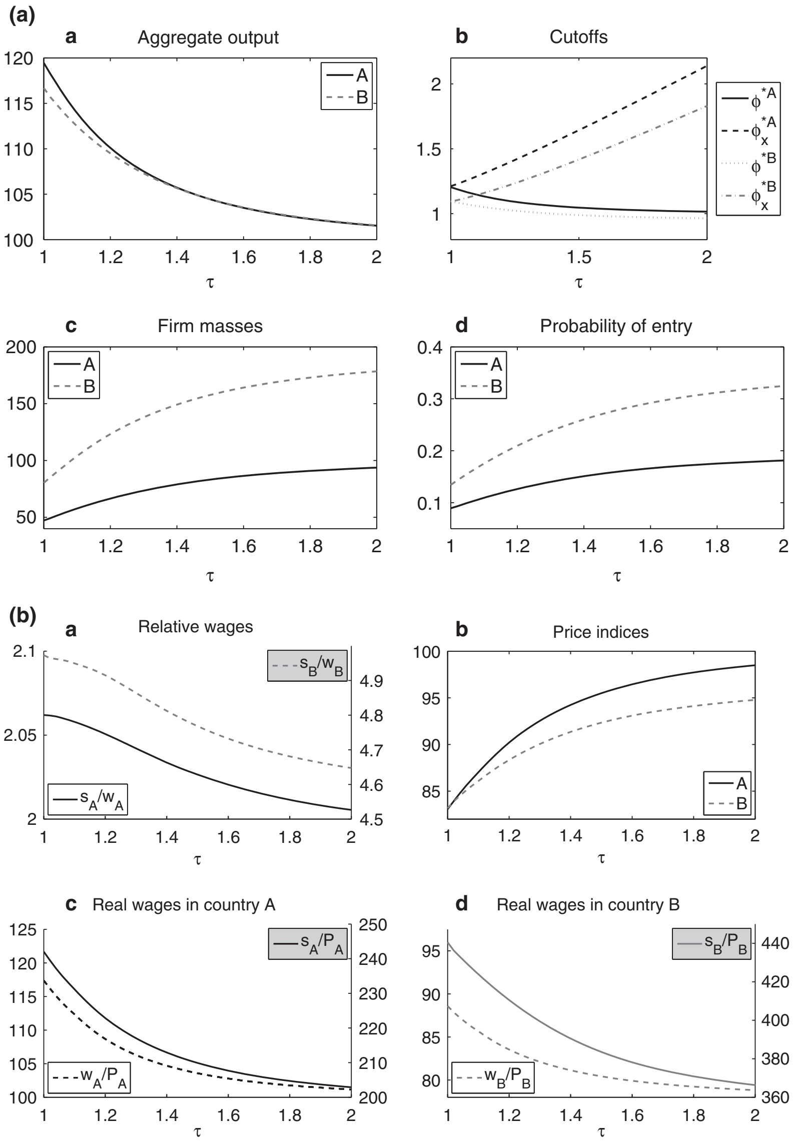

FIGURE 7 (a) Trade liberalization between asymmetric countries: gains from trade and entry. (b) Trade liberalization between asymmetric countries: prices
NOTES: 7(a): Real GDP and firm mass normalized to 100, and survival cutoff $\phi*$ normalized to one, in autarky in country A. Real GDP's equal in autarky by choice of population size. 7(b): Price index in A and real unskilled wage in A both normalized to 100 in autarky.

countries is illustrated in figure 8: *B* has more low-end and fewer high-end firms than does *A*, in both autarky and costless trade equilibria. Thus high cost firms in *B* earn more revenue than high cost firms in *A*, which makes survival easier.

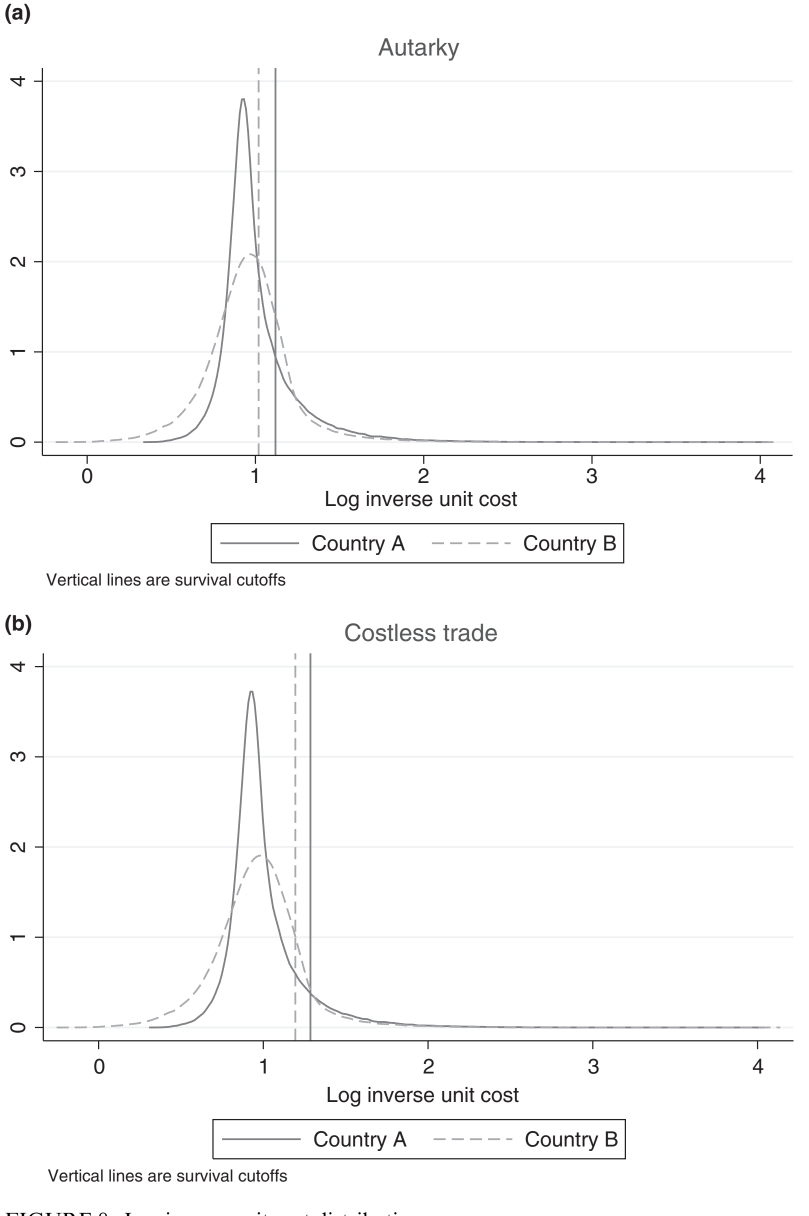

FIGURE 8 Log inverse unit cost distributions
NOTES: Kernel densities of ex ante log inverse unit cost ($ln\phi$) distributions, with ex post equilibrium survival cutoffs indicated by vertical lines.

A flip side to this is that *A* gains a bit more from trade: trade puts a premium on skill, and *A*'s greater skill abundance and lower skill premium means it can better take advantage of trade liberalization than can skill-scarce *B*.

The four panels of figure 7(b) illustrate conjecture 2: trade liberalization raises the skill premium in both countries, and in our numerical exercise this effect continues all the way to costless trade. As can be seen in table 4, the increases in the skill premium are fairly modest: in the move from autarky to moderate trade costs of $\tau = 1.4$, the skill premium increases by 2.1% in A and 5.7% in B, with increases of 3.5% and 8.5%, respectively, when moving all the way to costless trade. An implication is that our example world economy features relative factor price *divergence* as trade is liberalized, with the skill premium in B relative to A increasing from 2.30 to 2.41. The force behind this surprising factor price divergence result is that falling trade costs raise the relative demand facing high-productivity, skill-intensive firms. When combined with relative skill-scarcity in B, the result is that the skill premium rises much faster in B than it does in A. This result is very much at odds with the factor price equalization forces in Heckscher-Ohlin models.[23]

Our factor price divergence finding does not hold in all our numerical simulations, but the rising skill premium in both countries is a robust feature of all our simulations. This is to be expected: the fact that opening to trade raises the demand for skill in both A and B is a fundamental feature of our model, but the particular configuration of the levels of the skill premium (which depend on factor abundance in the two countries) is not. In short, there is no force in our model by which trade equalizes relative or absolute factor prices.

While the factor price implications of our model are completely at odds with Heckscher-Ohlin models, our model does feature trade in factor services that is predicted by factor abundance. This is illustrated in figure 9, which shows that the net factor content of trade increases quite rapidly with falling variable trade costs.[24] The mechanism is that skill-intensive goods are more globally competitive when they are produced in country A, where the skill premium is low. Equivalently, A has a comparative advantage in skill-intensive goods because $(s/w)^B > (s/w)^A$. This level effect is amplified in figure 9 due to relative factor price divergence, but the result that countries export the services of their abundant factors is robust and is not driven by relative factor price divergence.

To illustrate the key importance of skill bias in generating our results, in panel B of table 4 we report results when there is zero ex ante correlation between skill intensity and productivity. To compute these results, the only change we make is to the copula parameter θ, which we set to one. Differences in factor abundance still generate differences in the skill premium, but the level of the skill premium is much lower than in panel A. Trade liberalization leads to gains from trade that are comparable to the skill-bias case, but relative factor prices are virtually unchanged despite large net trade in factor services (similar to what is seen in figure 9 but

23 We refrain from reporting alternative simulations here in the interests of space, but supplementary results and MATLAB code are available from the authors by request.

24 We calculate the factor content of trade as follows. For exports, we use the exporting country's unit factor requirements. For imports, we use the exporting country's factor requirements, deflated by the iceberg transport cost factor τ. This explains why the two panels of figure 9 are not quite mirror images. When $\tau = 1$, the net factor contents sum to zero exactly.

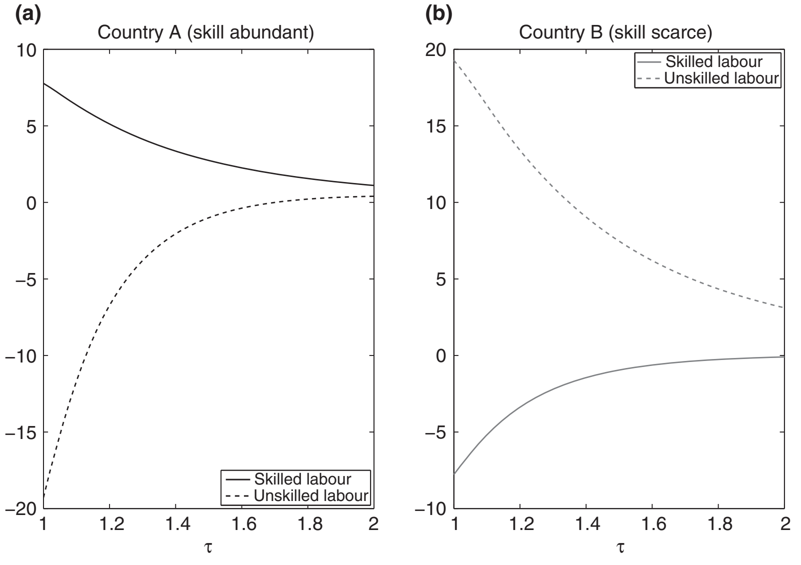

FIGURE 9 The factor content of trade
NOTE: Units on vertical axis are net factor content of trade as a share of aggregate labour force.

not shown in the interest of space). The skill premium does fall very slightly in each case as trade is liberalized, so our numerical results are consistent with conjecture 1. This illustrates again the absence of Stolper-Samuelson forces in our model: when factor intensities are unrelated to preferences, trade liberalization does not raise the skill premium unless there is skill bias.

As a final exercise, we consider convergence in relative factor endowments. We consider our base case of skill-biased technology ($\theta = 11$) and moderate trade costs ($\tau = 1.4$), and both countries have the same population. We begin with $(H/L)^B = 0.1$, and increase human capital in B until it reaches the level in A. Table 5 reports the results. Interestingly, A is essentially indifferent to human capital accumulation in B, with tiny increases in real wages and the skill premium. At first glance, the tiny effect that human capital accumulation in B has on factor markets in A might seem puzzling, since net trade in factor services are changing quite dramatically. The reason is the absence of Stolper-Samuelson effects in our model: though the average good imported by A from B is becoming more skill intensive as B develops, this has no direct effect on the relative demand for more and less skill-intensive goods produced in A. In contrast, B experiences a precipitous drop in the skill premium as real GDP rises, with real skilled wages falling and more than all of the 28% increase in GDP going to unskilled workers. The response in B of the skill premium to factor accumulation is consistent with a long-run labour demand elasticity of about -2, which is within the range found in the labour economics literature (see, for example, Autor and Katz 1999).[25]

25 We refer here to the parameter η in an equation of the form $(H/L) = A \times (s/w)^{\eta}$.

TABLE 5
Quantitative effects of skill accumulation in country B

	(H/L)_B	Country A	Country B	B/A
Real GDP	0.5	100	100	1
	0.3	99.6	90.7	0.91
	0.1	98.4	70.9	0.72
Skill premium	0.5	2.04	2.04	1
	0.3	2.04	2.76	1.36
	0.1	2.03	4.84	2.39
Real skilled wage	0.5	204	204	1
	0.3	203	240	1.18
	0.1	200	343	1.71
Real unskilled wage	0.5	100	100	1
	0.3	99.6	86.8	0.87
	0.1	98.6	70.8	0.72

NOTES: Real GDP and real wages are normalized by real GDP and by real wage of unskilled labour at symmetry (=100), respectively. Skill premium not normalized. Skill-biased technology and moderate trade costs, $\theta = 11$ and $\tau = 1.4$.

To summarize our most important results, we find that with skill-biased heterogeneous firms, opening to trade between skill-scare and skill-abundant countries leads to:

- a rise in the skill premium in both countries
- the skill-abundant country is a net exporter of the services of skilled labour, and vice versa for the skill-scarce country

The first bullet point contradicts the Stolper-Samuelson theorem, but is consistent with abundant evidence that falling trade barriers are associated with rising returns to skill in both rich and poor countries. The second bullet point is also consistent with the evidence (Davis and Weinstein 2001, 2003), but the mechanism in our model is very different from the mechanism in Heckscher-Ohlin models. Unlike in Heckscher-Ohlin models, changes in import competition in our model have no effect on the relative demand for home-produced goods. The reason that our model features trade in factor services that is predicted by relative factor endowments is due to the lower level of the skill-premium in the skill abundant country, which makes skill-intensive goods relatively more competitive in the skill-abundant than in the skill-scarce country.

5. Conclusion

In this paper, we propose a new model that explains why trade liberalization can be associated with a rising skill premium in both rich and poor countries. Our model has two dimensions in which firms differ—skill share and productivity, and our assumption that these two attributes are positively correlated is verified using Chilean firm-level data. Because of this correlation, opening to trade shifts up the relative demand for skilled workers, as low-cost, skill-intensive firms expand to seize new export opportunities and high-cost, low-skill firms contract or exit in the face of greater import competition. In equilibrium, we show analytically that the skill premium rises when trade is liberalized between identical countries. It is possible that less skilled workers will see their real wages fall in such a scenario if their nominal wages fall by more than the reduction in the price level, though this does not occur in our simulations: all workers gain from liberalization even as the skill premium rises.

When countries differ in their relative factor endowments, opening to trade also leads to an increase in the skill premium in both countries, and in our example economy there is relative factor price divergence, with the skill premium rising by more in the skill-scarce country. This result is consistent with much empirical evidence but is at odds with the Stolper-Samuelson theorem, which predicts that trade liberalization should lead to a fall in the skill premium in the skill-scarce country and the opposite in the skill-abundant country. The reason is that our model makes a simple and intuitive departure from one of the key assumptions in the Heckscher-Ohlin tradition: we assume that the elasticity of substitution in demand is common across goods, rather than being higher between goods with the same factor intensity. Finally, our model features net trade in factor services that is consistent with the evidence (Davis and Weinstein 2001, 2003). The mechanism is that the skill premium is lower in the skill abundant country, which makes skill-intensive firms more competitive.

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Supporting information

Additional supporting information can be found in the online version of this article.