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Technology, trade and skills in Brazil:
evidence from micro data

Bruno César Araújo, Francesco Bogliacino and Marco Vivarelli

Brazil was characterized by a rapid process of trade liberalization in the 1990s, resulting in a dramatic increase in the volumes of exports and imports since the year 2000. Over the same period, the relative demand for skilled labour has increased substantially. To investigate whether these two simultaneous phenomena are linked is the purpose of this paper. More particularly, this study focuses on the possible impact of domestic technology, capital complementarity and trade openness on the relative demand for skilled labour in Brazilian manufacturing firms, using a unique panel database of Brazilian manufacturing firms over the period from 1997 to 2005. The empirical evidence supports the hypothesis that technology played a role in determining the skill upgrading of Brazilian manufacturing firms. Indeed, the estimations show that domestic technology and capital formation are complements for skilled workers and that imported capital goods clearly act as a skill-enhancing component of trade.

Bruno César Araújo
Researcher, Institute of Applied Economic Research (IPEA)
bruno.araujo@ipea.gov.br

Francesco Bogliacino
Academic and researcher, Department of Economics and RISE Group, EAFIT University
Joint Research Centre (JRC)-Institute for Prospective Technological Studies (IPTS), European Commission
francesco.bogliacino@gmail.com

Marco Vivarelli
Professor of Economic Policy, Faculty of Economics, Università Cattolica del Sacro Cuore
marco.vivarelli@unicatt.it

I
Introduction

This paper deals with the relationship between trade openness, with particular reference to technology transfer, and the relative demand for skilled labour in Brazilian manufacturing firms.

Brazil was characterized by a rapid process of trade liberalization in the 1990s, resulting in a dramatic increase in export and import volumes since the year 2000. An important aspect of this process might be its effect on labour demand and, more specifically, its impact on the relative demand for skilled labour. And in fact, the relative demand for skilled labour has increased substantially over the period, affecting the equilibrium employment level in the presence of a significant increase in the supply of skilled labour. To investigate whether these two simultaneous phenomena are linked is the purpose of this paper.

The theoretical literature offers different predictions regarding the impact of trade liberalization on labour demand in middle-income developing countries. On the one hand, according to the central tenet of traditional trade theory, expressed in the Heckscher-Ohlin theorem and in its Stolper-Samuelson corollary (HOSS hereafter), we might expect a relative decrease in the demand for skilled labour, since openness should benefit a country's relatively abundant factor, which in the case of Brazil is unskilled labour. On the other hand, if the HOSS assumption of homogeneous production functions between countries (i.e., absence of technological differentials) is relaxed, international openness may facilitate technology transfer from richer countries to middle-income developing countries. In this context, trade may act as a stimulus for technological upgrading and shift the production function towards more skill-intensive technologies; in addition, if the dominant technological paradigm is skill-biased, trade may induce and foster both domestic and imported skill-biased technological change.

This paper contributes to the debate, presenting new empirical evidence. We estimate the impact of domestic technologies and trade openness on labour demand for skilled and unskilled workers, using a unique panel database (obtained by merging three different statistical sources) of Brazilian manufacturing firms over the period from 1997 to 2005.

The remainder of this paper is organized as follows: the next section reviews the theoretical and empirical literature on the interaction between trade openness and the relative demand for skilled labour, mainly focusing on developing countries. Section III introduces and describes the data. Section IV. is devoted to a closer investigation of recent economic trends in Brazil. In section V we explain our empirical strategy and present and discuss our econometric results. Finally, the last section offers some brief concluding remarks.

□ The views expressed herein are the authors' alone and may not in any circumstances be construed as stating an official position of the European Commission.

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II
Literature

After more than two decades of an ongoing debate focusing on the competing explanations for the increase in inequality in developed countries,[1] there has recently been a stream of literature on the determinants of inequality in low- and middle-income countries (LMICs). The shift in focus from the former to the latter originated in the discussion of the role played by trade: simply put, if inequality is driven by a specialization effect (countries with a skill abundance will reallocate their production towards it), there should be simultaneously an increase in inequality in the advanced countries (abundant in skilled labour) and a reduction of inequality in LMICs (abundant in unskilled labour).

However, this argument is proved invalid by the macroeconomic data (Acemoglu, 2003), which shows an increase in within-country income inequality in both developed and developing countries. This outcome can be ascribed to the various theoretical problems affecting the hypotheses of the Hecksher-Ohlin and Stolper-Samuelson (HOSS) theorems (see Leontief, 1953; Trefler, 1995; Davis and others, 1996, for an overall discussion). The core of the matter, first, is that neither consumers' preferences nor production functions can be assumed to be homogeneous.[2] Indeed, richer countries and LMICs are endowed with very different technological capabilities (Abramowitz, 1986; Lall, 2004), and trade may act as a pervasive channel of technology transfer.

From a microeconomic point of view, it is worth noting that, in a developing country, firms' reactions to trade openness are usually very heterogeneous. Some firms are simply crowded out by international competition and are eliminated from the market, others adapt their production processes to the new competitive environment (opting for technical or operational efficiency through outsourcing and imports of embodied technology), whilst others again rely on innovation and accumulation of domestic technological capabilities as their main competitive strategies. This process is well documented in De Negri and Turchi (2007) for Brazil and Argentina.

In this context, skill upgrading can be related to technology diffusion, either by way of complementarities with domestic research and development (R&D) and capital formation, or through the learning-by-doing or technology adoption effect connected with the implementation of imported technologies (Arrow, 1962; Nelson and Phelps, 1966), initially introduced in richer countries.

Where the first perspective is concerned, Berman and Machin (2000 and 2004) found strong evidence for an increased demand for skills in middle-income developing countries in the 1980s and related it to the diffusion of skill-biased technological change from the richer developed countries to middle-income ones. In this framework, a country like Brazil, characterized by a certain degree of indigenous innovation effort, might well exhibit a positive correlation between domestic technologies and skill upgrading. By the same token, domestic capital is also a vehicle of "embodied technological change" (see Salter, 1960; Solow, 1960) that can be skill-biased in nature; hence, capital/skills complementarity (see Griliches, 1969) may also have had an important role in the skill upgrading of the Brazilian labour force.

Where the second perspective is concerned, Robbins and Gindling (1999) and Robbins (2003) put forward the so-called skill-enhancing trade (SET) hypothesis, pointing out the potential skill-biased effect of technologies flowing in as a result of trade liberalization. The idea is that trade liberalization accelerates flows of imported technologies embodied in capital goods (especially machinery), and the resulting technology transfer induces adaptation to the modern skill-intensive technologies currently used in the most advanced countries, involving a substantial increase in the demand for skilled labour within the developing countries receiving them (for

[1] See Acemoglu (2002) for a discussion of the literature with a focus on the United States, where the debate started. The two competing explanations of inequality in developed countries are the one focusing on the role of trade (see Wood, 1994; Freeman, 1995) and the one identifying new technologies as the main drivers of a skill bias that in turn increases wage dispersion and inequality. Berman, Bound and Griliches (1994) were the first to point out the skill-biased nature of current information and communication technologies (ICTs). See also Katz and Autor (1999) and Machin and Van Reenen (1998) for an extension to the Organisation for Economic Co-operation and Development (OECD) countries and Caroli and Van Reenen (2001), Aguirregabiria and Alonso-Borrego (2001) and Piva, Santarelli and Vivarelli (2005) for analyses of individual European countries.

[2] The literature that has extended HOSS, while weakening its basic assumptions, is very extensive. For instance, Dornbush (1980) extended the model to multiple goods, Wood (1994) added multiple skills, and Davis (1995 and 1996) introduced the concept of "cones of diversification".

more extensive analyses, see Lee and Vivarelli, 2004 and 2006; Almeida and Fernandes, 2008). Obviously, this technology-related effect may more than counterbalance the HOSS predictions.[3]

Where the empirical literature is concerned, there is a growing body of studies associating trade with a rise in inequality in developing countries. For instance, Hanson and Harrison (1999) reported that trade liberalization was related to a rise in inequality in Mexico. Manacorda, Sanchez-Paramo and Schady (2006) found that the relative demand for skilled workers had risen in Argentina, Mexico, Chile and Colombia, with mixed results in Brazil.[4]

Following this line of research, Meschi and Vivarelli (2009), using a sample of 65 developing countries over the 1980-1999 period, found that trade with high-income countries made the income distribution more unequal in middle-income developing countries, by way of both imports and exports.[5] Similarly, Meschi, Taymaz and Vivarelli (2008) showed that SET was an important factor in explaining the rise of the skilled labour cost share in Turkey during the 1980-2001 period.[6]

Where Brazil is concerned, previous literature on the subject is scarce. According to Gonzaga, Menezes-Filho and Terra (2006), wage differentials between skilled and unskilled workers decreased during the 1988-1995 period, which is when trade liberalization started to be implemented in Brazil. The authors provided some evidence that HOSS mechanisms may have had a role in this process.[7]

However, Menezes-Filho and Giovanetti (2006) analysed the evolution of skilled employment in Brazil over the subsequent 1990-1998 period. First, partially contradicting the findings of Gonzaga, Menezes-Filho and Terra (2006), they detected an increase in the skilled labour share; this increase was entirely due to the ‘within-industry’ effect, while the ‘between-industries’ effect was negative, in line with the HOSS predictions. Then, inspired by Machin and Van Reenen (1998), they ran an econometric equation to test the trade-induced skill bias hypothesis. Their variable was input tariffs, the hypothesis being that the reduction of input tariffs should have induced the importation of technologically advanced inputs, in turn raising the demand for skilled labour. Consistently with their hypothesis, they found that tariffs were negatively related to skill upgrading, and that this effect was stronger in those sectors that used inputs more complementary to skills.

Relative to Menezes-Filho and Giovanetti (2006), our paper has three distinctive characteristics. Firstly, while that study analysed the most intensive period of trade opening, we cover the aftermath of this severe reshaping of industrial sectors in Brazil and part of the export boom triggered in 2002 (our data cover the period from 1997 to 2005). The second distinctive characteristic is that our dataset, which consists of firm-level micro data, comes from the merging of several databases.[8] Finally, our data allow us to use a direct and precise indicator of the SET effect (see below).

[3] Interestingly enough, if the technological effect prevails over the HOSS effect in developing countries, inequality rises in both developed and developing countries, which is what has been observed for the last two decades (see Feenstra and Hanson, 1996 and 1997). However, an increase in inequality as a consequence of economic growth in developing countries was predicted by Kuznets a long time ago (see Kuznets, 1955; Grimalda and Vivarelli, 2010).

[4] Similar results were found by Conte and Vivarelli (2011), using sectoral manufacturing data for 23 low- and middle-income countries over the 1980-1991 period.

[5] Similarly, Vivarelli (2004), using data for 45 developing countries in the 1990s, found that imports could entail an increase in the domestic income inequality of the recipient developing country, at least in the early stages of the opening process.

[6] The authors show that the increase in the skilled labour cost share was mainly driven by the “within” effect (increase in the demand for skills within industrial sectors, due to new technologies) rather than by the “between” effect (reallocation of skilled labour between sectors, as a possible outcome of HOSS specialization).

[7] For instance, their decomposition analysis of the increase in the skilled labour share of total employment showed that there was a negative “between-industries” effect in Brazil and that this was consistent with the HOSS predictions.

[8] Instead, Menezes-Filho and Giovanetti (2006) used a micro-aggregated database, in which each observational unit was a weighted average of three firms. For further details, see Menezes-Filho, Muendler and Ramey (2003).

III
Data

The data used in this paper are the outcome of efforts by the Institute of Applied Economic Research (IPEA) to merge several different databases:[9]

— The Brazilian annual industrial survey (PIA) of manufacturing firms: this is conducted by the Brazilian Geographical and Statistical Institute (IBGE), is available for the years from 1996 to 2005 and includes all firms with more than 30 employees plus a random sample of firms with between 10 and 30 employees.

— The annual social information report (RAIS): conducted by the Brazilian Ministry of Labour and Employment, this is an employee-level database that includes key information for all formal jobs; it is available for the years from 1993 to 2005.

— The Secretariat of Foreign Trade (SECEX) database: this is made available by the Ministry of Development, Industry and Commerce and includes data on import and export transactions, covering the 1997-2005 period.

We merged these three databases at the firm level, covering the years from 1997 to 2005. The sample is thus limited to manufacturing and is a balanced panel of 11,219 firms covered by the surveys.[10] All data relate to industries in National Classification of Economic Activities (CNAE)[11] sectors 10 to 37 and to firms with 30 or more employees the year before the survey.[12]

In our empirical specification, we used workers with a secondary education qualification or better to proxy skilled labour. We made this choice —instead of using occupational proxies, such as the share of non-production workers— for three reasons. First, Brazil has very good information on schooling of the labour force; in particular, about 30% of the labour force has completed secondary school. Second, as stated by Gonzaga, Menezes-Filho and Terra (2006), neither occupation nor educational measures provide exact proxies for skill intensity; for instance, the occupational proxy is problematic in countries like Brazil since there are a great many non-production tasks that do not require particular skills. Finally, Menezes-Filho and Giovanetti (2006) ran their estimates with both measures and did not perceive qualitative differences in the results.

Consistently with the skill-enhancing trade (SET) hypothesis discussed in the previous section, we used imports classified as capital goods as a proxy for SET.[13]

From the industrial surveys we extracted the variables indicating sales, capital (calculated by the perpetual inventory method) and expenditure on royalties.[14]

From RAIS we extracted the employment (number of employees) and wage variables.[15]

All variables are in constant prices, with base year 1997; for capital goods imports, we converted United States dollar prices into Brazilian real prices, using the average exchange rate for the year. Further details on the construction of the database are given in the Appendix.

In table 1, we report the descriptive statistics. We also split the period into three subperiods: 1997-1998 (before the Brazilian financial crisis), 1999-2001 (from the Brazilian crisis to the Argentine one) and 2002-2005 (the rest of the period).

[9] The "key" to merging all the databases is a firm's National Register of Legal Entities (CNPJ) number, an identifier used for tax purposes.

[10] The sole available proxy for domestic technological effort was the royalties variable. Missing values for this variable, for the capital measure and for the skilled and unskilled labour figures limited the final sample size to 10,785 and 10,810 firms, respectively, for the unskilled and skilled labour equations. The balanced nature of the final panel selected overrepresents medium-sized and large Brazilian firms at the expense of small and medium-sized enterprises (SMEs). However, our aim is not to construct a representative sample, but rather to investigate firms likely to have been affected by globalization and technological change, to see whether these phenomena have an impact upon the demand for skills. In this respect, Brazilian SMEs do not play a crucial role.

[11] The Brazilian equivalent of the International Standard Industrial Classification of All Economic Activities (ISIC).

[12] Selecting firms with 30 employees or more eliminates the randomized portion of the PIA database.

[13] This classification became possible as a result of conversion from the harmonized system (HS) product classification to a fourfold classification: capital goods, non-durable consumer goods, durable consumer goods and intermediate goods, provided by IBGE. See the Appendix for further details.

[14] Brazil is the Latin American country that scores best for total R&D expenditure per employee; thus, it is natural to include a proxy for domestic innovation effort. Unfortunately, PIA does not provide information on R&D and we have to rely on indirect proxies, such as expenditure on royalties, taken as an indicator of direct involvement in technological activities.

[15] In the official statistics, wages are expressed as multiples of the minimum wage, used as the measurement unit. To make matters clear: if the legal minimum wage is 3 and the worker's wage is 24, then the reported wage is 8.

TABLE 1

Brazil: Descriptive statistics

Variable	Mean 1997-2005	Mean 1997-1998	Mean 1999-2001	Mean 2002-2005	Unit
Skilled employment	111.21	80.72	97.76	136.65	NE[a]
Unskilled employment	136.65	152.67	134.39	130.01	NE[a]
Skilled wage	5.55	6.74	5.87	4.73	MLMW[b]
Unskilled wage	3.61	4.06	3.75	3.27	MLMW[b]
Capital	34.90	16.50	26.60	50.10	Millions of 1997 reais
Skill enhancing trade (SET)	711 623.4	462 010.5	687 770.4	854 319.7	1997 reais
Royalties	707 520.6	113 401.3	466 625.1	1 183 650.0	1997 reais
Sales	52.9	26.5	42.4	74.1	Millions of 1997 reais

Source: Prepared by the authors, on the basis of the following databases: the Brazilian annual industrial survey (PIA); the annual social information report (RAIS); and Secretariat of Foreign Trade (SECEX).
Note: Means are calculated at the firm level.

[a] Number of employees.
[b] Multiples of legal minimum wage (see footnote 15 for an example).

IV
Brazilian industry facts and figures

Brazil's recent economic history is largely comparable to that of other Latin American countries: after industrialization driven by import substitution policies involving the use of high tariffs and active State intervention, the country implemented a step-by-step liberalization policy. The first phase of liberalization was conducted during 1988-1994, when there was a drastic reduction in tariffs. By the end of 1995, the average tariff was below 14%, versus over 42% in 1988 (Kume, 2002). There have been no major tariff changes since 1995 except for the elimination of specific tariff peaks and tariff reduction rounds conducted by the World Trade Organization (WTO), the ending of the Multifibre Arrangement being an example.

The opening of the Brazilian economy induced a radical restructuring process in industry, but it did not generate the highly specialized trade pattern predicted by traditional comparative advantage models, like HOSS. However, it is true that certain sectors lost out significantly in the first instance, while others gained comparative dynamic advantages that did not formerly exist. Consider, for example, the successful case of the metallurgical sector, most notably its aircraft and automotive segments.

Although the sectoral profile was not dramatically altered, the opening up of the economy led to major changes in the competitive strategies and ownership of many firms. To adapt to the new international competitive environment, most Brazilian firms prioritized short-term technical and operational efficiency by means of deverticalization, outsourcing and the introduction of process innovations via the importation of machinery and intermediate inputs (Castro and Ávila, 2004). In contrast, the majority of firms failed to invest in long-term competitive strategies, such as product innovation and R&D investment.

Nevertheless, there is an elite group of Brazilian industrial firms able to compete via innovation, product differentiation and emerging brands. These firms have a strong presence on foreign markets and receive premium prices for their products. According to De Negri, Salerno and Castro (2005), approximately 1,200 firms that chose to adopt these strategies account for a fourth of total industrial revenues, despite representing no more than 2% of the total number of enterprises. This reorientation of resources towards exporting and more productive firms is consistent with the theoretical prediction of Melitz (2003).

Turning our attention to the macroeconomic situation, we find that Brazilian industrial output has grown by 40% since 1994, according to IBGE. However, aggregate industrial performance is closely linked to the macroeconomic environment and has evinced a stop-and-go pattern.[16]

Most striking in this period has been the growth of exports and imports, with a dramatic upward trend beginning in 2002. Exports totalled US$ 46.5 billion in 1995 and US$ 60.3 billion in 2002. By 2005, this figure had nearly doubled to US$ 118.3 billion. In 2008, exports totalled almost US$ 200 billion. Indeed, exports have accounted for a large part of the growth in Brazil's industrial output.

Part of this increase is explained by rising prices for the commodities Brazil exports, but the quantum exported has also increased significantly. Moreover, the composition of the export list reflects the heterogeneity of the Brazilian productive sector. For example, among the segments where export volume growth has been strongest, products such as mobile phones, aircraft and automobiles are found alongside traditional commodities such as coffee, sugar and iron ore.

Meanwhile, imports, which totalled US$ 47.2 billion in 2002 (slightly below the US$ 50 billion recorded in 1995), reached US$ 73.5 billion in 2005. In 2008, they were more than double this at US$ 173 billion. Brazilian exports and imports are illustrated in figure 1.

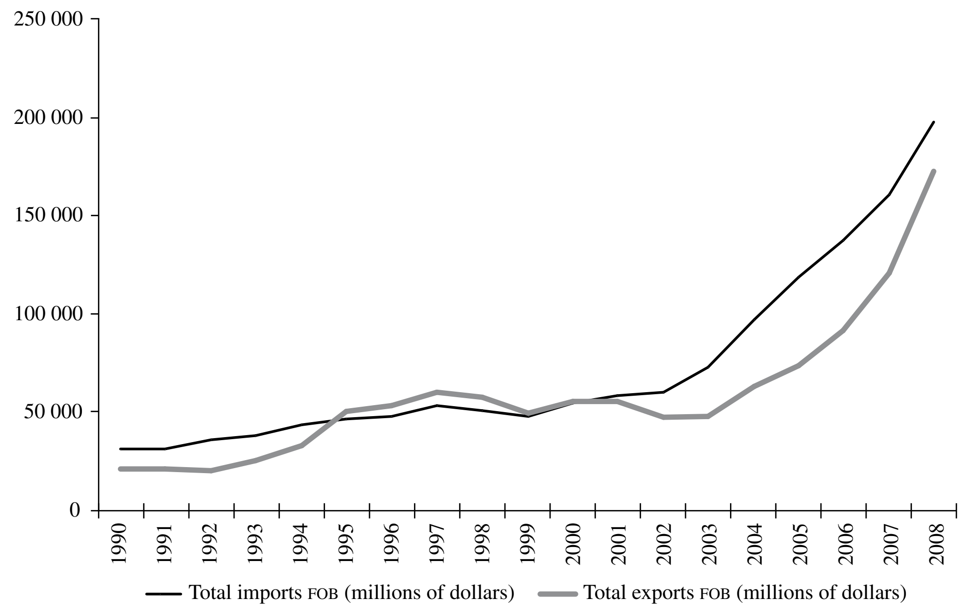
Turning our attention to the main focus of this study, i.e., the demand for skilled and unskilled labour in Brazilian industry, we can use our data (covering 10,785 manufacturing firms) to show the trend in the total employment share accounted for by skilled workers, defined as employees with secondary education or more (figure 2).

[16] Industrial output rose by 7.6% in 1994; unfortunately, this performance was not repeated in either 1995 (1.83%) or 1996 (1.73%), mainly due to the Mexican crisis. A partial recovery occurred in 1997, when industrial output rose by 3.88%, but the financial crisis that culminated in the abandonment of the foreign-exchange anchor affected the Brazilian economy in the following years; thus, industrial output dropped by 2.03% in 1998 and 0.66% in 1999. Then in 2000, as a result of a new macroeconomic context (fiscal discipline, a floating exchange rate and inflation targets), industrial output increased by 6.64%. This performance was subsequently interrupted in 2001 by both domestic events (energy crisis) and international ones (terrorist attacks, recession in the United States and Argentina), the result being that output increased by a mere 1.57%. In 2002, financial speculation and the restrictive monetary policy of the second half held output growth down to 2.7%. The monetary policy restrictions continued throughout the first half of the following year, so industrial output remained practically unaltered, with growth of just 0.1%. The opposite occurred in 2004, when the monetary policy restrictions were lifted and the international situation turned quite favourable, allowing industrial growth to recover strongly (8.4%). This growth trend, though somewhat weakened and not as sectorally homogeneous as in 2004, was maintained in 2005, when industrial output climbed by 3.1%. Industrial production in Brazil kept rising in 2006 and 2007, and this growth pattern was interrupted only in the second half of 2008 by the world financial crisis.

FIGURE 1

Brazilian foreign trade, 1990-2008

(Millions of dollars)

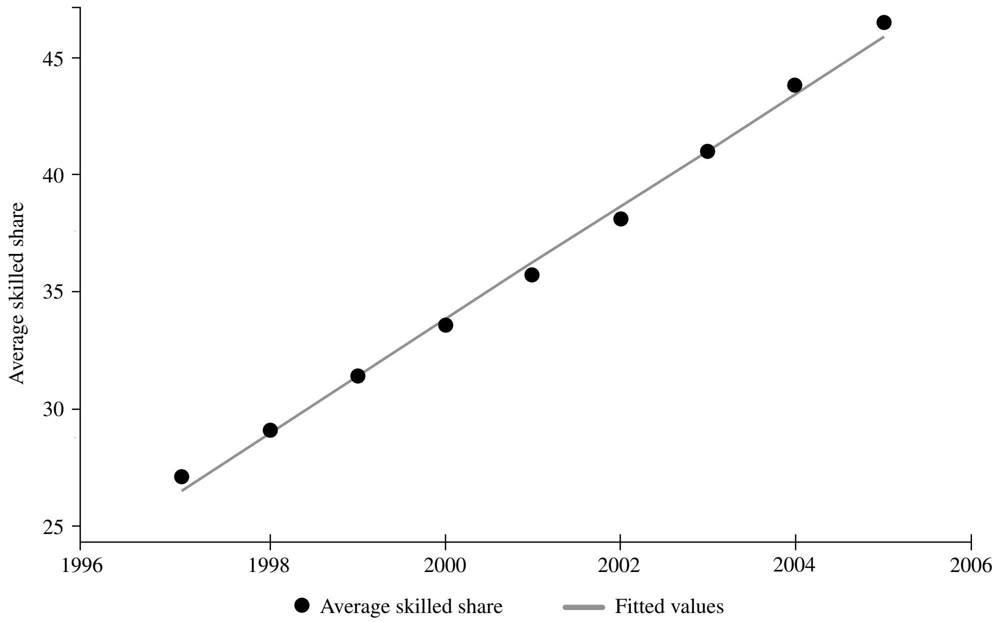


Source: Prepared by the authors, on the basis of the SECEX database.

FIGURE 2

Brazil: Average skilled share of employment in the labor market, 1996-2006

(Percentages)



Source: Prepared by the authors, on the basis of the RAIS database.

Figure 2 clearly suggests a rising trend; indeed, by the end of the period considered, the share of skilled workers was close to half the firms' workforce.

An initial attempt to determine the main forces behind skill upgrading can be made by splitting the revealed increase in the demand for skilled labour into its between- and within-industry components. The aggregate increase in the demand for skills may have been driven by

— employment reallocation across industries (for a number of reasons, such as trade shifts, structural change, evolving tastes or changes in economic policy) or
— skill upgrading within industries (mainly due to technological change).

Therefore, we decompose the aggregate change in the demand for skilled labour (ΔSL) in the $i = 1,\ldots, N$ industries (with N going from sector 10 to sector 37) according to the following formula:

$$\Delta SL = \sum_{i=1}^{N} \Delta SL_i \overline{P}_i + \sum_{i=1}^{N} \Delta P_i \overline{SL_i} \qquad (1)$$

where SL is skilled labour (number of skilled workers) and P_i is industry i's share of total employment.

The first term is the within-industry component of skill upgrading, weighted by $\overline{P}_i$, the relative size of industry i (i.e., industry i's share of total employment), where the bar is a time mean. The second term measures the contribution of between-industry shifts, i.e., how much bigger or smaller an industry is becoming over time, weighted by time-averaged skill demand.

Table 2 shows that the increase in the demand for skilled labour was driven by the within-industry variation, which basically accounts for the whole of the overall change. This interesting preliminary evidence

TABLE 2

Brazil: Decomposition of the skilled employment share[a]

	Within	Between	Overall	Within/Between
1997-2005	0.23	-0.01	0.22	1.04
1997-1998	0.03	0.00	0.03	1.00
1999-2001	0.06	-0.01	0.05	1.20
2002-2005	0.08	0.00	0.08	1.00

Source: Prepared by the authors, on the basis of the PIA, RAIS, and SECEX databases.

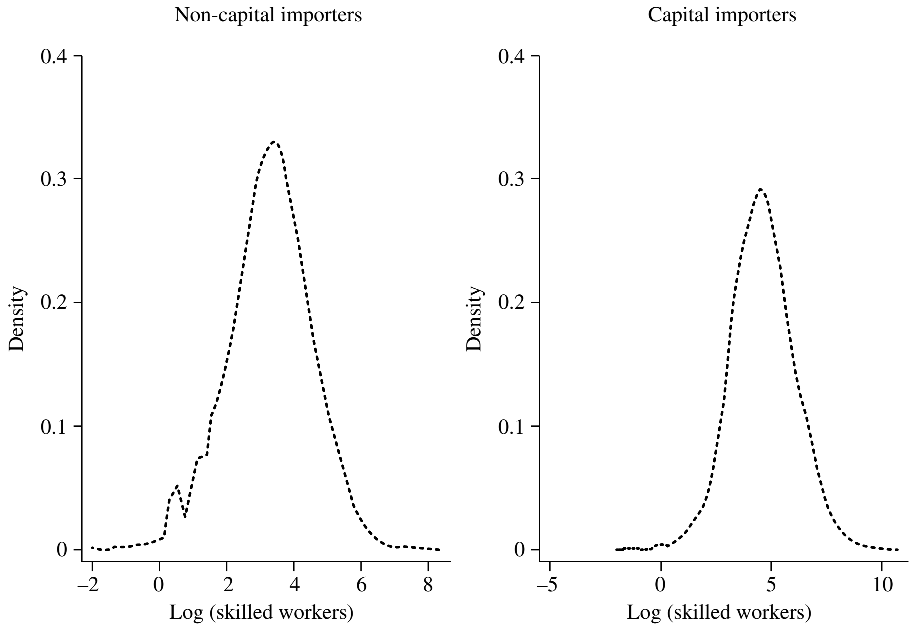
[a] The sum of rows 2, 3 and 4 does not add up to the row 1 total. The row 1 total is the sum of the three plus the changed occurred during the years 1998 and 2001. Both were years of financial crisis, so their effect is difficult to interpret.

supports the hypothesis that technology (and in particular technology transfer from richer countries) may have played a crucial role as a determinant of skill upgrading in Brazilian manufacturing.

Other preliminary evidence is obtained by considering the density functions of skilled employment and the skilled employment share in the subsample of firms that do not import capital goods and the subsample of those that do, respectively (figures 3 and 4). Since in both cases we can see that the distribution is more right-skewed for the subsample of technology adopters, we again find some empirical evidence in favour of the SET hypothesis.

FIGURE 3

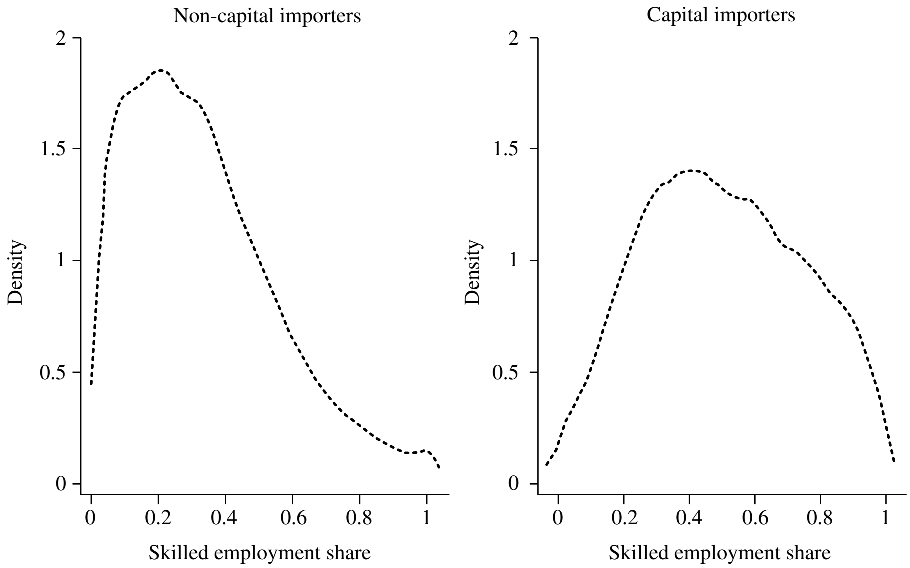
Brazil: Density of (log) skilled employment for non-importers of capital goods (left) and for capital-importing firms (right)



Source: Prepared by the authors, on the basis of the RAIS and SECEX databases.

FIGURE 4

Brazil: Density of the skilled employment share for non-importers of capital goods (left) and for capital-importing firms (right)



Source: Prepared by the authors, on the basis of the RAIS and SECEX databases.

V

Econometric analysis

In order to test the determinants of labour demand and its composition, we run two dynamic estimates of the demand for skilled and unskilled labour. Starting with the former:

$$\log(S_{it}) = \alpha_0 + \rho \log(S_{it-1}) + \alpha_1 \log(Y_{it}) + \alpha_2 \log(K_{it}) + \alpha_3 \log(R\&D_{it}) + \alpha_4 \log(SET_{it}) + \alpha_5 \log(ws_{it}) + \mathbf{T}'\gamma + \mathbf{S}'\delta + \varepsilon_i + u_{it} \quad (2)$$

where S is the number of workers with at least secondary education, Y is output (sales), K is capital stock (see Appendix for definitions), *R&D* is a domestic innovation variable (here proxied by royalties expenditure), *SET* is importation of capital goods and *ws* is the wage of skilled workers. The lagged dependent variable captures the very likely event that adjustment costs arise (see Nickell, 1984; Van Reenen, 1997), making the demand for labour sticky and persistent.[17] The terms preceding the errors are time and industry dummy variables (at the CNAE two-digit level).[18]

The corresponding equation for unskilled labour is:

$$\log(U_{it}) = \beta_0 + \psi \log(U_{it-1}) + \beta_1 \log(Y_{it}) + \beta_2 \log(K_{it}) + \beta_3 \log(R\&D_{it}) + \beta_4 \log(SET_{it}) + \beta_5 \log(wu_{it}) + \mathbf{T}'\gamma + \mathbf{S}'\delta + v_i + e_{it} \quad (3)$$

[17] The coefficient for the log of S from a regression on its lag and a constant turns out to be 0.96. Labour demand calls for a dynamic specification, and in fact the first applications of the dynamic econometric methodologies used demand for labour as a testing benchmark (see Arellano and Bond, 1991).

[18] Since we do not want the log transformation to affect our sample size (think, for example, of SET, which displays a mass of zero values), we keep the log variable at 0 when the level variable is also 0 and calculate the log only for positive values. Since there is no single case in which the original variable is equal to 1, this does not induce any noise.

where U stands for the unskilled (workers with primary education or less) and wu is the unskilled workers' wage.

Dynamic equations (2) and (3) above cannot be consistently estimated by ordinary least squares (OLS) or fixed effects (FE) (Nickell, 1981), and we have to rely on panel estimators such as generalized method of moments (GMM) (see Arellano and Bond, 1991) and its improved system version (SYS-GMM) (see Blundell and Bond, 1998), which takes into account both the difference equations and the original equations in levels. The latter estimator is more efficient in the presence of short time series (such as that used in this study, nine years) and very persistent dependent variables such as the employment indicators used in this empirical analysis; thus, SYS-GMM was chosen as our estimation technique. We used robust standard errors, applying the Windmeijer correction (see Windmeijer, 2005).

Since the wage terms are obviously endogenous, we instrumented them. However, we suspect that all the other regressors (except the dummy variables) are endogenous, being part of an extended production function and proving to be highly persistent as well. Hence, instrumentation was applied to all the variables. Since we do not have small sample properties to deal with, we use all lags.

In order to detect potential supply effects, we not only controlled for the endogeneity of wages but added time dummy variables, detecting the trend effect of the rise in the share of the labour force with at least secondary education.

We expect capital-skills complementarity to hold, especially for skilled labour, and we expect both SET and domestic generation of innovation to play a skill-biased role.

The results are shown in tables 3 and 4.[19]

Unsurprisingly, tables 3 and 4 clearly show that the demand for both skilled and unskilled labour is strongly path-dependent, being positively affected by output expansion and negatively affected by the relevant wage. Hence, the estimates obtained support the adopted dynamic specification of standard demand for labour, split by skills.

Where capital formation is concerned, the results clearly show that capital is a complement to skilled workers, since the corresponding regressor is positive and significant only in table 4, being negative and significant in table 3. This is strong evidence in favour of the capital-skills complementarity hypothesis.

Turning our attention to domestic technology (proxied by royalties), it is a positive driver of the upskilling trend (the corresponding coefficient is positive and significant in the skilled labour equation, but not significant in the unskilled labour equation). This evidence indicates the skill-biased nature of Brazilian domestic technologies, supporting the thesis that imported skill-biased technological change is spreading from high- to middle-income countries (see section II).

Finally, results for the key SET variable support our hypothesis. Imported capital goods act as a skill-enhancing component of trade: although positive in both the equations, the SET coefficient is highly significant only in the skilled labour equation, where it exhibits a magnitude almost four times as great as the one estimated in the unskilled labour equation.

[19] Where the diagnostic tests are concerned, in tables 3 and 4 the AR(1) and AR(2) tests always confirm the validity of the specifications adopted. In contrast, the Sargan tests always turn out to be significant, thereby rejecting the null of adequate instruments. Indeed, the Sargan test of overidentifying restrictions verifies the overall validity of the GMM instruments where the null hypothesis suggests that the instruments are uncorrelated to some set of residuals. In our regressions, the null hypothesis is always rejected; however, we are not overly worried by the failure of the test, for four reasons. First, the Sargan test "should not be relied upon too faithfully, as it is prone to weakness" (Roodman, 2006, p. 12). Second, in their Monte Carlo experiments Blundell and Bond (2000) "observe some tendency for this test statistic to reject a valid null hypothesis too often in these experiments and this tendency is greater at higher values of the autoregressive parameter" (Blundell and Bond, 2000, p. 329). Third, the very large number of observations makes the occurrence of a significant Sargan more likely. Finally, the Wald test supports the overall validity of the regression.

TABLE 3
Brazil: Unskilled workers

Log(unskilled workers)	0.7990
(First lag)	[0.0142]***
Log(unskilled wage)	-0.2911
	[0.0473]***
Log(sales)	0.2377
	[0.0087]***
Log(capital)	-0.0970
	[0.0121]***
Log(royalties)	-0.0006
	[0.0008]
Log(SET)	0.0010
	[0.0005]*
Constant	-0.7774
	[0.1498]***
Year dummy variables	Yes
Industry dummy variables	Yes
Firms	10 810
No. of observations (nT)	80 951
AR(1)	-16.04
P-value	0.000
AR(2)	1.72
P-value	0.085
Wald test	37 926.00
P-value	0.000

Source: Prepared by the authors, on the basis of the RAIS and SECEX databases.
Notes: Dependent variable: log of unskilled workers. Methodology: SYS-GMM with robust standard errors (in brackets).
* Significant at 10% ** Significant at 5% *** Significant at 1%.

TABLE 4
Brazil: Skilled workers

Log(skilled workers)	0.6729
(First lag)	[0.0111]***
Log(skilled wage)	-0.6538
	[0.0294]***
Log(sales)	0.2569
	[0.0095]***
Log(capital)	0.1019
	[0.0120]***
Log(royalties)	0.0019
	[0.0008]**
Log(SET)	0.0038
	[0.0006]***
Constant	-2.6376
	[0.1892]***
Year dummy variables	Yes
Industry dummy variables	Yes
Firms	10 785
No. of observations (nT)	79 619
AR(1)	-20.61
P-value	0.000
AR(2)	-0.09
P-value	0.926
Wald test	59 444.31
P-value	0.000

Source: Prepared by the authors, on the basis of the RAIS and SECEX databases.
Notes: Dependent variable: log of unskilled workers. Methodology: SYS-GMM with robust standard errors (in brackets).
* Significant at 10% ** Significant at 5% *** Significant at 1%.

VI
Concluding remarks

This study has investigated the impact of trade opening and technology transfer on the relative demand for skilled labour in Brazilian manufacturing firms, using a unique panel database of almost 11,000 Brazilian manufacturing firms over the 1997-2005 period.

The findings show that the increase in relative demand for skilled labour recorded in that period was mainly driven by within-industry variation, supporting the hypothesis that technology (and in particular technology transfer from richer countries) may have played a role in determining the skill upgrading of Brazilian manufacturing firms.

The econometric results further support this hypothesis. Indeed, the estimations show that capital stock and domestic technology are complements of skilled workers. Moreover, imported capital goods clearly act as a skill-enhancing component of trade. Hence, our results support the view that capital-skills complementarity, domestic skill-biased technological change and skill-enhancing trade have all played an important role in shaping the Brazilian manufacturing workforce.

In terms of policy implications, our results suggest that the HOSS predictions do not apply to the current wave of globalization; on the contrary, marginalization of unskilled workers within developing countries is very likely to emerge as a consequence of skill-enhancing trade.

In this framework, there is scope for active social intervention in developing countries, such as targeted education and training policies designed to increase the domestic supply of skilled labour. At the same time, the construction of a welfare system able to create safety nets and insurance schemes for the possible victims of globalization would also be advisable. In this context, domestic industrial and labour policies in developing countries might be severely limited by government budget constraints, with international organizations instead playing a pivotal role (see, for instance, ILO, 2004).

APPENDIX

Sample and variables

We chose to build a large balanced panel of 11,219 manufacturing firms, observed for nine years: this is the largest panel obtainable by merging the original PIA, RAIS and SECEX databases. After purging it of unreliable observations and obvious outliers, we ended up with 10,785 firms for which we have information on skilled employment and 10,810 for which we have information on unskilled employment.

We deflated expenditure variables by the Extended National Consumer Price Index (IPCA), published by IBGE, with base year 1997. Since import data are provided in United States dollars, we converted them into Brazilian reais using the average exchange rate for the year of reference.

We used SECEX to construct a SET variable capturing imported capital goods embodying technology. IBGE makes available a classification of products into four categories, in accordance with the harmonized system (HS) code for foreign trade. These four macro categories are: capital goods, non-durable consumer goods, durable consumer goods and intermediate goods. This classification underwent some minor changes in 2002, and it is not possible to carry out a one-to-one mapping from the old to the new categories. However, the unclassified import transactions are less than 5% of the total, so we simply used the updated taxonomy and left out unclassifiable imports.

Since SECEX is a registry database, we can legitimately assume that missing values for imports are actually zeros. Given our use of log scale data, the log transformation of zero values would have dropped a significant portion of the sample; thus, we constructed log(SET) as 0 if capital goods imports were 0 and we applied the log transformation only to positive values (the absence of values equal to 1 makes this exercise meaningful).

Regarding PIA, we used a capital measure obtained from IBGE that employs the perpetual inventory methodology applied to investment data.

From PIA we also took total sales and expenditure on royalties (in Section C5 of the PIA questionnaire there is in fact a specific question about expenditure on royalties and technical assistance) (see IBGE, 2004).

With regard to employment, we used a firm-level database extracted from RAIS, which is provided by the Ministry of Labour and Employment. We deemed workers with secondary or tertiary education to be skilled and those with primary education or below to be unskilled. Wages are at firm level for both categories and are expressed as multiples of the minimum wage.

(Original: English)

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