Trade, Technology, and Productivity: A Study of Brazilian Manufacturers, 1986-1998

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Abstract

Brazil's trade liberalization between 1990 and 1993, and its partial reversal in 1995, are used to study how trade affects productivity. The production function of Brazilian manufacturers is estimated at the *SIC* two-digit level under an extension of Olley and Pakes' (1996) procedure. Firm-level productivity is inferred and then related to trade in a causal analysis. Findings suggest that (1) the use of foreign inputs plays a minor role for productivity change, whereas (2) foreign competition pressures firms to raise productivity markedly. (3) The shutdown probability of inefficient firms rises with competition from abroad, thus contributing positively to aggregate productivity. Counterfactual simulations indicate that the competitive push (2) is a salient source of immediate productivity change, while the elimination of inefficient firms (3) unfolds its impact slowly. JEL F14, F43

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Does an open economy grow faster than a closed economy, and, if so, why? Over the past two decades, many developing countries and transition economies have liberalized international trade. In the early nineties, Brazil reduced tariffs and eliminated import barriers. Among other motives, Brazil aimed to promote productivity gains by exposing firms to fiercer international competition and facilitating access to global markets.

Different branches of empirical research investigate how more open countries fare. One line of empirical studies approaches the question through cross-country comparisons. For the most part, findings indicate that open countries tend to grow faster (e.g. Ben-David 1993, Sachs and Warner 1995). However, these studies have spawned criticism for the possible arbitrariness of indices of openness and endogeneity problems (Slaughter 1997, Harrison and Hanson 1999, Rodríguez and Rodrik 2000). Sector-level studies circumvent these problems but cannot unmask underlying microeconomic processes either (e.g. Keller 2000, Kim 2000). Using longitudinal data, a microeconomic branch of empirical research traces the effects of trade exposure and foreign direct investment on firms or plants in select countries. Caves (1998), Bartelsman and Doms (2000), and Tybout (2001) review the microeconometric literature on industry turnover and productivity change. The present paper belongs in this latter branch, too.

For the first time, the present study employs an unbalanced panel of 9,500 medium-sized to large Brazilian manufacturers between 1986 and 1998. Beyond commonly available variables, firms report foreign equipment acquisitions and the use of foreign intermediate inputs. Special variables trace a firm's economic destiny—its state of operation, and its suspension or extinction. These groups of variables permit refinements in the estimation technique that were not feasible with previous data.

Brazil strongly reduced import barriers during the early nineties. Exports, however, remained subject to largely unaltered taxes and tariffs between 1986 and 1998 (Veiga 1998). As a welcome consequence, the impact of trade reform on the import side can be isolated from other effects of trade. Foreign direct investment, a further key aspect of an economy's openness, rose strongly in Brazil over the same period (Bonelli 1999) and will be controlled for. This paper asks: *How did Brazil's removal of import barriers affect productivity among its medium-sized to large manufacturers?*

Trade reform may affect productivity through three primary "channels".

1. *Foreign Input Push*: High-quality equipment and intermediate goods allow firms to adopt new production methods. Their use can raise efficiency.

2. *Competitive Push*: The removal of import barriers increases competition on the product market side. This can allow firms to remove agency problems and induce them to innovate processes.

These two effects tend to shift a *firm's* productivity. In addition, a separate group of trade effects on productivity can only be observed at the level of *sectors or industries*. The present analysis focuses on

3. *Competitive Elimination*: Increased foreign competition makes the least efficient firms shutdown and enables the surviving, competitive firms to increase market share. This turnover raises average productivity.

The present dataset allows for the separation of the foreign input push (1). Feenstra, Markusen and Zeile (1992, Korean business groups) and Fernandes (2001, Colombian manufacturers) also trace effects of inputs on productivity at the micro-level. Their studies suggest that productivity is positively related to the use of high-quality inputs. The present study shows, however, that this effect is relatively small compared to the other two channels. Microeconometric studies on the competitive push (2) and competitive elimination (3) include Cox and Harris (1985), Levinsohn (1993), Roberts and Tybout, eds (1996) and Pavcnik (2000). For Brazil, Cavalcanti Ferreira and Rossi Júnior (1999) find a positive impact of trade reform on productivity in sector-level data and Hay (2001) in a sample of 320 large manufacturers. In general, these studies show that higher efficiency and faster turnover follow trade liberalization. However, as Tybout (2001, p. 16) concludes in a recent literature review, "it is difficult to find studies that convincingly link these processes to the trade regime." The present paper aims to establish causal relationships between productivity and trade exposure, and sets out to evaluate the relative importance of the above three channels.

Like previous studies, the paper employs Olley and Pakes' (1996) estimation algorithm to obtain consistent productivity estimates. A new structural model motivates the procedure. The model resolves a previous shortcoming, which demanded that observations with zero (negative) investment be excluded. This would have caused the loss of up to a third of all observations. Productivity estimates are corrected for the endogeneity of price in sales figures (Klette and Griliches 1996) and for changing managerial efficiency under increasing competition. Firm-level productivity estimates and turnover are then related causally to the trade regime.

Results for the foreign input push (1) indicate that, on average, the efficiency of foreign equipment and intermediate inputs is higher than the efficiency of domestic inputs. To measure their effect, foreign inputs are included in the production function and distinguished regarding their role as capital goods or intermediate inputs. However, their overall efficiency contribution is minor. The adoption of new technologies can reduce productivity initially. Firms need to put high-quality inputs to adequate use in order to achieve productivity gains. In several sectors, Brazilian firms do not appear to succeed with necessary rearrangements in the short term.

Evidence regarding the competitive push (2) indicates that firms respond strongly to increased competitive pressure and raise their efficiency. To draw this causal conclusion, the analysis employs instrumental variables and controls for the endogeneity of foreign market penetration and trade policy. Third, firm turnover and the exit of the least productive firms contributes positively to productivity change in the aggregate. In an effort to evaluate this competitive elimination (3) causally, probabilities of Markov transitions between states of operation are estimated as a function of the trade regime. The exit probability increases strongly with foreign competition.

To understand the relative importance of the three channels *vis à vis* each other, counterfactuals are evaluated in simulations. The counterfactuals ask how much less productivity change would have occurred through each channel had Brazil not reduced tariffs. These simulations show that the competitive push (2) is a salient source of immediate productivity change, while competitive elimination (3) unfolds its impact slowly.

The remainder of the paper is divided in six sections. Section 1 gives a short overview of the Brazilian trade liberalization programme. The data are described briefly in section 2. Section 3 presents the behavioral framework. It bases Olley and Pakes' (1996) estimation procedure on different theoretical grounds and adapts the technique to the present context. Section 4 summarizes how consistent firm-specific productivity measures are obtained, while details are relegated to the appendix. Using the resulting firm-level productivity estimates, section 5 evaluates how Brazil's trade policy affected productivity and distinguishes the three above-mentioned channels. Section 6 concludes.

1 Brazilian Trade Policy

For decades, policies of import substitution and industry protection were part of Brazil's broader development strategy. Until the early nineties, high tariffs, exchange rate controls and interventions, and especially prohibitive non-tariff barriers were intended to reduce the competitive pressure on domestic industries (Bonelli, Veiga and Brito 1997). From the mid seventies until the late eighties, for example, potential importers to Brazil had to undergo a rigorous examination as to whether their commodities were similar to domestic products. If so, their imports were banned. As a result, the Brazilian domestic market remained essentially closed for a broad range of foreign equipment, including computers.

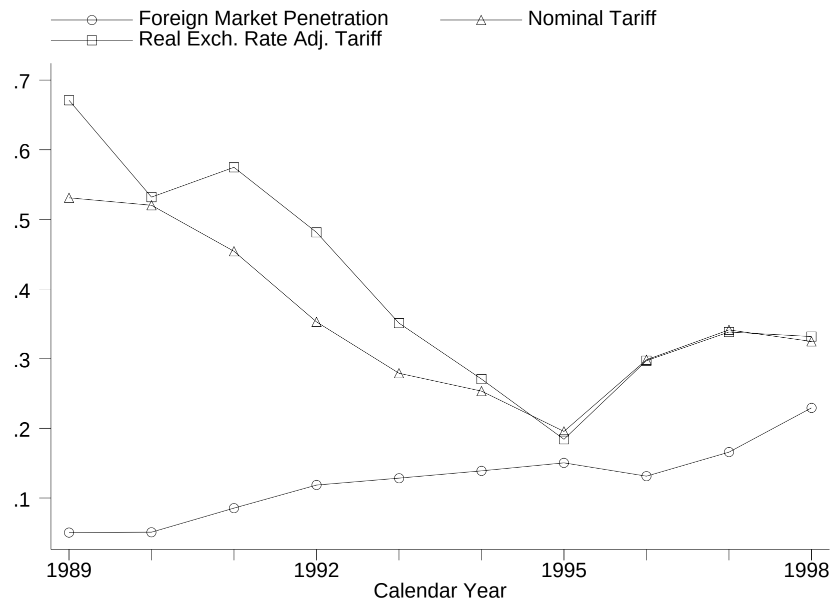
In 1988, the federal government initiated a process of trade liberalization that reduced both the level and the cross-industry dispersion of tariffs. Redundant tariffs were eliminated from Brazil's tariff act by 1990, but the binding non-tariff barriers remained largely untouched. Only the Collor de Melo administration in 1990 was able to break with earlier Brazilian policies of import substitution and industrial targeting (Bonelli et al. 1997). The government presented a detailed schedule for tariff reductions to be completed by 1994 and announced the elimination of non-tariff barriers (Horta, Piani and Kume 1991). Tariffs on equipment not produced in Brazil, for instance, were immediately reduced to zero and non-tariff barriers were eliminated. At the other extreme, tariffs for information technology remained at 40 percent in order to protect Brazil's fledgling computer industry. In fact, the liberalization programme was concluded in less than three years by July 1993. This speed and the far reaching removal of non-tariff barriers shocked the domestic manufacturing sector considerably. However, when president Cardoso took office in 1995, some of the earlier liberalization efforts were reversed.

The capital goods and transport equipment sectors are a striking example. Their tariffs and market penetration are depicted in figure 1. Brazil's elevated real exchange rate added to protection until 1994. To show this, a tariff series weighed by the real exchange rate is depicted alongside. Foreign market penetration tends to mirror the moves of Brazil's effective tariffs fairly closely. Machinery producers and car makers were among the most successful lobbyists to argue for an increase in tariffs in 1995. Other sectors faced less of a reversal.

Cavalcanti Ferreira and Rossi Júnior (1999) argue that, on average, the effective rate of protection was about 80 percent of the import price in 1985. They control for both tariffs and non-tariff barriers. According to their measure, effective protection fell to 21 percent by 1997—a quarter of the level twelve years earlier. Brazil took hardly any steps to stimulate exporting (Veiga 1998). Select sectors benefit from largely unaltered export incentives. However, peculiar double-taxation schemes could and still can make exporting more expensive for firms in most sectors than selling to the domestic market.

2 Data

The Brazilian census bureau *IBGE* surveys manufacturing firms and plants annually in its *Pesquisa Industrial Anual* (*PIA*). Plant data in *PIA* are considerably less comprehensive, so the present study only draws on firm data. In



Source: Own calculations, tariffs weighted by imports. Sector: *Bens de capital e equipamentos de transporte* (definition according to Mesquita Moreira and Correa 1997).

Data: Ramos and Zonenschain (2000) for market penetration; Kume, Piani and Souza (2000) for nominal tariffs; Brazilian central bank and US census bureau for real exchange rate.

Figure 1: **Tariffs and foreign market penetration. Capital goods**

addition, firm data are more likely to capture unobserved characteristics and inputs such as managerial ability than are plant data. The current sample is not strictly representative for the manufacturing sector as a whole. Yet, to trace the effects of trade liberalization on productivity, only a random sample is needed that was selected independent of trade exposure. This is satisfied.

A firm qualifies for *PIA* if at least half of its revenues stem from manufacturing activity and if it is formally registered with the Brazilian tax authorities. In 1986, the initial *PIA* sample was constructed from three layers: (1) A non-random sample of the largest Brazilian manufacturers with output corresponding to at least 200 million Reais in 1995 (around 200 million US dollars in 1995). There were roughly 1,000 of them. (2) A random sample among medium-sized firms whose annual output in 1985 exceeded a value corresponding to R$ 100,000 in 1995 (around US$ 100,000 in 1995). About 6,700 firms made it into *PIA* this way. (3) A non-random selection of newly founded firms. *PIA* only included new firms that surpassed an annual average employment level of at least 100 persons. The inclusion process ended in 1993, however.

Until then, around 1,800 firms were identified in this manner.

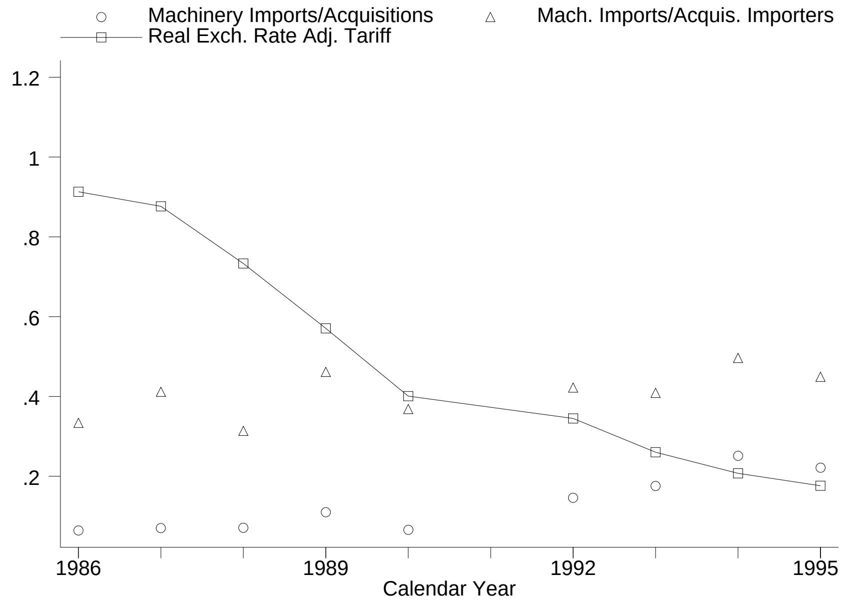
Departing from this initial sample, *PIA* identifies more than 9,500 active firms over the years. A firm that ever enters *PIA* through one of the selection criteria remains in the sample unless it is legally extinct. Moreover, if an existing firm in *PIA* reports the creation of a new firm as a subsidiary or spin-off, this new firm enters *PIA*, too. No sample was taken in 1991 due to a federal austerity program. The sampling method changed in 1996, and no capital stock figures are reported since. Therefore, the dataset of this paper only embraces firms after 1995 that were present in *PIA* earlier or that were longitudinally related to an earlier firm. Their capital stock is inferred with a perpetual inventory method. Following the change in methods, there is a drop in the sample in 1996. Tests at various stages of the estimation prove it exogenous.

PIA includes precise longitudinal information for every firm. Special variables summarize a firm's state of operation and make sure that observations with missing economic information are not confused with a shutdown or a temporary suspension of production. This is particularly important since it was quite common among Brazilian manufacturers between 1986 and 1998 to "mothball" for extended periods of time. Among the 9,500 firms, more than 1,100 state in at least one year that they suspended production temporarily or for the entire year. The construction of an unbalanced panel from *PIA* is documented in Muendler (2002).

Economic variables in *PIA* include sales figures and changes in final goods stocks, costs of inputs, salaries, employment of blue- and white-collar workers, and several variables related to investment and the capital stock. Most interestingly, firms in *PIA* report their acquisitions of foreign equipment until 1995 and their purchases of foreign intermediate goods since 1996. These foreign acquisitions are reported with their prices at the time of purchase. So, prices properly reflect the goods' relative economic values at which the firms decide to buy. I describe in detail in Muendler (2002) how coherent capital stock and foreign equipment series are obtained. Foreign equipment shares are inferred from foreign equipment investments and overall retirements.

Figure 2 plots the evolution of foreign equipment acquisitions between 1986 and 1995. Importers of foreign equipment before 1991 continue to invest in foreign equipment at roughly the same rate after 1991. However, the share of foreign equipment in total equipment acquisitions jumps up significantly. This suggests that mostly firms that did not acquire foreign equipment before 1991 do so after trade liberalization.

Sector classifications in *PIA* would allow for the estimation of production functions at a level that corresponds to three *SIC* digits (*nível 100*). However,



Source: Own calculations.

Data: *Pesquisa Industrial Annual* for equipment acquisitions. Effective equipment tariffs from Kume et al. (2000) weighed by the national capital formation vector (*IBGE*).

Figure 2: **Foreign equipment acquisitions. All manufacturing**

large firms in *PIA* are likely to offer product ranges beyond narrowly defined sector limits. Data at more aggregate levels also provide more variation in the cross section because market penetration and tariff series then become available for two or more subsectors within several sectors. Moreover, switching from the three to the two-digit level increases the number of observations per estimation considerably. So, estimations are carried out at the *SIC* two-digit level (*nível 50*).

3 Behavioral Framework

Three main types of biases affect estimates of production with microdata. First, there is self-selection. Surviving firms exhibit higher productivity than less competitive exiting firms. So, an unbalanced panel of firms needs to be constructed.

Second, firms choose investment and decide whether to stay in business given their productivity. However, productivity is not observable directly. Marschak and Andrews (1944) outline this simultaneity problem early on. It has become known as 'transmission bias'. Such a bias may affect the capital coefficient for two reasons. For one, firms with a large capital stock are more likely to remain in business and tolerate lower productivity levels. This can introduce a negative bias in the capital coefficient as Olley and Pakes (1996) show. On the other hand, if firms can invest both in capital goods and in productivity, they may choose to raise or let decay capital and productivity simultaneously. The model below will clarify that this can introduce a positive bias. Theoretically, either source can dominate. Some sectors in the present data exhibit a positive bias, while others suffer from a negative bias.

Third, error in production function estimates and hence productivity measures arises from an 'omitted price bias' as discussed by Klette and Griliches (1996). This problem occurs when sales figures are used to approximate output. It has also been known since at least Marschak and Andrews (1944).

The present section develops a behavioral framework suitable to address these issues. The model resolves a previous shortcoming of Olley and Pakes (1996) that called for observations with zero (negative) investment to be dropped from the sample. In addition, the model provides a production-side explanation why the bias in the capital coefficient may be positive, a frequent empirical finding. The model motivates Olley and Pakes' estimation procedure differently and incorporates Klette and Griliches' (1996) correction method. Its main feature is that firms can invest in both capital goods and productivity. Finally, the model permits that competition may induce managers to remove inefficiencies—a maintained hypothesis of the present study. Optimality conditions are derived using principal-agent and q-theory, and Olley and Pakes' regression equations will be based on those conditions. Two main testable implications of the proposed model are that the productivity level and the capital stock should be positively correlated and that productivity should be procyclical. Both implications are borne out in the present data (the level regressions in table 8 are examples).

3.1 Assumptions

Firms can invest in two state variables: capital and total factor productivity. There are several flow variables. Besides investment, which moves the two state variables, firms employ labor and use intermediate goods. For ease of exposition, consider just one type of capital and labor for now and neglect intermediate inputs. Table 1 gives an overview of the main ingredients and the consequences of the model to be derived.

The variable $\Omega_{i,t}$ is the total of a firm's tacit knowledge, organizational skills, and efficiency-relevant arrangements embodied in the production pro-

Table 1: COMPONENTS OF q-THEORY MODEL

Variable	Evolution / Timing	Observed	Olley & Pakes
State Variables			
TFP: $(\Omega_{i,t})^{\nu}$	$\Omega_{i,t} = \left[\Omega_{i,t-1}(1-\delta^{\Omega}) + I^{\Omega}_{i,t-1}\right] \tilde{x}_{i,t}$	no	Markovian[a]
Capital $K_{i,t}$	$K_{i,t} = K_{i,t-1}(1-\delta^{K}) + I^{K}_{i,t-1}$	yes	same
Control Variables			
Investment $I^{\Omega}_{i,t-1}$	before $\tilde{x}_{i,t}$ realized (based on $q^{\Omega}_{i,t}$)	no	
Investment $I^{K}_{i,t-1}$	before $\tilde{x}_{i,t}$ realized (based on $q^{K}_{i,t}$)	yes	same
Survival $\chi_{i,t}$	after $\tilde{x}_{i,t}$ realized	yes	same
Labor $L_{i,t}$	after $\tilde{x}_{i,t}$ realized	yes	same
Implications			
Upward bias in capital coefficient explained			
Observations with zero (negative) investment permissible			no

[a]Olley and Pakes (1996) consider an exogenous Markov process of *TFP* beyond a firm's control. Alternatively, Ericson and Pakes (1995) allow for a binary choice of *TFP* improvement that affects the Markov process. The current model allows managerial effort to alter the distribution of $\tilde{x}_{i,t}$ as in a standard principal-agent model. Whereas $I^{\Omega}_{i,t}$ is observable to a firm's owner from cash flows, managerial effort is not.

cess. All of these factors contribute to a firms' *TFP* level. They are not transferrable from one firm to another but can be accumulated within a firm. They depreciate unless cultivated with investment $I^{\Omega}_{i,t}$. For simplicity, *TFP* is assumed to be

$$TFP_{i,t} = (\Omega_{i,t})^{\nu} \tag{1}$$

for some coefficient $\nu > 0$. As opposed to physical capital accumulation, there is a stochastic factor $\tilde{x}_{i,t}$ to the evolution of organizational knowledge:

$$\Omega_{i,t} = \left[\Omega_{i,t-1}(1-\delta^{\Omega}) + I^{\Omega}_{i,t-1}\right] \cdot \tilde{x}_{i,t}. \tag{2}$$

The parameter δ^{Ω} expresses the depreciation rate of organizational knowledge. Productivity choice is an imperfect substitute for physical capital because $(\Omega_{i,t})^{\nu}$ will enter the production function separately and a firm cannot anticipate the realization $x_{i,t}$. The stochastic factor $\tilde{x}_{i,t}$ captures a firm's efficiency and is assumed to be uncorrelated with its past realizations and factor inputs—similar to the spirit of Olley and Pakes' model. However, the efforts of a firm's management to improve efficiency and make better use of organizational skills can affect the distribution of $\tilde{x}_{i,t}$ favorably (more on this in subsection 3.3).

Consider a market with monopolistic competition. Each firm manufactures one variety of a good. Consumers have income Y_t and preferences as in a standard model for intraindustry trade: $u(Z_1, ...Z_N; C) = (\theta/\alpha)\ln(\sum_{n=1}^{N}(Z_n)^{\alpha}) + (1-\theta)\ln C$. There are N varieties of good Z. Under this utility, price elasticity of demand for a modern good i is approximately $-1/(1-\alpha)$. With a price index $\bar{P}_t \equiv [\sum_{n=1}^{N} P_{n,t}^{-\alpha/(1-\alpha)}]^{-(1-\alpha)/\alpha}$, similar to a census bureau's price index, demand for firm i's good can be stated as

$$D_{i,t} = \frac{\Theta_t}{\bar{P}_t} \cdot \left(\frac{P_{i,t}}{\bar{P}_t}\right)^{-\frac{1}{1-\alpha}}, \tag{3}$$

where $\Theta \equiv \theta Y_t$ is the income share that domestic consumers spend on goods Z, including imports. This will be a key relationship for the correction of endogenous price in sales (Klette and Griliches 1996).

To see more clearly how foreign competition affects demand, suppose that domestic varieties of a good sell at about the same price. However, there is a possibly different world market price P_t^f for foreign varieties that compete with firm i's good. Then, domestic demand for a domestic manufacturer i's variety can be approximated by[1]

$$D_{i,t} = \frac{1}{1 + \frac{N_t^{for}}{N_t^{dom}}\left(\frac{P_{i,t}}{\varepsilon_t P_t^f (1+\tau_{i,t})}\right)^{\frac{\alpha}{1-\alpha}}} \; \frac{\Theta_t}{N_t^{dom}\, P_{i,t}}, \tag{4}$$

where ε_t is the nominal exchange rate, and $\tau_{i,t}$ the nominal tariff in the market of firm i. N_t^{dom} and N_t^{for} denote the number of domestic and foreign varieties, respectively. Their ratio is a measure of foreign market penetration. Demand for a domestic firm's variety increases when there are relatively fewer foreign competitors, or when foreign price is higher, tariffs are higher, or the exchange rate is more favorable—as one would expect.

3.2 A firm's price, factor, and investment choice

A monopolist in the market for good Z sets price and chooses the variable factors in every period t, given his capital stock and *TFP*. The production technology for variety i of good Z is assumed to be Cobb-Douglas:

$$Z_{i,t} = (\Omega_{i,t})^{\nu}(K_{i,t})^{1-\beta}(L_{i,t} - L_0)^{\beta}, \tag{5}$$

[1] See Muendler (2001, equation (26)).

where $(\Omega_{i,t})^\nu$ is *TFP*. $L_{i,t}$ denotes employment, the only variable factor for now. L_0 is the fixed labor input and needed in every period to keep the firm in operation. It gives rise to monopolistic competition in equilibrium.

Consider a firm's intertemporal choice of its capital stock and organizational knowledge, and whether to continue in business or to shutdown. If the firm exits, it receives a payment Φ_t for its remaining assets. Tomorrow's capital stock is certain, $K_{i,t+1} = K_{i,t}(1-\delta^K) + I^K_{i,t}$, whereas tomorrow's organizational knowledge is partly random and given by (2). Adjustment costs for organizational knowledge, $\psi^\Omega (I^\Omega_{i,t})^2/(2\Omega_{i,t})$, are quadratic as in a textbook model of Tobin's q. Similarly, adjustment costs for the capital stock are $\psi^K (I^K_{i,t})^2/(2K_{i,t})$. Then the Bellman equation becomes

$$\begin{aligned} V(\Omega_{i,t}, K_{i,t}) \;\; = \;\; \max \Bigg[\Phi_t, & \sup_{I^\Omega_{i,t}, I^K_{i,t}, L_{i,t}} P^*(Z_{i,t}, \mathbf{D}_t)\, Z_{i,t} - w_t L_{i,t} - I^\Omega_{i,t} - I^K_{i,t} \\ & - \frac{\psi^\Omega}{2} \frac{(I^\Omega_{i,t})^2}{\Omega_{i,t}} - \frac{\psi^K}{2} \frac{(I^K_{i,t})^2}{K_{i,t}} + \frac{1}{R} \mathbb{E} \left[V(\Omega_{i,t+1}, K_{i,t+1}) \,|\mathcal{F}_{i,t} \right] \Bigg], \quad (6) \end{aligned}$$

where $R \equiv 1 + r$ is the real interest factor and $\mathcal{F}_{i,t}$ a firm's information set at time t. General market conditions, such as foreign market penetration, enter the decision through their effect on price. Each monopolist takes into account that higher supply depresses price given demand schedule (4). So, a monopolist sees price as a function $P^*(Z_{i,t}, \mathbf{D}_t)$, where $\mathbf{D}_t \equiv (N^{for}_t / N^{dom}_t,\, \varepsilon_t, P^f_t, \tau_{i,t})$ stands for the vector of market conditions that firm i faces. Demand elasticity $-(1-\alpha)$ is constant, however, and independent of $\mathbf{D}_t$.

First, consider the case of a firm that continues in business. Tobin's q's for organizational knowledge and physical capital can be defined as

$$q^\Omega_{i,t} \equiv \mathbb{E}_t \left[\frac{1}{R} \frac{\partial V(\Omega_{i,t+1}, K_{i,t+1})}{\partial \Omega_{i,t+1}} \cdot x_{i,t+1} \right] \text{ and } q^K_{i,t} \equiv \mathbb{E}_t \left[\frac{1}{R} \frac{\partial V(\Omega_{i,t+1}, K_{i,t+1})}{\partial K_{i,t+1}} \right]. \quad (7)$$

Then, the first order conditions for the Bellman equation (6) imply that

$$q^\Omega_{i,t} = 1 + \psi^\Omega \frac{I^\Omega_{i,t}}{\Omega_{i,t}}, \quad q^K_{i,t} = 1 + \psi^K \frac{I^K_{i,t}}{K_{i,t}}, \quad \text{and} \quad L_t = L_0 + \frac{\alpha\beta}{w_t} P^*(Z_{i,t}, \mathbf{D}_t) Z_{i,t}. \quad (8)$$

Differentiating the value function with respect to the current state variable $\Omega_{i,t}$ and leading it by one period, one finds

$$R\, q^\Omega_{i,t} = \alpha\nu \mathbb{E}_t \left[\frac{P^*(\cdot)_{t+1} Z_{i,t+1}}{\Omega_{i,t+1}} \right] + \mathbb{E}_t \left[\frac{\psi^\Omega}{2} \frac{(I^\Omega_{i,t+1})^2}{(\Omega_{i,t+1})^2} \right] + (1-\delta^\Omega)\, \mathbb{E}_t \left[q^\Omega_{i,t+1} \right] \quad (9)$$

by (7) and the envelope theorem. An according condition applies to Tobin's q for physical capital.

So, under the usual regularity (no bubble) conditions,

$$q^{\Omega}_{i,t} = \frac{1}{1-\delta^{\Omega}} \sum_{s=t+1}^{\infty} \left(\frac{1-\delta^{\Omega}}{R}\right)^{s-t} \mathbb{E}_t \left[\frac{\nu}{\Omega_{i,s}}\, \alpha P^*(Z_{i,s}, \mathbf{D}_s)\, Z_{i,s} + \frac{\psi^{\Omega}}{2} \frac{(I^{\Omega}_{i,s})^2}{(\Omega_{i,s})^2}\right] \quad (10)$$

and

$$q^{K}_{i,t} = \frac{1}{1-\delta^{K}} \sum_{s=t+1}^{\infty} \left(\frac{1-\delta^{K}}{R}\right)^{s-t} \mathbb{E}_t \left[\frac{1-\beta}{K_{i,s}}\, \alpha P^*(Z_{i,s}, \mathbf{D}_s)\, Z_{i,s} + \frac{\psi^{K}}{2} \frac{(I^{K}_{i,s})^2}{(K_{i,s})^2}\right]. \quad (11)$$

A firm is uncertain about the realization of both future *TFP* and market conditions. The two terms in the expectations operator reflect the value of the respective state variable given market prospects $\alpha P^*(Z_{i,s}, \mathbf{D}_s)\, Z_{i,s}$ and savings in future adjustment costs $(I^K_{i,s})^2/(K_{i,s})^2$. So, market conditions affect the value of both state variables in a very similar way.

As a consequence, the model implies that a firm's capital stock and organizational knowledge are correlated from a researcher's perspective. By (8) and (2),

$$\Omega_{i,t+1} = x_{i,t+1} \cdot \Omega_{i,t} \left[\frac{q^{\Omega}_{i,t} - 1}{\psi^{\Omega}} + (1 - \delta^{\Omega})\right]. \quad (12)$$

An according condition holds for $K_{i,t}$. So, for the researcher, the correlation between *TFP* and capital becomes

$$\mathbb{C}ov_t\left(\Omega_{i,t+1}, K_{i,t+1} \,|\Omega_{i,t}, K_{i,t}\right) = \frac{\Omega_{i,t} K_{i,t}}{\psi^{\Omega}\psi^{K}}\ \mathbb{C}ov_t\left(q^{\Omega}_{i,t}\,,\, q^{K}_{i,t}\right). \quad (13)$$

For the firm, $q^{\Omega}_{i,t}$ and $q^{K}_{i,t}$ are certain, given its information. The correlation is zero from its point of view. The researcher, on the other hand, does not know a firm's information set. Therefore, the data will exhibit a correlation between capital and *TFP*. The correlation is likely to be positive since future revenues affect both $q^{\Omega}_{i,t}$ and $q^{K}_{i,t}$ positively.[2] Olley and Pakes' original model does not

[2]Concretely, by (10) and (11),

$$\begin{aligned}(1-\delta^{\Omega})q^{\Omega}_{i,t} \;=\; & (1-\delta^{K})\rho_{i,t}\, q^{K}_{i,t} + \frac{1}{2}\sum_{s=t+1}^{\infty}\left(\psi^{\Omega}\left(\tfrac{1-\delta^{\Omega}}{R}\right)^{s-t}\mathbb{E}_t\left[\left(\tfrac{I^{\Omega}_{i,s}}{\Omega_{i,s}}\right)^2\right]\right.\\ & \left. -\psi^{K}\rho_{i,t}\left(\tfrac{1-\delta^{K}}{R}\right)^{s-t}\mathbb{E}_t\left[\left(\tfrac{I^{K}_{i,s}}{K_{i,s}}\right)^2\right]\right),\end{aligned}$$

allow for this possibility.[3]

However, since there is exit from the sample, the correlation in (13) does not give the complete picture. In general, the shutdown rule for a firm depends on the firm's state variables and its information about revenue prospects. Since the value function is increasing in both state variables, there are lower threshold levels for the states below which a firm exits, given market prospects. Alternatively, the shutdown rule can be written as a function of the realization of the *TFP* innovation. After observing the realization of $x_{i,t}$, a firm decides whether or not it prefers to exit. Then,

$$\chi_{i,t} = \begin{cases} 0 & \text{if } x_{i,t} < \underline{x}(\Omega_{i,t-1}, I^{\Omega}_{i,t-1}; K_{i,t}, \mathbf{D}_t) \\ 1 & \text{else} \end{cases} , \tag{14}$$

where $\chi_{i,t} = 0$ means that firm i chooses to shutdown at the beginning of period t. If the value of current and discounted future profits falls short of the outside value Φ_t, the firm has no incentive to produce in the current or any future period. Since the value function (6) is strictly increasing in the capital stock,[4] the threshold level $\underline{x}(\cdot)$ is strictly decreasing in $K_{i,t}$. A capital-rich firm is willing to bear lower *TFP* levels and still continues in business.

As Olley and Pakes (1996) pointed out, this introduces a negative correlation between the capital stock of survivors and the expected *TFP* level. Call the probability that a firm survives

$$Pr(\chi_{i,t+1} = 1 | \Omega_{i,t}, I^{\Omega}_{i,t}; K_{i,t+1}, \mathbf{D}_{t+1}) = P(\Omega_{i,t}, I^{\Omega}_{i,t}; K_{i,t+1}, \mathbf{D}_{t+1}). \tag{15}$$

Then by (2),

$$\mathbf{E}[\Omega_{i,t+1} | \chi_{i,t+1} = 1] = \left[(1-\delta^{\Omega})\Omega_{i,t} + I^{\Omega}_{i,t}\right] \int_{\underline{x}(\cdot)} x_{i,t+1} \frac{f\,(x_{i,t+1})}{P(\cdot)}\, dx_{i,t+1} \tag{16}$$

---

where

$$\rho_{i,t} \equiv \frac{\nu \sum_{s=t+1}^{\infty} \left(\frac{1-\delta^{\Omega}}{R}\right)^{s-t} \mathbb{E}_t \left[\frac{P^*(\cdot)_s \, Z_{i,s}}{\Omega_{i,s}}\right]}{(1-\beta) \sum_{s=t+1}^{\infty} \left(\frac{1-\delta^{K}}{R}\right)^{s-t} \mathbb{E}_t \left[\frac{P^*(\cdot)_s \, Z_{i,s}}{K_{i,s}}\right]} > 0.$$

[3] It is sometimes argued that a positive productivity shock may push demand for a firm's good more than proportionally and thus capital input, giving rise to a positive correlation through demand rather than production effects. In a model of the present structure but with productivity beyond a firm's control, an exogenous productivity shock translates one to one into an output change with no effect on input choice. Specific assumptions on demand elasticity would allow a positive productivity shock to cause a more than proportional output increase and higher capital input. But *temporary* productivity shocks affect capital input little even under such assumptions.

[4] $\partial V(\cdot)/\partial K_{i,t} = \alpha(1-\beta)P^*(\cdot)_t Z_{i,t}/K_{i,t} + (1-\delta^K)q^K_{i,t} + \psi^K (I^K_{i,t})^2/(2K_{i,t}) > 0$. Estimates in tables 6 and 9 confirm empirically that capital-rich firms are less likely to exit.

for the researcher. The firm is indifferent between staying in business and exit at the lower bound on $x_{i,t+1}$, $\underline{x}(\Omega_{i,t}, I^{\Omega}_{i,t}; K_{i,t+1}, \mathbf{D}_{t+1})$. The bound strictly decreases in the capital stock $K_{i,t+1}$. Thus, the value of the integral will be the lower the higher the capital stock happens to be. In the data, a negative relation between capital and the expected *TFP* level is likely to result. It is not clear *a priori* whether a positive correlation from (13) would outweigh the negative bias from (16) or not. At any rate, a correlation exists between observed capital and unobserved *TFP*, and needs to be addressed in the estimation procedure.

3.3 Competition and a manager's efficiency choice

A maintained hypothesis of the present paper is that trade liberalization induces managers to raise efficiency under fiercer international competition. Boone (2000), for example, shows conditions when more competition provides incentives to innovate products or processes. Hermalin (1992) and Schmidt (1997) present theoretical circumstances when increasing competition forces firms to reduce agency problems and managerial slack. An extension of the present model incorporates this insight and clarifies implications for productivity estimation.

A firm's investment in organizational skills $I^{\Omega}_{i,t}$ is observable to the firm's owner through cash flows. Similarly, $\Omega_{i,t}$ can be inferred from output. However, the manager's efforts in employing these organizational skills are not known. Successful efforts affect the distribution of the productivity shock $\tilde{x}_{i,t}$ in (2) favorably. In more profane words, efficiency improving investments are only successful if the management subsequently makes good use of the results. This gives rise to moral hazard. Suppose that a manager can either choose high efforts or low efforts ($E_{i,t} \in \{e^H_{i,t}, e^L_{i,t}\}$) and that the distribution of $x_{i,t+1}|e^H_{i,t}$ stochastically dominates the distribution $x_{i,t+1}|e^L_{i,t}$.[5] Under the assumption that efforts only affect next year's productivity $x_{i,t+1} \sim f(x_{i,t+1}|E_{i,t})$, it is easy to see that the firm's owner bases the optimal (end-of-year) remuneration $w(\cdot)$ on the observation of $x_{i,t+1}$. The owner maximizes $V(\Omega_{i,t}, K_{i,t}) - (1/R)\mathbb{E}\left[w(x_{i,t+1})\right]$ given the risk averse manager's participation constraint $\mathbb{E}\left[u\left(w(x_{i,t+1})\right)\right] - E_{i,t} \geq \underline{u}$ and the manager's optimality condition

$$\int_{\underline{x}} u\left(w(x_{i,t+1})\right) \frac{f(x_{i,t+1}|e^H_{i,t})}{1 - F(\underline{x}|e^H_{i,t})} \, \mathrm{d}x_{i,t+1} - e^H_{i,t} \geq$$

[5] Second-order dominance is assumed for $\nu < 1$. A mean-preserving spread leaves the firm-fixed effect unchanged.

$$\geq \int_{\underline{x}} u\left(w(x_{i,t+1})\right) \frac{f(x_{i,t+1}|e^L_{i,t})}{1-F(\underline{x}|e^L_{i,t})} \, \mathrm{d}x_{i,t+1} - e^L_{i,t}. \tag{17}$$

It is straight forward to use the principal's first order conditions and show that the optimal remuneration for the manager is strictly increasing in $x_{i,t+1}$ if and only if the likelihood ratio $f(x_{i,t+1}|e^H_{i,t})/f(x_{i,t+1}|e^L_{i,t})$ is strictly increasing in $x_{i,t+1}$. Suppose this is the case.

Fiercer competition raises $\underline{x}(\cdot;\mathbf{D}_{t+1})$ and firms go out of business more frequently. Hermalin (1992) and Schmidt (1997) show that high-effort contracts can but need not become easier to institute under fiercer competition. A similar ambiguity arises here but for different reasons. Note that the likelihood ratio is increasing in $x_{i,t+1}$ and hence in $\underline{x}$, but the ratio $(1-F(\underline{x}|e^H_{i,t})/(1-F(\underline{x}|e^L_{i,t})$ is also increasing in $\underline{x}$. Together, these facts can but need not make the left-hand side in (17) grow larger relative to the right-hand side under fiercer competition and may facilitate the institution of high-effort contracts. Irrespective of whether competition has a positive or negative effect on efficiency, productivity estimation should account for it.

4 Firm-level Productivity

This section turns to the estimation of production functions at the level of sectors. Each firm's individual productivity is inferred. The estimation procedure is based on Olley and Pakes' (1996) algorithm to address the 'transmission bias' and extended to correct for the 'omitted price bias' in the spirit of Klette and Griliches (1996). The procedure also accounts for possible effects of competition on efficiency. Technical details of the estimation are relegated to appendix A.

A 'transmission bias' in the capital coefficient arises because firms invest and decide whether to exit given their knowledge of productivity. Olley and Pakes' (1996) algorithm approximates the affected parts of the production function semiparametrically, uses the exit behavior of firms to extract additional information about expected productivity, and then removes the bias from the capital coefficients by leading the affected part of the production function one period. The remaining error term contains only an unpredictable shock to productivity, which is unrelated to a firm's investment choice.

When using revenues to approximate output, price is kept in the regression equation implicitly. An 'omitted price bias' arises. Productivity estimates are corrected for this following Klette and Griliches (1996). However, the structural model in the preceding section implies that the effect of expected revenues on *TFP* investment and the effect of competition on efficiency cannot be separated from the effect of omitted price. A remaining cyclical component in productivity estimates needs to be controlled for in subsequent analyses.

4.1 Production and foreign input efficiency

To measure the effect of foreign inputs on production directly, a modification of the production function is proposed here. Suppose firm i produces with the same Cobb-Douglas technology in every year t but with possibly different total factor productivity. The capital stock is divided into three parts. Domestic and foreign equipment, $K_{i,t}^{dom}$ and $K_{i,t}^{for}$, and structures $S_{i,t}$. The variable structures includes real estate, premises, but also other capital goods such vehicles, computers, and rented or leased capital goods. Foreign equipment exceeds the efficiency of domestic equipment by a factor $(1+\gamma_K)$. The parameter γ_K is to be estimated and the hypothesis that $\gamma_K > 0$ will be tested.

Denote the share of foreign equipment in total equipment with $\kappa_{i,t}^{f} \equiv K_{i,t}^{for}/(K_{i,t}^{dom} + K_{i,t}^{for})$, the log of the total equipment stock with $k_{i,t}$, and the log of structures with $s_{i,t}$. Then, the production function can be written as

$$\begin{aligned} z_{i,t} &= \beta_K \ln\left(K_{i,t}^{dom} + (1+\gamma_K)K_{i,t}^{for}\right) + \beta_S\, s_{i,t} + \beta_L\, l_{i,t} + \beta_M\, m_{i,t} + \omega_{i,t} + \epsilon_{i,t} \\ &= \beta_K \ln\left(1 + \gamma_K\, \kappa_{i,t}^{f}\right) + \beta_K\, k_{i,t} + \beta_S\, s_{i,t} + \beta_M\, m_{i,t} + \beta_L l_{i,t} + \omega_{i,t} + \epsilon_{i,t} \\ &\approx \beta_K\, \gamma_K\, \kappa_{i,t}^{f} + \beta_K\, k_{i,t} + \beta_S\, s_{i,t} + \beta_M\, m_{i,t} + \beta_L\, l_{i,t} + \omega_{i,t} + \epsilon_{i,t}. \end{aligned} \tag{18}$$

$z_{i,t}$ denotes the logarithm of output, and $l_{i,t}$ denotes the log of the number of blue and white-collar workers (to be separated in the actual estimation). $m_{i,t}$ is the log of intermediate inputs. Since $\ln(1+c) \approx c$ for small values of c, one can recast the production function as on the third line, and a linear estimation technique can be employed.[6] The error term $\epsilon_{i,t}$ in (18) is a white noise shock to the production technology, its variance (but not its mean) is taken to be constant across firms in a sector, and its realization is unknown both to a firm and the researcher.

The term $\beta_K\, \gamma_K\, \kappa_{i,t}^{f}$ measures the differential effect of foreign equipment on output. It can be interpreted as the efficiency difference between foreign and domestic equipment that would otherwise be attributed erroneously to *TFP*. A similar decomposition is made for the share of foreign intermediates μ^f in total intermediate inputs.

[6] Among the firms that dispose of foreign equipment, the average foreign equipment share is about 15.1 percent in *PIA*. Among the firms that use foreign intermediates, the average share of foreign intermediates is 23.8 percent. Sample means are 3.1 and 10.3 percent, respectively. So, the approximation should be quite precise.

Table 2: Production Functions

Nív.50	Obs.	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
08	*Machinery and equipment*							
	1,742	-*.037*	.047	.077	*.154*	.222	.238	.439
		(.129)	(.02)	(.022)	(.098)	(.014)	(.018)	(.025)
11	*Electronic equipment*							
	934	.24	.061	.053	*.094*	.244	.27	.261
		(.11)	(.022)	(.025)	(.121)	(.039)	(.024)	(.039)
12	*Cars, trucks, and buses*							
	308	-*.272*	.113	*.055*	-*.032*	.156	.186	.588
		(.179)	(.043)	(.038)	(.406)	(.035)	(.043)	(.061)
13	*Other vehicles and parts*							
	1,249	*.032*	.089	*.043*	.237	.221	.178	.532
		(.075)	(.019)	(.022)	(.094)	(.017)	(.019)	(.027)

κ^f: share of foreign equipment, k: log total equipment, s: log structures, μ^f: share of foreign intermediates, m: log total intermediates, l^{wh}: log number of white-collar workers, l^{bl}: log number of blue-collar workers.

Standard errors from 250 bootstraps. Estimates in italics not significant at the .95 level.

Data: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG*.

Production functions are estimated for 27 manufacturing sectors at *nível 50*, which corresponds to the *SIC* two-digit level. Table 2 gives an overview of the estimates for four select sectors that received much attention after trade reform. Table 10 in the appendix lists all sectors and compares key estimates to fixed-effect regressions (FE), an alternative estimation method under the behavioral assumptions.

The equipment coefficients under FE are higher than the Olley-Pakes estimates in 21 out of 27 sectors, and the structures coefficients under FE are higher than the Olley-Pakes estimates in 10 cases. So, a positive correlation between the productivity index and capital stocks occurs frequently. Pavcnik (2000) and Levinsohn and Petrin (2000) report larger OLS than Olley-Pakes estimates for several sectors in Chilean industry. These findings cast doubt on the assumption that productivity evolves in a purely Markovian manner, whereas they can be explained by a q-theory model as in section 3.

To infer the efficiency differential of foreign equipment and intermediate goods, γ_K and γ_M, one can divide the coefficients in column 1 by the coefficients in column 2 and those in column 4 by column 5. The implied differentials are large in absolute value. For instance, $\gamma_K \approx 3.9$ for electronic equipment in table 2. The magnitude may be due in part to a bias from omitted variables such as managerial ability or quality and heterogeneity of output.

The discussion in section 5.1 (*Foreign Input Push*) will show that even high and potentially upward biased estimates for γ_K and γ_M do not yield a strong effect of foreign inputs on efficiency. The analysis is based on the more reliable measures $\beta_K \gamma_K$ and $\beta_M \gamma_M$. Foreign equipment is not always used more efficiently than domestic equipment. The coefficients on κ^f turn negative in 3 out of 7 sectors with significant estimates. Table 10 in the appendix shows that γ_K varies between -8.6 and 15.7 (with a mean of 3.0) when significant, and γ_M takes values between .83 and 4.9 (mean 2.3) when significant. A negative coefficient can be interpreted as evidence that the average firm in a given sector fails to adjust its surrounding production process accordingly and does not realize the potential benefits of high-quality equipment.

4.2 Total factor productivity

Given production function estimates, the logarithm of total factor productivity at the firm level is inferred as

$$\begin{aligned} \ln TFP_{i,t} &= y_{i,t} - \widehat{(1-\alpha)}\bar{\theta} \\ &\quad - \left(\hat{\beta}_K \, k_{i,t} + \hat{\beta}_S \, s_{i,t} + \hat{\beta}_M \, m_{i,t} + \hat{\beta}_{bl} \, l^{bl}_{i,t} + \hat{\beta}_{wh} \, l^{wh}_{i,t} \right), \end{aligned}$$

where $y_{i,t} = (p_{i,t} - \bar{p}_t) + z_{i,t}$ denotes the total of deflated sales and production for store. The term $(1-\alpha)\bar{\theta}$ corrects for fixed demand-side effects that affect productivity estimates through price $p_{i,t}$ in $y_{i,t}$ (Klette and Griliches 1996, see appendix A.2). The quality of output and the number of varieties that multi-product firms produce are unobserved. As Melitz (2000) shows, both quality and variety increase the firm fixed effect $\beta_{0,i}$. Firm fixed effects are not subtracted from log *TFP* here, but will be controlled for subsequently. The efficiency contributions of foreign inputs $\hat{\beta}_K \hat{\gamma}_K \kappa^f$ and $\hat{\beta}_M \hat{\gamma}_M \mu^f$ are subtracted before the analysis of channels 2 and 3.

Figure 3 illustrates how *TFP* evolves in the aggregate of all 27 manufacturing sectors between 1986 and 1998. Except for a larger drop during the recession in the late eighties and the subsequent recovery, changes are small in general. At its trough, log *TFP* drops to .982 in 1990, but recovers and reaches 1.032 by 1998. Cavalcanti Ferreira and Rossi Júnior (1999) find a weaker recovery of *TFP* until 1997 to only about the level of 1986. Gomes (2001) reports similar, though more volatile aggregate *TFP* figures for Brazilian industry. The present study is the first to employ an extensive firm-level sample. Most previous studies on Brazilian industry considered labor produc-

Data: Firm-level productivity in 27 manufacturing sectors in *Pesquisa Industrial Annual*.

Figure 3: **Log *TFP* and labor productivity in manufacturing**

tivity. As figure 3 shows, labor productivity increases more strongly than *TFP* during the 1990s because firms raise their capital stock.

5 Causes of Productivity Change

How does productivity change with trade liberalization? Do firms advance to best practice? If so, do foreign inputs contribute to the convergence? Do managers move their firms' efficiency ahead? Or does productivity improve primarily because the least competitive firms are shaken out? Questions like these can be related to three channels of trade effects on productivity: (1) A *Foreign Input Push* (section 5.1), (2) a *Competitive Push* (section 5.2), and (3) *Competitive Elimination* (section 5.3). An adequate way to evaluate the effects of trade on productivity seems to be a counterfactual approach. How would productivity have evolved in the absence of any of the three channels?

The present study treats foreign inputs as separate factors in the production function. Their effect on productivity is traced in subsection 5.1 (*Foreign Input Push*). Subsection 5.2 investigates whether reducing trade barriers has a positive effect on efficiency because of fiercer competition in the product market (*Competitive Push*). Subsection 5.3 analyzes to what degree inefficient firms are shaken out (*Competitive Elimination*) and sheds light on the question whether efficient firms become exporters. Subsection 5.4 discusses

Table 3: Efficiency of Foreign Inputs

	11 *Electronics*		22 *Textiles*		24 *Leather*	
	log *TFP*	Input	log *TFP*	Input	log *TFP*	Input
	(1)	(2)	(3)	(4)	(5)	(6)
		$\beta_K \gamma_K \kappa^f$		$\beta_K \gamma_K \kappa^f$		$\beta_K \gamma_K \kappa^f$
1986	8.882	.004	7.564	.003	9.292	.004
1990	8.630	.024	7.522	.016	8.949	.018
1992	9.137	.027	7.611	.025	9.194	.031
1995	9.426	.085	7.498	.050	9.014	.065
		$\beta_M \gamma_M \mu^f$		$\beta_M \gamma_M \mu^f$		$\beta_M \gamma_M \mu^f$
1996	9.503	.044	7.460	.071	8.945	.204
1998	9.784	.047	7.500	.068	9.043	.199

Effect of foreign inputs in sectors with highest $\beta_K \gamma_K$ (24,11,22) estimates and highest $\beta_M \gamma_M$ (24) estimate.

Data: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG*.

briefly the effects of potential further channels. Subsection 5.5 compares the three primary channels, posing the counterfactual that no trade liberalization was undertaken. The *Competitive Push* is singled out as the most important channel.

5.1 Channel 1: Foreign Input Push

The counterfactual question for this channel is: How would firm productivity have evolved if firms had not been able to install foreign equipment, or if they had not been able to use foreign intermediates? Supposedly, foreign inputs exhibit higher quality and efficiency.

The estimated production functions have accounted for the potential efficiency differential. Under a fairly precise logarithmic approximation, the efficiency differential of foreign equipment and foreign intermediates *vis à vis* their domestic Brazilian counterparts is measured by $\beta_K \gamma_K \kappa^f$ and $\beta_M \gamma_M \mu^f$, where β_K and β_M are the elasticities of output with respect to total equipment and total intermediate goods. $(1 + \gamma_K)$ and $(1 + \gamma_M)$ are the factors of excess efficiency of foreign inputs, and κ^f and μ^f are the shares of foreign inputs in the respective totals. κ^f is available for the years 1986 through 1995, while μ^f is observed from 1996 until 1998. The coefficients are identified in an accordingly stacked system.

Table 3 summarizes mean log *TFP* and the effect of foreign inputs for the three sectors with the highest significant $\beta_K \gamma_K$ estimates (electronic equipment, textiles, and leather products and footwear). The leather and footwear sector exhibits the highest $\beta_M \gamma_M$ estimate. The figures show that foreign input efficiency contributes only minimally to productivity. It is orders of magnitude smaller than average productivity even in the sectors with the strongest differentials. Foreign input efficiency neither serves as a break in times of falling productivity nor as a push in times of rising log *TFP*. Take the electronics sector as an example. Between 1986 and 1990, firms invested strongly in foreign equipment and pushed $\beta_K \gamma_K \kappa^f$ from .004 to .024. Without that push, log *TFP* would have fallen to 8.61 but foreign equipment stopped the fall at 8.63. This is less than a one percent difference for one of the strongest positive effects in the sample.

Some sectors exhibit significantly negative estimates of γ_K. They can be viewed as evidence that the average firm in the sector fails to effectively implement foreign equipment in the short term. Technology adaption takes time because of factor complementarities, learning effects and necessary production rearrangements. Similar arguments have been advanced to explain the productivity slowdown in industrialized countries in periods of technology adoption. Foreign machines of high quality sell at a price premium over domestic counterparts, and firms need to put foreign machines to more efficient uses than domestic ones in order to avoid a productivity loss. To test for this supposition, one can split κ^f into recent-year investment and the lagged κ^f level and re-estimate production. Two of the three sectors with significantly negative κ^f estimates confirm that the recent-year term exceeds the longer-back foreign equipment term in absolute value and can explain most of the negative effect. Delayed adjustments to new machinery may thus be behind both occasional negative effects of foreign machinery on productivity and the small positive effects.

It has been argued that firms may benefit from embodied technology when acquiring foreign goods. That is, foreign drilling machines or turning lathes are supposed to do more than just process a workpiece. They are thought to be essentially different from their domestic counterparts under this hypothesis. If it is true, foreign inputs should enter the production function separately and interact with other factors in a different way than domestic inputs. However, foreign inputs are often zero. In fact, 79.7 percent of all firms in 1986-1995 dispose of no foreign machines, and 56.8 percent of all firms in 1996-1998 use no foreign intermediate inputs. So, standard production functions cannot be estimated. Instead, a Box-Cox transformation can be used for both types of foreign inputs. Production functions were re-estimated under an accordingly adjusted Olley-Pakes procedure.

With the Box-Cox transformation, *TFP* can be reassessed under the extreme counterfactual hypothesis that all inputs had to be Brazilian rather than partly foreign. In the case of foreign equipment, for instance, the difference $[\hat{\beta}_{K^f}((K^f_{i,t})^{\hat{\lambda}_K} - 1)/\hat{\lambda}_K + \hat{\beta}_{K^d} \ln K^d_{i,t}] - [\hat{\beta}_{K^d} \ln(K^d_{i,t} + K^f_{i,t})]$ can be taken as a measure for the contribution of foreign equipment efficiency. It can be compared to the value in columns 2, 4 and 6 of table 3 and should be understood as the difference that setting κ^f to zero would make. Resulting log *TFP* figures are lower and behave more erratically under a Box-Cox transformation, while estimates of input efficiency differentials are higher. However, the relative magnitude of foreign input efficiency is still not high enough to account for much *TFP* change over time. This corroborates previous findings and there is little evidence that effects of embodied technology are sources of immediate productivity change.

Keller (2000) finds for a sample of industries in 8 OECD countries that machinery imports matter but that their impact may be limited conditional on the effect of domestic technology. To my knowledge, only Feenstra, Markusen and Zeile (1992) and Fernandes (2001) estimate the effect of inputs on production at the micro-level. Feenstra et al. (1992) distinguish the effect of more inputs of the same type from the effect of a greater range of them in a sample of Korean *chaebol*—albeit not with respect to foreign trade. They detect a positive correlation between their input measure and the change in *TFP*. Using a large sample of Colombian plants, Fernandes (2001) finds that productivity gains are stronger in sectors that use foreign intermediates to a higher degree. However, neither one of the studies reports how much *TFP* change their estimates predict and their findings cannot be compared to those of table 3.

Funk and Strauss (2000) show that productivity change triggers (Granger-causes) capital investment, and not the other way around. Their analysis employs a time-series of investment in 450 US manufacturing sectors. Results of the present paper paint a similar picture. The causal link from the quality of installed equipment to productivity does not appear to be strong. To make appropriate use of new inputs, firms need to embed foreign equipment into the production process and may have to adopt new processes. If they can take such measures only over time, foreign inputs will not create value beyond cost in the short run.

5.2 Channel 2: Competitive Push

Increased foreign competition can foster product and process innovation (Boone 2000). Foreign competition may also end the "quiet life" of managers and allow firms to enforce higher efficiency (Hermalin 1992, Schmidt 1997). The counterfactual question is: What would firm-level productivity have looked like had there not been an increase in competitive pressure due to foreign imports, or the threat of more foreign imports? To find an answer, the change in firm-level productivity can be regressed on two variables related to foreign competition: the nominal tariff in the firms' respective output markets and the penetration of their markets with foreign imports. Market penetration proxies the level of non-tariff barriers in Brazil, while nominal tariff levels capture the effect of tariff barriers directly. Foreign penetration is measured as the share of imports per absorption in a given market.

However, there are econometric concerns. Market penetration and low tariff barriers may not only induce firms to strive for higher productivity. The causation can also go in the opposite direction. Consider tariffs. When motivating trade reform, the Brazilian government declared that it aimed to instill efficiency change through foreign competitive pressure. If the government obeyed the principle, it applied lower tariffs to low-growth sectors. This introduces a positive correlation between *TFP* change and tariff levels. Second, take market penetration. When barriers to imports fall, the least efficient sectors are likely to attract the strongest influx of competing imports. In other words, low productivity performance may cause high market penetration, which brings about a negative correlation between *TFP* change and market penetration.

Instrumental variables can remedy both sources of simultaneity. Foreign market penetration not only depends on tariffs and competitors' productivity but also responds to a country's terms of trade. The real exchange rate fluctuated considerably over the period 1986 to 1998 and was thus an important factor for the relative price of imports. Certain components of the real exchange rate are exogenous variables in the sense that they affect foreign firms' entry decision (and the government's tariff choice) but are unanticipated by Brazilian firms.

The real exchange rate is decomposed here into the nominal exchange rate relative to the US dollar and into two foreign price components, an average European and an average Asian price index (using Brazilian imports in 1995 as weights). Nominal exchange rates are difficult to predict, and Brazilian firms were most likely not able to anticipate the US dollar exchange rate. This makes the nominal exchange rate a valid instrument. Brazilian domestic inflation was more predictable and had likely an impact on managers' efficiency choice. It is therefore not considered a valid instrumental variable, notwithstanding its importance for the real exchange rate. One might suspect that Brazilian manufacturers were able to anticipate well the price level of major trading partners such as the US (number one in 1995) or Argentina (number two).

Firms can expect less foreign competition whenever a high price level of a major trading partner raises the bilateral real exchange rate, and vice versa. The suspicion is testable. It turns out that the US price index is a valid instrument, but not Argentina's price level.

On the other hand, the average European price index and the average Asian price index are taken *a priori* to be valid instruments for two reasons. First, the exports of foreign firms from these regions appear to be less sensitive to price movements. Most countries in these regions are small trading partners of Brazil, and the quantity of specialized products they sell to Brazil is likely to remain about the same even if prices fluctuate. Second, Brazilian firms are less likely to anticipate correctly the effect of prices in regions that are not major trading partners. The later result that even the US price index is a valid instrument justifies this reasoning *ex post*. There are two endogenous variables, tariffs and market penetration, and three instruments, the nominal exchange rate, the European and the Asian price index. When dropping the European price index, a Hausman test for overidentification shows no evidence that the European price index is not a valid instrument.

Table 4 summarizes the regression results under both a two-stage least squares approach (columns 1 and 5) and a simple regression (column 4). The dependent variable is the first difference in log *TFP* (except for the first-stage IV regressions in columns 2 and 3). Unobserved firm-specific factors such as managerial ability are likely to affect a firm's *TFP* level. So, a fixed-effects model is employed throughout and standard errors are corrected accordingly.

Both tariffs and market penetration are measured on a scale from zero to one. Lower tariffs induce firms to raise efficiency, as does higher market penetration (column 1). The effects are considerable. A reduction of nominal tariffs by 10 percentage points (.1) induces firms to increase log *TFP* by .225. An increase of foreign market penetration by 1 percentage point (.01) raises *TFP* by another .28. Log *TFP* is about 8.1 on average across all sectors and years. So, a reduction of nominal tariffs by 10 percentage points pushes log *TFP* by 2.8 percent ($[.225/8.1] * 100$). A careful counterfactual simulation will follow in section 5.5.

How important were the treatments in productivity estimation for this result? Column 5 shows that estimates would be slightly less favorable but not strongly different when inferring productivity from simple OLS regressions on the unbalanced panel. Piecewise estimations reveal that the point estimates change mostly because of the correction following from section 3.3 and little because of Olley and Pakes. To isolate the effect of foreign competition from possibly confounding effects, firm-level variables such as foreign inputs and indicators for firm size are included in the regression. Firms that start to use

Table 4: Foreign Competition and Productivity Change

	2SLS-FE			FE	2SLS-FE
	$\Delta \ln TFP$	Tariff	M.Pen.	$\Delta \ln TFP$	OLS $\Delta \ln TFP$
	(1)	(2)	(3)	(4)	(5)
Nominal tariff	-2.249			-.115	-1.467
	(.201)			(.027)	(.186)
Market penetration	27.989			.691	23.056
	(2.163)			(.151)	(2.006)
Age	-.294	-.022	.008	-.02	-.22
	(.023)	(.0007)	(.0001)	(.002)	(.021)
κ^f	-.424	-.058	.008	-.092	-.191
	(.053)	(.006)	(.001)	(.029)	(.049)
μ^f	-.504	.05	.027	.173	-.477
	(.074)	(.007)	(.001)	(.033)	(.069)
ι(medium L^{tot})[a]	.116	*.0003*	*.0007*	.123	.113
	(.043)	(.006)	(.001)	(.029)	(.04)
ι(big L^{tot})[a]	.176	*-.007*	*-.0006*	.152	.175
	(.045)	(.006)	(.001)	(.03)	(.042)
ι(medium cap.)[b]	-.038	.018	.001	-.038	*-.03*
	(.017)	(.002)	(.0004)	(.011)	(.016)
ι(big cap.)[b]	*-.017*	.024	*.0002*	-.047	*-.007*
	(.024)	(.003)	(.0006)	(.015)	(.022)
Sector demand[c]	-.548	-.02	.012	-.225	-.455
	(.034)	(.003)	(.0005)	(.013)	(.031)
Cum. FDI[d]	.185	.027	-.004	-.014	.14
	(.019)	(.001)	(.0003)	(.007)	(.018)
FDI flow[d]	-.14	-.034	.0008	-.029	-.098
	(.016)	(.002)	(.0003)	(.008)	(.015)
Nom. exch. rate (US$)		.04	.035		
		(.01)	(.002)		
Prices EU		-.587	-.015		
		(.013)	(.002)		
Prices Asia		*.041*	.171		
		(.062)	(.012)		
Obs.	33,493	33,493	33,493	33,493	33,493
R^2	.0002	.846	.551	.0005	.0001

[a]Medium: $(30 \leq L^{tot}_{i,t} < 300)$, big: $(L^{tot}_{i,t} \geq 300)$.
[b]Medium: $K_{i,t} + S_{i,t}$ in middle tercile of all firms in a year, big: in upper tercile.
[c]Sector-wide sales in *PIA*, augmented by foreign market penetration.
[d]Billion US$ per sector. Cumulated FDI is end-of-year stock of invested foreign capital.

more foreign inputs suffer a slowdown in productivity in the subsequent year. They face implementation costs and may need to train workers and carry out adjustments to the production process (subsection 5.1).

The stock of sector-wide invested foreign capital correlates positively with productivity increases at the firm-level. FDI directed to a sector as a whole forces each individual firm to improve efficiency because foreign-owned domestic competitors are likely to become more productive with foreign capital. So, FDI may work like a substitute for trade liberalization. However, it takes US$ 1 Billion to raise log *TFP* by .185—an increase that a tariff reduction by 8 percentage points (.08) can also achieve. The invested foreign capital stock in Brazilian manufacturing totalled US$ 30 Billion in 1998. In this light, an FDI inflow of US$ 1 Billion in a single sector would be substantial. In addition, FDI flows seem to have an offsetting negative effect on productivity. This may be because FDI to foreign-owned domestic competitors also reduces the market penetration of foreign firms that export to Brazil (column 3).

In the first stage of the instrumental variable estimation (columns 2 and 3), fixed-effects regressions are run using all observations. This makes the regressions in columns 2 and 3 weighted ones. The tariff cannot be used as a predictor of market penetration (column 3). If included, order conditions would fail and the system would not be identified. Separate regressions show that market penetration falls 1.73 percentage points on average across all sectors when tariffs are raised 10 percentage points.

The consistency of estimates in table 4 depends on the validity of the proposed instruments. A comparison of a simple regression (column 4) to the current results (column 1) confirms that the suspected negative bias in tariffs and the positive bias in the market penetration do exist. The same biases can be detected in a level regression, as table 8 in the appendix shows (column 8 vs. 5). In this case, the bias is strong enough to reverse the sign on tariffs. Table 8 in the appendix also documents the procedure to test for the validity of instruments. Depart from a regression that includes only the clean instruments (the nominal US dollar exchange rate, the EU price level and the Asian price level; columns 1 and 5). Additional instruments can be inserted and tested using a Hausman test for overidentification. For the US price level, the test statistic is negative in the *TFP* change regression (column 3) and the test cannot be conducted. However, the US price level turns out to be a valid instrument in the *TFP* level regression (column 6). This can be interpreted as *ex post* evidence that the European and Asian price levels are also valid. When dropping the European price index, an overidentification test shows no evidence that the European price index is invalid (not reported). The price indices of Brazil and Argentina, however, are not valid instruments (columns 2,

Table 5: TRANSITIONS BETWEEN STATES OF OPERATION BEFORE AND AFTER 1991

Firm $\sigma_{i,t}$ \ $\sigma_{i,t+1}$	*active* *exporter* (1)	*non-exporter* (2)	*suspended* (3)	*extinct* (4)	*Total*
	$Pr(\sigma_{i,t+1}\|\sigma_{i,t})$				
active					
exporter	86.2 ▷ 88.2	12.5 ▷ 8.5	.8 ▷ .9	.6 ▷ 2.4	*100.0*
non-exp.	3.7 ▷ 7.0	91.2 ▷ 85.9	1.6 ▷ 2.0	2.8 ▷ 5.1	*100.0*
suspended	1.9 ▷ 7.6	31.6 ▷ 32.5	57.3 ▷ 40.4	9.2 ▷ 19.5	*100.0*
extinct	.0 ▷ .0	.0 ▷ .0	.0 ▷ .0	100.0 ▷ 100.0	*100.0*

Source: Own calculations from observed transitions. (Observations of mergers, acquisitions and split-ups treated as missing. Transitions 1990-92 treated as if 1990-91.)

Data: *Pesquisa Industrial Anual.* Firm-level exports from *SECEX*, 1989-1998.

4 and 7).

Only regressions of the *change* in log *TFP* separate the present channel 2 from effects of exit from the sample (channel 3). A difference-in-difference analysis confirms that exiting firms have lower productivity on average. Fiercer foreign competition is likely to bring about more exits. So, level regression would confuse the two channels and inappropriately boost the estimates.

5.3 Channel 3: Competitive Elimination

What would industry turnover have looked like in the absence of trade liberalization? There are many aspects to industry turnover and it is hard to link them directly to the trade regime. A new method to evaluate turnover causally is proposed here: the estimation of Markov probabilities for an active firm's transition between possible states of operation.

The transition probabilities in table 5 reflect the likely pattern of a Brazilian manufacturer's choice between 1989 and 1991 (to the left of the arrow), and between 1991 and 1998 (to the right of the arrow). Data on the exporting status of firms are not available before 1989. The competitive environment changes with trade liberalization and the transition matrices reflect this. The survival probability of a non-exporter, for instance, drops from 95.6 percent to 92.9 percent (100 percent less estimates in columns 3 and 4).

To evaluate causally how the trade regime influences turnover, transition probabilities can be estimated as functions of the market environment and firm characteristics, among them productivity. Unnested unconditional multi-

Table 6: Multinomial Logit Estimates of Transition Probabilities

$\sigma_{i,t}$	Exporter			Non-Exporter		
$\sigma_{i,t+1}$	Non-Exp.	Susp.	Exit	Exp.	Susp.	Exit
	(1)	(2)	(3)	(4)	(5)	(6)
Tariff[a]	2.026	*-.507*	-1.915	*-.187*	-1.028	-1.049
	(.288)	(.962)	(.855)	(.139)	(.46)	(.373)
Real exch. rate (US$)[b]	-.728	*.262*	-2.84	-1.454	*-.455*	-3.369
	(.247)	(.722)	(.59)	(.115)	(.375)	(.322)
$\ln TFP$	-.078	-.214	*-.003*	.072	-.28	-.232
	(.035)	(.083)	(.066)	(.019)	(.057)	(.04)
Age	*0*	*-.004*	*.003*	*.0002*	*-.003*	*.005*
	(.002)	(.007)	(.004)	(.001)	(.005)	(.003)
κ^f	-.752	*-1.014*	-2.187	1.239	*-.122*	*-.658*
	(.296)	(1.137)	(.822)	(.213)	(.84)	(.58)
μ^f	-1.022	*-.117*	*.096*	*.102*	*-3.494*	*-.739*
	(.389)	(.773)	(.517)	(.344)	(2.628)	(.762)
ι(med. L^{tot})[c]	-1.01	*-1.045*	-1.649	.457	*-.29*	-.803
	(.345)	(.746)	(.523)	(.171)	(.264)	(.16)
ι(big L^{tot})[c]	-1.612	-2.169	-1.887	1.094	-.891	-1.196
	(.347)	(.761)	(.532)	(.173)	(.303)	(.192)
ι(med. cap.)[d]	-.663	*.459*	-1.1	.558	*-.034*	*-.148*
	(.19)	(.708)	(.335)	(.109)	(.193)	(.129)
ι(big cap.)[d]	-1.079	*.565*	-1.436	1.239	*.009*	*-.147*
	(.201)	(.726)	(.357)	(.115)	(.249)	(.171)
Sector demand[e]	*.041*	*-.068*	.121	-.112	*-.025*	.14
	(.023)	(.057)	(.039)	(.01)	(.024)	(.018)
Cum. FDI[f]	.097	-.215	-.215	*.027*	*-.032*	*-.032*
	(.037)	(.067)	(.067)	(.025)	(.043)	(.043)
FDI flow[f]	*.03*	.642	.342	-.426	*.162*	*-.123*
	(.092)	(.227)	(.168)	(.065)	(.176)	(.116)
Obs.		13,123			27,424	
Pseudo R^2		0.694			0.664	
$\hat{\chi}^2$		8412.43			22780.80	
$Pr(\chi^2_{39} > \hat{\chi}^2)$		.0000			.0000	

[a]Next year's tariff.
[b]Annual. Based on *IPA-OG* and US producer price index.
[c]Medium: ($30 \leq L^{tot}_{i,t} < 300$), big: ($L^{tot}_{i,t} \geq 300$).
[d]Medium: $K_{i,t} + S_{i,t}$ in middle tercile of all firms in a year, big: in upper tercile.
[e]Sector-wide sales in *PIA*, augmented by foreign market penetration.
[f]Billion US$ per sector. Cumulated FDI is end-of-year stock of invested foreign capital.

nomial logit (MNL) appears to be an appropriate estimation technique because the states of operation have no specific characteristics and independence from irrelevant alternatives holds. A firm's probabilistic choice is taken to satisfy

$$Pr(\sigma_{i,t+1}|\sigma_{i,t}; \mathbf{x}, \beta_{\mathbb{A}}) = \frac{e^{\beta_\sigma' \mathbf{x}}}{\sum_{\varsigma \in \mathbb{A}} e^{\beta_\varsigma' \mathbf{x}}},$$

where the choice set $\mathbb{A}$ includes four alternatives for $\sigma_{i,t+1}$: to be an exporter, to be a domestically active firm only, to suspend production temporarily, or to exit. The model is estimated independently for the three possible current states $\sigma_{i,t}$: exporter, non-exporter, or temporarily suspended firm.

Table 6 reports results for active firms ($\sigma_{i,t}$: exporter or non-exporter), and table 9 in the appendix presents the remaining category ($\sigma_{i,t}$: suspended firm). Since probabilities have to sum to unity, the parameter vector β_σ is only identified for three choices relative to a fourth choice of reference. Here, the current states of operation ($\sigma_{i,t+1} = \sigma_{i,t}$) are chosen as the respective points of reference. The reference for a non-exporter, for instance, is that the firm remains a non-exporter.

In order to look at the effect of trade on turnover beyond previous channels, a firm's *TFP* needs to be controlled for. Productivity itself has the expected effect on turnover. The lower it is, the more likely a firm exits or suspends production (columns 2, 3, 5 and 6 in table 6). Both theoretical and empirical evidence suggests that more efficient firms self-select into becoming exporters (Hopenhayn 1992, Melitz 1999, Clerides, Lach and Tybout 1998, Bernard and Jensen 1999). The present analysis supports this hypothesis. When productivity is high, non-exporters start exporting more often (column 4) and exporters abandon exporting less frequently (column 1). Incentives for exporting from Brazil hardly changed over the period. So, one may interpret the positive effect of higher productivity as close to causal: Higher productivity encourages firms to be exporters.

Findings for both tariffs and the real exchange rate show that reduced barriers to imports cause more exits. Firms choose next period's state of operation with regard to market prospects (exit in the data means exit in the following year). So, tariffs here are next year's tariffs. The lower the tariff, the more likely it is that a firm goes out of business (columns 3 and 6). The estimate of -1.049 in column 6 means that a reduction of tariffs by 10 percentage points (.1) raises the exit probability by 1.11 ($= e^{.1049}$) percent relative to a non-exporter's likelihood of remaining a non-exporter. Similarly, lower tariffs make it more likely that a firm suspends production (column 5), possibly to wait for a return to higher tariff protection.

A low real exchange rate has a similarly strong effect on exit (columns 3 and 6) but no significant effect on the suspension decision (columns 2 and 5).

Since firms are likely not able to predict the real exchange rate, current levels are used in the regression. The lower the real exchange rate, the harder it is to compete abroad, and more Brazilian exporters stop exporting (column 1). Interestingly, a low real exchange rate induces non-exporting firms to start exporting (column 4). The result could imply that exporters benefit from observing the influx of foreign goods to identify internationally competitive product characteristics.

In the previous MNL regressions, both the government's choice of tariff levels and the real exchange rate are taken as exogenous to transition choices. The Brazilian government aimed to induce a competitive push. The inclusion of log *TFP* in the regression controls for this. Only if the Brazilian government also wanted to induce more exits with trade reform, a simultaneity problem would arise. If existent, the simultaneity is alleviated because future rather than current tariffs are used in the regression. To check the estimates nevertheless, the same instrumental variables as in section 5.2 can be used to predict tariffs. The non-linear structure of the logit regression does not allow to remove the simultaneity if existent. However, a regression with predicted variables can serve as a robustness check. If coefficient estimates do not change significantly, simultaneity is likely not a problem. Table 9 in the appendix reports estimates when predicted tariffs are used. The estimates hardly change compared to the previous regression. This is especially the case for the exit decision, which is most important here.

A difference-in-difference analysis shows that exiting firms have 8.2 percent lower productivity than survivors on average. So, exits may help raise average productivity. However, the shutdown probability ranges between two and five percent only. The bearing of exits on aggregate productivity remains to be evaluated. A counterfactual simulation follows in section 5.5.

5.4 Possible additional channels

Entry is another aspect of turnover. Fiercer foreign competition can deter entry—a competitive elimination of business projects before they are realized. However, entry is excluded from the present analysis for two reasons. For one, entry was not always recorded systematically in *PIA*. Second, the counterfactual is hard to answer in general: How many more business proposals would have been pulled out from the drawers had trade not been reformed? It is likely that only the most productive projects will be realized after trade reform. Then the net effect on efficiency is ambiguous. Less but more productive entrants can move aggregate productivity either way.

At least from a theoretical perspective, there are two additional channels through which trade may affect productivity. In the aggregate of sectors, a fourth channel can be *Induced Size Change*. Less competitive firms lose market share, while more competitive firms grow in relative size. Models with Cournot or monopolistic competition predict this. The effect raises sector-wide productivity because averages are size-weighted. It is difficult, however, to causally relate size change to trade liberalization. In fact, it is likely to be an indirect effect in several ways. First, trade encourages firms to raise individual productivity through the foreign input push and the competitive push. Firms that are faster at adopting higher productivity grow in relative size. Therefore, size change gives the foreign input push (1) and the competitive push (2) an extra boost. Similarly, after suspension or exit has occurred due to competitive elimination (3), the surviving firms grow in size, and the fittest among them grow relatively faster. In this way, size change also gives channel 3 an extra boost. Finally, increased foreign competition squeezes the market share of domestic Brazilian firms. Again, the less productive ones are squeezed more strongly which promotes channels 1 and 2. This suggests that, on all of these accounts, size change should not necessarily be considered its own channel but rather an augment to previous channels.

Size change does seem to be a channel of its own with regard to economies of scale. If economies of scale exist, firms that face import competition may suffer from lower scales of production after being squeezed, while exit of their domestic competitors helps them realize previously unexploited economies of scale. So, there are conflicting forces at work and it is not clear which would prevail. Studies that investigate scale effects from trade are, in general, not able to confirm an effect empirically (Tybout and Westbrook 1995, Roberts and Tybout, eds 1996). Unfortunately, productivity and economies of scale are not identified simultaneously (see section A.2). So, this channel cannot be evaluated in the present context.

Regarding trade effects in the aggregate of industry, a fifth channel of trade is *Induced Specialization*. Due to Ricardian or Heckscher-Ohlin type forces of trade, a country's industry may specialize in sectors where the innovative potential is largely exhausted. This can lower average productivity of industry as a whole. Theoretical contributions in favor of this hypothesis include Young (1991) and Xie (1999). (I express theoretical doubt in Muendler 2001.) This fifth channel seems to be difficult to evaluate in general and especially so in the current context with incomplete sector data. Using cross-country data, Weinhold and Rauch (1999) find empirical evidence against the hypothesis.

Table 7: Counterfactual Simulations

	Counterfactual	log *TFP* 1986	1990	1992	1995	1998
De facto		1.0	.9821	.9983	1.0051	1.0317
Ch. 1 off	κ^f and μ^f lower[a]	1.0	.9776	.9979	1.0050	1.0312
Ch. 2 off	Tariffs unchanged[b]	1.0	.9679	.9604	.9976	1.0356
Ch. 3 off	Tariffs unchanged[c]	1.0	.9826	.9979	1.0034	1.0278

[a]Based on separate regressions, a one percentage point lower tariff is assumed to result in a 28.9 percentage point higher demand for foreign inputs relative to domestic inputs.

[b]Tariffs assumed to affect *TFP* change according to the estimate in table 4, column 1.

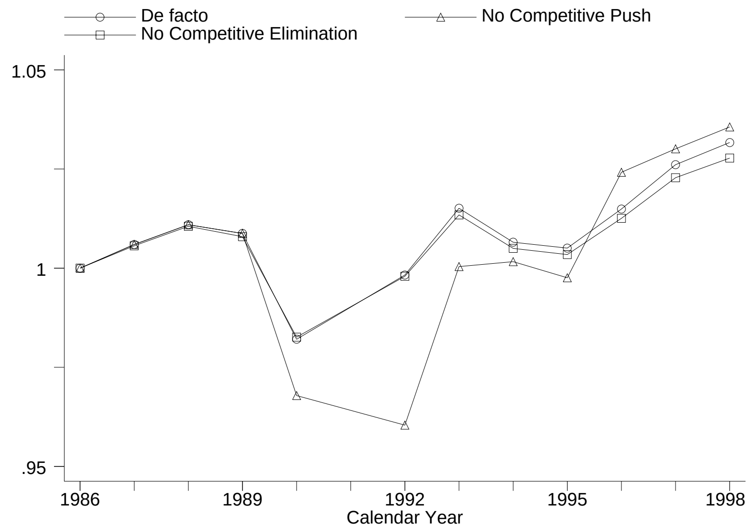
[c]Tariffs assumed to affect exit according to estimates in table 6, columns 3 and 6. In the counterfactual sample, an according share of exiting firms is randomly kept (with productivity at the level of their *de facto* exit).

5.5 Counterfactual simulations

The first row in table 7 shows how productivity evolves in the sample. To assess the relative importance of the three channels, one can switch them off individually and calculate log *TFP* in their absence. Trade reform took effect in 1990, whereas previous tariff reductions most likely did not matter for productivity change because non-tariff barriers remained binding. In the following simulations, only the effect of tariffs is considered.

For the foreign input push (1), one needs to infer what share of foreign inputs after trade reform is due to lower tariffs. Firms did buy foreign equipment before trade liberalization. Lower tariffs will make the equipment cheaper, however, and boost demand. Simple regressions on the estimation sample show that market penetration rises 1.73 percentage points on average across all sectors when tariffs are reduced by 10 percentage points. In the machinery sector, however, market penetration almost triples (increases 289 percentage points) when tariffs are lowered by 10 percentage points. The estimate is likely upward biased because tariffs also catch the effect of the strongly changing non-tariff barriers. The estimate is still used. Even then, the simulated impact of foreign factors on productivity will be small.

The counterfactual share of foreign equipment (between 1990 and 1995) is calculated as $\hat{\kappa}^f_{i,t} = \kappa^f_{i,t} + .289 \cdot (\tau_t - \tau_{1988})$, where τ_t denotes nominal tariffs on investment goods in year t (measured on a scale from 0 to 1). This is a further favorable assumption for channel 1 since installed capital stocks would not respond as fast as equipment acquisitions. A similar calculation is applied to foreign intermediates (1996 through 1998). The results in table 7 corroborate



Data: Simulated and *de facto* productivity in *Pesquisa Industrial Annual*.

Figure 4: **Log *TFP* under three scenarios**

that this channel is not important even under favorable assumptions. Except for a slight effect in 1990, productivity would have evolved in about the same way had less foreign inputs been used.

To assess the competitive push (2), each individual firm's observed TFP is reduced by $\hat{\Delta} \ln TFP_{i,t} = -2.249(\tau_t - \tau_{t-1})$ year over year between 1990 and 1998 (but not cumulatively). The coefficient estimate -2.249 for tariff levels is taken from table 4, column 1. Now, τ_t denotes nominal tariffs for products in that firm's sector. In 1990 only, TFP would have remained 1.4 percent lower had there not been an increase in foreign competition. Since tariffs were raised again after 1995, however, about .4 percent less TFP is observed in 1998 than would have been feasible had tariffs remained at their low.

For competitive elimination (3), exit among exporters and non-exporters is considered. Given the standardization chosen in the MNL model of section 5.3, the expected share of exits in year t can be expressed as $\mathbb{E}\left[n_{exit,t+1}/N_{active,t}|\tau_t\right] = \exp[\hat{\beta}_\tau(\tau_t - \tau_{1988})] \cdot P(\tau_{1988})$ where $\hat{\beta}_\tau$ is the coefficient estimate for tariffs (table 6, columns 3 and 6). Expected exit would be $\hat{\mathbb{E}}\left[\hat{n}_{exit,t+1}/N_{active,t}|\tau_{1988}\right] \equiv P(\tau_{1988})$ at 1988 tariffs. So, one can consider $1-\exp[-\hat{\beta}_\tau(\tau_t - \tau_{1990})]$ an estimate for the relative share of exits $(n_{exit,t+1} - \hat{n}_{exit,t+1})/n_{exit,t+1}$ that is attributable to tariff reductions. To assess the counterfactual of frozen tariffs at the 1988 level, a share $1 - \exp[-\hat{\beta}_\tau(\tau_t - \tau_{1988})]$ was randomly drawn from the observed exiting firms and put back into the sample, duplicating their year t observation for $t+1$ and beyond.

In the reported simulation, 432 observations of otherwise exiting firms are randomly added to the total sample of 65,621 observations. Surprisingly, simulated *TFP* in 1990 turns out to be slightly higher than *de facto* productivity on average. This may mean that trade reform induced high productivity firms to exit initially. Anecdotal evidence for the equipment sector, for instance, confirms this. Relatively advanced firms chose to exit in the early nineties since their products could often not compete with foreign goods, while domestic firms with low-quality and low-productivity products were favored. By 1998, the effect turns round. Had exiting firms stayed, productivity could have been up to .4 percent lower—close to a tenth of the *de facto* productivity change between 1990 and 1998.

Figure 4 depicts simulation results for the competitive push and competitive elimination. The competitive push (2) has a considerable and immediate impact on productivity. Competitive elimination (3) affects too few firms to have an immediate effect but unfolds a sizeable impact over time. Qualitative evidence confirms this pattern. Amann (1999) investigates the Brazilian non-serial capital goods sector and argues that managers did not find foreign inputs with embodied technology a major source for innovation (p. 342). In other words, they did not expect much of a foreign input push (1). Amann (1999, p. 351) also states that managers restructured processes after 1989 but engaged in little efforts of their own to innovate products. This supports the importance of the competitive push (2). However some managers chose to obtain foreign designs to improve their products (Amann 1999, p. 342). That is a possibly important channel of knowledge flows unrelated to the flow of traded goods.

6 Conclusion

The Brazilian trade liberalization in the early nineties provides a natural setting to trace effects of international trade on productivity change. Brazil reduced tariffs and non-tariff barriers for imports but kept the treatment of exports largely unchanged. This gives the study a welcome focus. A sample of medium-sized to large Brazilian manufacturers is followed over the years from 1986 until 1998. Three channels through which trade reform affects productivity can be distinguished in the present data: (1) Easier access to foreign equipment and intermediates may allow for a *Foreign Input Push* at the firm level. (2) On the product market side, foreign imports constitute a *Competitive Push* on individual firms. Theory predicts that managers choose to innovate processes and remove slack under fiercer competition. (3) Competition in the product market may also induce more exits and cause a *Competitive Elimination* of inefficient firms.

The *Foreign Input Push* (channel 1) is found to be relatively unimportant. The efficiency difference between foreign and domestic inputs has only a minor impact on productivity. Foreign technology adoption takes time due to learning effects, factor complementarities and necessary production rearrangements. Estimates nevertheless support the view that foreign inputs create additional value, mostly in the medium term.

Trade liberalization induces high competitive pressure. First, it unleashes a *Competitive Push* on firms to raise their efficiency (channel 2). This proves to be a salient source of productivity change. Controlling for the endogeneity of foreign market penetration and tariffs, small changes in the tariff act are shown to induce impressive efficiency improvements among surviving firms. Second, when trade barriers fall, the *Competitive Elimination* of the least efficient firms (channel 3) strikes more fiercely. Estimates of turnover probabilities with multinomial logit confirm that both the likelihood of survival drops markedly when trade barriers fall and that low-efficiency firms go out of business more frequently. Counterfactual simulations indicate, however, that *Competitive Elimination* only unfolds an impact on aggregate productivity over time. It stems from just a small share of firms. The simulations underscore the force of the *Competitive Push* on the other hand. This channel is a dominant source of productivity change among Brazilian manufacturers between 1990 and 1998.

Appendix

A Productivity Estimation

Production function (18) is augmented to account for all factors and estimated for 27 sectors under the restriction that all factor elasticities are constant between 1986 and 1998. This assumption yields time-invariant weights for the productivity indices. The variable κ^f is available for 1986 through 1995 and μ^f from 1996 to 1998. The observations are stacked accordingly so that $\beta_K \gamma_K$ and $\beta_M \gamma_M$ are identified in the respective subperiods.

To check for sensitivity, the data have been deflated with three different price indices. The sector-specific wholesale price index *IPA-OG* underlies all results in this paper. Another sector-specific wholesale price index, *IPA-DI* (excluding imports), and the economy-wide price index *IGP-DI* (a combined wholesale and consumer price index) do not yield substantially different results. There is no producer price index for Brazil.

The productivity index $\omega_{i,t}$ follows from (2):

$$\omega_{i,t} = \nu \ln \left(\Omega_{i,t-1}(1-\delta^{\Omega}) + I^{\Omega}_{i,t-1} \right) + \beta_{0,i} + f(\mathbf{D}_t) + \xi_{i,t}, \tag{19}$$

where $\beta_{0,i} \equiv \nu \mathbb{E}\left[\ln x_{i,t}\right]$ is the firm-specific mean of productivity shocks, and $\xi_{i,t} \equiv \nu(\ln x_{i,t} - f(\mathbf{D}_t) - \mathbb{E}\left[\ln x_{i,t}\right])$ is a serially uncorrelated shock to productivity with mean zero and constant variance across firms in a sector. The function $f(\mathbf{D}_t)$ of market conditions captures their effect on the management's efficiency choice (see section 3.3). Both $\beta_{0,i}$ and $\xi_{i,t}$ are known to the firm when it chooses variable factor inputs and investment for next period. While entirely known to the firm's management, $\omega_{i,t}$ is unobservable to the researcher.

A.1 Correcting for 'Transmission Bias'

A transmission bias in the capital stock arises because both investment and the exit choice are correlated with $\omega_{i,t}$. A firm chooses organizational investment as a function of the state variables and market expectations. The model in section 3 implies that this choice is closely related to investment in capital goods. By (8), organizational investment is a function of q^{Ω}, $I^{\Omega}_{i,t-1} = (q^{\Omega}_{i,t-1} - 1)\Omega_{i,t-1}/\psi^{\Omega}$, and the q's for organizational skills and capital are positively related through (10) and (11): $q^{\Omega}_{i,t-1} = q(q^{K}_{i,t-1}; \cdot)$.[7] So,

$$I^{\Omega}_{i,t-1} = \frac{q(q^{K}_{i,t-1}; \cdot) - 1}{\psi^{\Omega}} \, \Omega_{i,t-1} = \frac{q(1 + \psi^{K} I^{K}_{i,t-1}/K_{i,t-1}; \cdot) - 1}{\psi^{\Omega}} \, \Omega_{i,t-1}.$$

[7]See footnote 2, p. 13.

As a consequence, the function $h(\cdot)$ in

$$\omega_{i,t} = h(I^K_{i,t-1}, I^S_{i,t-1}, a_{i,t}, k_{i,t}, s_{i,t}) + \beta_{0,i} + f(\mathbf{D}_t) + \xi_{i,t} \tag{20}$$

can be used to approximate the log *TFP* level in (19). In (20), $I^K_{i,t-1}$ and $I^S_{i,t-1}$ denote past investment in equipment and structures, respectively, and $a_{i,t}$ is the log of a firm's age at time t. Since market expectations affect the q's in a similar way, capital stocks and organizational skills should evolve roughly parallel to each other for surviving firms. A second-order polynomial in five variables related to business expectations (the foreign penetration rate, the real exchange rate, tariffs, aggregate sector-wide demand and the annual inflation rate) is used to proxy $f(\mathbf{D}_t)$. Interestingly, mostly labor coefficients change when $f(\mathbf{D}_t)$ is included. This points to a relationship between efficiency change and worker layoffs but is not further explored here.

Whereas Olley and Pakes (1996) have to assume that gross investment (capital good acquisitions less retirements) be strictly positive or at least non-zero to derive the equivalent of (20), no such assumption is needed in the present q-theory model. This is important. Firms stop to invest or even disinvest, especially in years before they go out of business. When excluding firms with zero gross investment, more than a third of all valid observations in the present sample would have to be ignored.[8]

The first regression equation follows,

$$\begin{aligned} z_{i,t} &= \beta_{0,i} + \beta_K \gamma_K \kappa^f_{i,t} + \beta_K k_{i,t} + \beta_S s_{i,t} + \beta_M \gamma_M \mu^f_{i,t} + \beta_M m_{i,t} \\ &\qquad + \beta_{bl} l^{bl}_{i,t} + \beta_{wh} l^{wh}_{i,t} + h(I^K_{i,t-1}, I^S_{i,t-1}, a_{i,t}, k_{i,t}, s_{i,t}) + f(\mathbf{D}_t) + \xi_{i,t} + \epsilon_{i,t} \\ &\equiv \beta_{0,i} + \beta_M \gamma_M \mu^f_{i,t} + \beta_M m_{i,t} + \beta_{bl} l^{bl}_{i,t} + \beta_{wh} l^{wh}_{i,t} \\ &\qquad + \phi(I^K_{i,t-1}, I^S_{i,t-1}, a_{i,t}, \kappa^f_{i,t}, k_{i,t}, s_{i,t}) + f(\mathbf{D}_t) + \xi_{i,t} + \epsilon_{i,t}. \end{aligned} \tag{21}$$

To be explicit, all regression variables are listed in (21). This includes the share of foreign intermediate inputs μ^f and the two groups of labor, blue- and white-collar workers. Only part of the equation is linear. The term $\phi(\cdot) \equiv \beta_K \gamma_K \kappa^f_{i,t} + \beta_K k_{i,t} + \beta_S s_{i,t} + h(\cdot)$ arises because the effect of log *TFP* on output cannot be separated from the effect of physical capital on output as long as their correlation is not removed. The coefficient estimates for β_{bl}, β_{wh} and β_M, on the other hand, are consistent if $\phi(\cdot)$ is approximated well. A polynomial series estimator of fourth degree is used here.[9] Neither year dummies nor time trend variables are significant when included.

[8] More than 20,000 observations among the close to 60,000 valid ones exhibit zero gross investment in at least one capital good category, and 5,500 show negative gross investment.

[9] Levinsohn and Petrin (2000) argue that Olley and Pakes's (1996) algorithm suffers from two problems. First, they point out that investment in the past was made in anticipation of a firm-specific and forecasted shock to productivity. To account for this, equation (21) is estimated with the according fixed effect $\beta_{0,i}$ here. Second, Levinsohn and Petrin stress that a correlation between $\xi_{i,t}$ and the choice of labor and materials may exist, and address the issue in their algorithm. It follows from Newey (1994), however, that the estimates

These findings lend support to the assertion that the drop in the sample in 1996 does not affect productivity estimates.

Next, one can estimate the probability of a firm's survival given today's information. This probability is given by (15) and can be restated as

$$Pr\,(\chi_{i,t}=1|\cdot)=P(I^K_{i,t-1},I^S_{i,t-1},a_{i,t},k_{i,t},s_{i,t};\mathbf{D}_t), \tag{22}$$

in the present context. There is no variable for a firm's expectations but one may suppose that the medium-sized to large firms in the sample are fairly well-informed about expected market outcomes. So, the vector of current market conditions $\mathbf{D}_t$, including tariff levels and market penetration rates, is taken as a proxy for past expectations. Equation (22) is the second estimation equation. It is estimated using a probit and a logit model.

Both the probit and the logit model predict slightly too few exits as compared to the data, and less dispersion. The inclusion of the vector of environment variables, $\mathbf{D}_t$, improves the correlation between probabilities (between zero and one) and observed outcomes (either zero or one) considerably. Financial variables of the firm turn out to reduce the fit and are not included. The logit model (correlation coefficient .223) outperforms probit (.211) in the estimation sample and is kept subsequently. Two different logit functions are estimated for the pre-1991 data and for the post-1991 data, taking into account that the shutdown probabilities may have changed systematically after trade liberalization. Contrary to the general finding that time indicators are not significant, the fit improves in this case.[10] A closer analysis of changes in exit (and other turnover) probabilities is provided in section 5.3.

Finally, to obtain a consistent estimate of the capital coefficients β_K and β_S, consider the contribution of capital to production one period in advance: $z_{i,t+1}-\beta_{0,i}-\beta_{bl}\,l^{bl}_{i,t+1}-\beta_{wh}\,l^{wh}_{i,t+1}-\beta_M\,\gamma_M\,\mu^f_{i,t+1}-\beta_M\,m_{i,t+1}$. Conditional on survival, the expectation of this term is

$$\begin{aligned}\mathbb{E}&\left[z_{i,t+1}-\beta_{0,i}-\beta_{bl}\,l^{bl}_{i,t+1}-\ldots-\beta_M\,m_{i,t+1}\,\middle|\,A_{i,t},\kappa^f_{i,t},K_{i,t},S_{i,t};\omega_{i,t},\chi_{i,t}=1\right]\\ &=\beta_K\,\gamma_K\,\kappa^f_{i,t+1}+\beta_K\,k_{i,t+1}+\beta_S\,s_{i,t+1}+\mathbb{E}\left[\omega_{i,t+1}\,|\omega_{i,t},\chi_{i,t}=1\right]\\ &=\beta_K\,\gamma_K\,\kappa^f_{i,t+1}+\beta_K\,k_{i,t+1}+\beta_S\,s_{i,t+1}+\int_{\underline{\omega}(\cdot)}\omega_{i,t+1}\frac{f\left(\omega_{i,t+1}|h(\cdot)\right)}{P(\cdot)}\,d\omega_{i,t+1}\end{aligned}$$

by equations (18), (20), and (22). Under regularity conditions (the density of $\xi_{i,t+1}$ needs to be positive in a neighborhood around $\xi_{i,t}$), $\underline{\omega}(\cdot)$ can be inverted and ex-

on current inputs are consistent under a proper series approximation. In fact, Levinsohn & Petrin find that only one in seven Olley & Pakes estimates for current inputs differs significantly (5% level) from the Levinsohn & Petrin estimates.

[10]No survival probability can be estimated for 1991 but is needed on the third step. In order not to lose all 1992 observations, the survival probability in 1991 is imputed as the unweighted average of the 1989, 1990, and 1992 predictions for each firm.

pressed as a function of $P(\cdot)$, too. So,

$$\begin{aligned} & z_{i,t+1} - \beta_{0,i} - \beta_{bl}\, l^{bl}_{i,t+1} - ... - \beta_M\, m_{i,t+1} \\ & \quad = \beta_K\, \gamma_K\, \kappa^f_{i,t+1} + \beta_K\, k_{i,t+1} + \beta_S\, s_{i,t+1} \\ & \quad\quad + g\left(P(\cdot), \phi(\cdot) - \beta_K\, \gamma_K\, \kappa^f_{i,t} - \beta_K\, k_{i,t} - \beta_S\, s_{i,t}\right) + \xi_{i,t+1} + \epsilon_{i,t+1} \end{aligned} \tag{23}$$

for some unspecified function $g(\cdot)$ since $h(\cdot) = \phi(\cdot) - (\beta_K\, \gamma_K\, \kappa^f_{i,t} + \beta_K\, k_{i,t} + \beta_S\, s_{i,t})$. $\xi_{i,t+1}$ is the unanticipated innovation in $\omega_{i,t+1}$. Hence, it is not correlated with net investment (gross investment less depreciation) or tomorrow's capital stock ($k_{i,t+1}$ and $s_{i,t+1}$), and the estimates of β_K, β_S and $\beta_K \gamma_K$ are consistent under the assumptions made. Equation (23) is the third estimation equation.

To approximate $g\left(P(\cdot), h(\cdot)\right)$ in equation (23), a third order polynomial expansion

$$\begin{aligned} & z_{i,t+1} - \hat{\beta}_{0,i} - \hat{\beta}_{bl}\, l^{bl}_{i,t+1} - \hat{\beta}_{wh}\, l^{wh}_{i,t+1} - \hat{\beta}_M\, \hat{\gamma}_M\, \mu^f_{i,t+1} - \hat{\beta}_M\, m_{i,t+1} \\ & \quad = \beta_K \gamma_K \kappa^f_{i,t+1} + \beta_K k_{i,t+1} + \beta_S\, s_{i,t+1} + \sum_{m=0}^{3} \sum_{n=0}^{3-m} \beta_{m,n} (\hat{P})^m (\hat{h})^n + \eta_{i,t+1} \end{aligned}$$

is used, where $\hat{\beta}_{0,i}$, $\hat{\beta}_{bl}$, $\hat{\beta}_{wh}$ and $\hat{\beta}_M$ are known from the first step. The capital coefficients enter this equation twice: in the additive terms, and through $\hat{h}(\cdot) = \hat{\phi}(\cdot) - (\beta_K\, \gamma_K\, \kappa^f_{i,t} + \beta_K\, k_{i,t} + \beta_S\, s_{i,t})$. The equation is estimated with non-linear least squares, using the fixed-effects estimates of equation (18) as starting values. Subtracting the fixed effect $\beta_{0,i}$ from $z_{i,t}$ on the left hand side reduces the fit in some sectors. However, the error term needs to be identically distributed for the bootstrap to follow. This requires the subtraction of $\beta_{0,i}$.

A.2 Correcting for 'Omitted Price Bias'

While the production function is estimated consistently in section A.1, a source of bias remains for productivity estimates. It arises because price is unknown but endogenous. Klette and Griliches (1996) address this problem.

The total of a firm's sales and production for store, deflated by sector-specific price indices, are used to approximate output. So, the dependent variable in the first regression equation (21) is in fact $p_{i,t} + z_{i,t} - \bar{p}_t$, where $p_{i,t}$ denotes the log of firm i's price and $\bar{p}_t$ the value of the price index used for deflation. By demand (3), the difference between a firm's price and market price is $p_{i,t} - \bar{p}_t = -(1-\alpha) d_{i,t} + (1-\alpha)(\bar{\theta}_t - \bar{p}_t)$, where $\bar{\theta}_t$ denotes the log of market-wide demand θY_t. Because of this relationship and since $d_{i,t} = z_{i,t}$ in equilibrium, the *de facto* regression is

$$\begin{aligned} p_{i,t} + z_{i,t} - \bar{p}_t &= \alpha z_{i,t} + (1-\alpha)(\bar{\theta}_t - \bar{p}_t) \\ &= \alpha\beta_{0,i} + (1-\alpha)\bar{\theta} \\ &\quad +\alpha\beta_M\,\gamma_M\,\mu^f_{i,t} + \alpha\beta_M\,m_{i,t} + \alpha\beta_{bl}\,l^{bl}_{i,t} + \alpha\beta_{wh}\,l^{wh}_{i,t} \\ &\quad +\alpha\phi(I^K_{i,t-1}, I^S_{i,t-1}, a_{i,t}, \kappa^f_{i,t}, k_{i,t}, s_{i,t}) + (1-\alpha)(\Delta\bar{\theta}_t - \bar{p}_t) \\ &\quad +\alpha\xi_{i,t} + \alpha\epsilon_{i,t}, \end{aligned} \tag{24}$$

instead of (21). Here, the log of market-wide demand for substitutes $(1-\alpha)(\bar{\theta}_t - \bar{p}_t)$ is decomposed into a preference based component $(1-\alpha)\bar{\theta}$ that does not vary over time, and into a time-varying component $(1-\alpha)(\Delta\bar{\theta}_t - \bar{p}_t)$ that moves with the business cycle $(\Delta\bar{\theta}_t \equiv \bar{\theta}_t - \bar{\theta})$.

The demand-side parameter α (which gives rise to a demand elasticity approximately equal to $-1/(1-\alpha)$) confounds the estimate of returns to scale by appearing in front of $z_{i,t}$. In addition, the time-invariant demand component $\bar{\theta}$ gets buried in the fixed-effects estimator. Klette and Griliches (1996) propose to use the sum of all firms' sales to approximate market-wide demand and to include it explicitly in the regression.Their purpose is to correct the scale estimate. Here, however, the focus lies on a consistent productivity estimate, and there are theoretical and practical reasons not to use Klette and Griliches' correction.

The model in section 3 (in particular (2) and (10)) implies that a firm's investment in $\omega_{i,t}$ depends on market expectations. In addition, the implementable efficiency choice of a manager depends on market conditions (17). If these market expectations are rational and firms are able to anticipate demand fairly well, the coefficient on sector-wide demand in an according regression will capture efficiency choice rather than the omitted price effect.

To understand the consequences, I also estimate (24) as suggested by Klette and Griliches (1996) and included the sum of sales (augmented by the degree of foreign market penetration) in the regression. The implied average log *TFP* level turns negative in all but two sectors. This finding indicates that market expectations go a long way in explaining productivity choice. Removing demand effects from productivity appears to be problematic. Moreover, production sectors may not coincide with consumer markets for the relevant substitutes. A wooden and a glass desk, for instance, show up in two different sectors in the present data but are close substitutes from a consumer's perspective. So, sector-wide sales seem to be too rough a proxy to demand θY_t in the relevant consumption markets.

Given these concerns, productivity estimates are only corrected for the time-invariant component $\bar{\theta}$. It can be extracted from the fixed-effects estimates by taking their sector-wide average. As a result, productivity estimates are clean of fixed demand components, but procyclical demand-side effects remain. To control for the remaining cyclicality, a demand proxy (the sum of sector-wide sales, augmented by the degree of foreign market penetration) will be included in all subsequent regressions. However, α will remain unidentified and no inference about economies of scale can be made. Yet, the assumption that α is constant across markets is likely not satisfied in practice so that economies of scale are not identified even if one is willing to make strong assumptions on the sources of cyclical TFP moves.

A.3 Estimates

Table 10 lists production function estimates for all 27 sectors and contrasts key estimates with fixed-effect regressions, an alternative estimation method under the behavioral assumptions. The fixed-effects correction under the Olley-Pakes method tends to reduce capital coefficients. Similarly, simple OLS fixed-effects regressions are known to lower the capital coefficients. On average across sectors, the sum of capital coefficients is about a quarter of the sum of labor coefficients. This is a low ratio. One might expect a ratio of double the magnitude. A reason for the low capital share may be that marginal returns on capital remain low despite low capital-labor ratios in Brazilian manufacturing or that production processes in Brazil are particularly labor intensive. Remaining measurement error in the capital stock series could bias the probability limits of the capital coefficients towards zero so that capital coefficients turn insignificant in some sectors. Since ratios rather than totals can be used to measure the effect of foreign inputs, formulation (18) makes sure that measurement error affects the estimates for $\beta_K \gamma_K$ and $\beta_M \gamma_M$ possibly little.

Table 8: Foreign Competition and Productivity Change, Validity of Instruments

	$\Delta \ln TFP^a$				$\ln TFP^a$			
	base IVs	add P_{Brazil}	add P_{USA}	add $P_{Argent.}$	base IVs	add P_{USA}	add $P_{Argent.}$	No IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tariff	-2.249	-1.909	-2.008	-1.604	-.609	-.516	.302	.184
	(.201)	(.119)	(.185)	(.115)	(.198)	(.145)	(.098)	(.021)
Mkt. Penetr.	27.989	22.595	24.316	22.903	10.652	9.695	2.438	1.468
	(2.163)	(1.485)	(1.981)	(1.596)	(1.904)	(1.312)	(1.076)	(.108)
κ^f	-.424	-.369	-.385	-.332	*-.043*	*-.033*	.055	*.033*
	(.053)	(.043)	(.049)	(.043)	(.034)	(.031)	(.027)	(.025)
μ^f	-.504	-.356	-.405	-.419	-.301	-.272	*-.07*	*-.004*
	(.074)	(.061)	(.068)	(.064)	(.063)	(.047)	(.043)	(.025)
ι(big L^{tot})[b]	.176	.168	.171	.182	.133	.129	.102	.087
	(.045)	(.041)	(.042)	(.041)	(.021)	(.02)	(.019)	(.018)
Demand[c]	-.548	-.492	-.509	-.466	.244	.261	.395	.392
	(.034)	(.024)	(.031)	(.024)	(.035)	(.026)	(.02)	(.01)
Cum. FDI[d]	.185	.148	.16	.138	.039	.031	-.03	-.029
	(.019)	(.014)	(.018)	(.014)	(.017)	(.012)	(.01)	(.005)
FDI flow[d]	-.14	-.121	-.127	-.113	*-.008*	*-.004*	.033	.033
	(.016)	(.013)	(.015)	(.013)	(.012)	(.01)	(.009)	(.007)
$\hat{\chi}^2$		98.5	-56.6	35.5		.634	192.4	
$Pr(\chi^2_{12} > \hat{\chi}^2)$		.0000	-	.0004		1.000	.0000	

[a]Regressors age, ι(medium L^{tot}), ι(medium cap.) and ι(big L^{tot}) not reported (see table 4).
[b]Labor force indicator: ($L^{tot}_{i,t} \geq 300$).
[c]Sector-wide sales in *PIA*, augmented by foreign market penetration.
[d]Billion US$ per sector. Cumulated FDI is end-of-year stock of invested foreign capital.

Table 9: Further Multinomial Logit Estimates of Transition Probabilities

$\sigma_{i,t}$	Suspended Firm[a]			2S-IV: Non-Exporter[a]		
$\sigma_{i,t+1}$	Exp.	Dom.	Exit	Exp.	Susp.	Exit
	(1)	(2)	(3)	(4)	(5)	(6)
Tariff[b]	-18.728	-8.537	-4.264			
	(3.329)	(2.639)	(1.719)			
Real exch. rate (US$)[c]	11.012	8.441	4.661	-1.304	*-.359*	-3.851
	(2.551)	(1.993)	(2.118)	(.133)	(.433)	(.327)
$\ln TFP$	.662	*-.032*	*-.218*	.076	-.281	-.236
	(.262)	(.223)	(.181)	(.019)	(.058)	(.037)
Age	*.024*	*-.017*	*-.002*	*.0001*	*-.003*	.007
	(.019)	(.018)	(.018)	(.001)	(.005)	(.003)
κ^f	6.621	*3.184*	*1.19*	1.215	*-.136*	*-.522*
	(3.338)	(3.495)	(2.91)	(.213)	(.846)	(.579)
μ^f				*-.001*	*-3.607*	*-.257*
				(.349)	(2.685)	(.716)
ι(big L^{tot})[d]	4.607	*1.503*	*.6*	1.158	-.882	-1.269
	(1.585)	(.869)	(.851)	(.181)	(.305)	(.192)
ι(big cap.)[e]	*-.101*	-2.067	*-.994*	1.242	*.006*	*-.114*
	(.951)	(.829)	(1.006)	(.116)	(.25)	(.172)
Sector demand	-.87	*-.1*	*-.1*	-.129	*-.034*	.193
	(.203)	(.123)	(.123)	(.013)	(.03)	(.02)
Cum. FDI[f]	*-.318*	*-.265*	*-.265*	*-.0008*	*-.096*	*.09*
	(.251)	(.34)	(.34)	(.028)	(.077)	(.051)
FDI flow[f]	*.898*	*.92*	*.92*	-.393	*.178*	*-.235*
	(1.263)	(.973)	(.973)	(.065)	(.178)	(.127)
Tariff[g]				*-.144*	-.994	-1.442
				(.14)	(.457)	(.388)
Mkt. Penetr.[g]				3.297	*2.158*	-14.636
				(1.43)	(4.044)	(2.524)
Obs.		146			27,391	
Pseudo R^2		0.302			0.665	
	$Pr(\chi^2_{36} > \hat{\chi}^2 = 137.68) = .0000$			$Pr(\chi^2_{42} > \hat{\chi}^2 = 22965.94) = .0000$		

[a] Regressors ι(medium L^{tot}) and ι(medium cap.) not reported (see table 6).
[b] Next year's tariff.
[c] Annual. Based on *IPA-OG* and US producer price index.
[d] Labor force indicator: ($L^{tot}_{i,t} \geq 300$).
[e] Capital stock indicator: $K_{i,t} + S_{i,t}$ in upper tercile of all firms in a year.
[f] Billion US$ per sector. Cumulated FDI is end-of-year stock of invested foreign capital.
[g] Instrumented as in columns 2 and 3 of table 4.

Table 10: Production Functions

Nív.50	Olley-Pakes and further treatments							FE			
	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}	κ^f	k	μ^f	m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
04	*Non-metal mineral products* (OP: 2,074, FE: 2,775 observations)										
	-*.007*	.065	.061	-*.095*	.239	.167	.461	-*.005*	.067	-.625	.221
	(.071)	(.011)	(.014)	(.124)	(.016)	(.013)	(.019)	(.092)	(.013)	(.133)	(.01)
05	*Basic metal products* (OP: 500, FE: 648 observations)										
	-*.211*	*.021*	-*.0006*	*.847*	.243	.116	.491	-*.248*	*.021*	*.029*	.265
	(.179)	(.031)	(.04)	(.876)	(.042)	(.033)	(.047)	(.188)	(.034)	(.215)	(.02)
06	*Non-ferrous metal products* (OP: 341, FE: 689 observations)										
	-*.154*	.056	*.013*	*.152*	.315	.151	.461	-*.131*	.056	*.05*	.314
	(.197)	(.021)	(.017)	(.237)	(.032)	(.032)	(.039)	(.173)	(.024)	(.128)	(.016)
07	*Metal products* (OP: 1,890, FE: 2,503 observations)										
	.064	*.022*	.065	*.348*	*.227*	.17	.524	*.064*	*.022*	*.099*	.215
	(.055)	(.016)	(.017)	(.788)	(.263)	(.08)	(.092)	(.073)	(.013)	(.13)	(.009)
08	*Machinery and equipment* (OP: 1,742, FE: 2,291 observations)										
	-*.037*	.047	.077	*.154*	.222	.238	.439	-*.047*	.047	-*.03*	.229
	(.129)	(.02)	(.022)	(.098)	(.014)	(.018)	(.025)	(.12)	(.016)	(.088)	(.01)
10	*Electrical equipment* (OP: 1,552, FE: 2,042 observations)										
	-*.043*	*.019*	.106	*.075*	.188	.212	.384	-*.027*	*.019*	.326	.219
	(.158)	(.017)	(.014)	(.121)	(.012)	(.018)	(.028)	(.153)	(.018)	(.098)	(.011)

κ^f: share of foreign equipment, k: log of total equipment, s: log of other structures goods, μ^f: share of foreign intermediates, m: log of total intermediates, l^{wh}: log of number of white-collar workers, l^{bl}: log of number of blue-collar workers.

Standard errors: Estimates from 250 bootstraps.

Source: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG* (as documented in Muendler 2002).

Table 10: PRODUCTION FUNCTIONS, continued

Nív.50	Olley-Pakes and further treatments							FE			
	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}	κ^f	k	μ^f	m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
11	*Electronic equipment* (OP: 934, FE: 1,207 observations)										
	.24	.061	.053	*.094*	.244	.27	.261	*.252*	.066	*.211*	.298
	(.11)	(.022)	(.025)	(.121)	(.039)	(.024)	(.039)	(.142)	(.022)	(.11)	(.013)
12	*Automobiles, trucks, and buses* (OP: 308, FE: 406 observations)										
	-*.272*	.113	*.055*	-*.032*	.156	.186	.588	-.567	.153	-*.132*	.201
	(.179)	(.043)	(.038)	(.406)	(.035)	(.043)	(.061)	(.228)	(.041)	(.242)	(.022)
13	*Other vehicles and parts* (OP: 1,249, FE: 1,621 observations)										
	.032	.089	*.043*	.237	.221	.178	.532	*.032*	.09	.465	.239
	(.075)	(.019)	(.022)	(.094)	(.017)	(.019)	(.027)	(.102)	(.018)	(.085)	(.01)
14	*Timber and furniture* (OP: 1,975, FE: 2,689 observations)										
	-.175	.116	.07	.689	.233	.163	.446	-.203	.124	-*.323*	.222
	(.068)	(.017)	(.014)	(.202)	(.015)	(.016)	(.027)	(.092)	(.015)	(.203)	(.01)
15	*Paper, pulp, and cardboard* (OP: 866, FE: 1,148 observations)										
	.146	.106	*.021*	*.521*	.267	.193	.386	*.118*	.113	-*.151*	.263
	(.194)	(.03)	(.02)	(.278)	(.028)	(.022)	(.03)	(.142)	(.017)	(.214)	(.013)
16	*Rubber products* (OP: 596, FE: 796 observations)										
	-*.387*	.063	.084	*.402*	.215	.163	.344	-*.377*	.064	-.491	.245
	(.274)	(.032)	(.019)	(.275)	(.036)	(.032)	(.044)	(.237)	(.029)	(.224)	(.021)

κ^f: share of foreign equipment, k: log of total equipment, s: log of other structures goods, μ^f: share of foreign intermediates, m: log of total intermediates, l^{wh}: log of number of white-collar workers, l^{bl}: log of number of blue-collar workers.

Standard errors: Estimates from 250 bootstraps.

Source: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG* (as documented in Muendler 2002).

Table 10: Production Functions, continued

	Olley-Pakes and further treatments							FE			
Nív.50	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}	κ^f	k	μ^f	m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
17	*Non-petrochemical chemical elements* (OP: 1,071, FE: 1,412 observations)										
	-.813	.059	.093	*.103*	.413	.115	.226	-.823	.059	-.53	.412
	(.534)	(.027)	(.035)	(.146)	(.025)	(.014)	(.018)	(.309)	(.021)	(.153)	(.013)
18	*Basic petrochemical products* (OP: 790, FE: 1,025 observations)										
	-.067	.068	.099	*.052*	.186	.171	.3	*-.079*	.068	-.322	.135
	(.191)	(.02)	(.023)	(.133)	(.016)	(.017)	(.031)	(.169)	(.019)	(.11)	(.012)
19	*Chemical products* (OP: 1,111, FE: 1,422 observations)										
	.099	*-.006*	.047	*.053*	.156	.273	.458	*.067*	*-.006*	*.055*	.134
	(.155)	(.022)	(.019)	(.136)	(.018)	(.026)	(.029)	(.235)	(.019)	(.086)	(.013)
20	*Pharmaceutical products and perfumes* (OP: 1,201, FE: 1,570 observations)										
	-.159	.095	*-.014*	*.164*	.163	.167	.402	*-.258*	.093	-.613	.094
	(.113)	(.02)	(.019)	(.104)	(.015)	(.024)	(.029)	(.196)	(.023)	(.096)	(.013)
21	*Plastics* (OP: 1,492, FE: 1,964 observations)										
	-.00009	.033	.057	.606	.189	.223	.479	*-.00009*	.034	*.213*	.174
	(.095)	(.016)	(.014)	(.152)	(.019)	(.017)	(.024)	(.113)	(.014)	(.109)	(.01)
22	*Textiles* (OP: 2,483, FE: 3,225 observations)										
	.168	*.016*	.067	.258	.311	.15	.407	.168	*.016*	-.167	.297
	(.044)	(.014)	(.013)	(.067)	(.016)	(.015)	(.023)	(.059)	(.013)	(.076)	(.009)

κ^f: share of foreign equipment, k: log of total equipment, s: log of other structures goods, μ^f: share of foreign intermediates, m: log of total intermediates, l^{wh}: log of number of white-collar workers, l^{bl}: log of number of blue-collar workers.

Standard errors: Estimates from 250 bootstraps.

Source: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG* (as documented in Muendler 2002).

Table 10: Production Functions, continued

Nív.50	Olley-Pakes and further treatments							FE			
	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}	κ^f	k	μ^f	m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
23	*Apparel* (OP: 1,559, FE: 2,091 observations)										
	.116	.128	.106	*.259*	.195	.215	.406	*.116*	.128	.388	.216
	(.072)	(.026)	(.02)	(.137)	(.016)	(.021)	(.025)	(.096)	(.018)	(.143)	(.01)
24	*Leather products and footwear* (OP: 1,371, FE: 1,745 observations)										
	.34	*.022*	*.023*	.995	.201	.127	.541	.255	*.024*	.521	.221
	(.086)	(.019)	(.016)	(.185)	(.023)	(.023)	(.034)	(.11)	(.018)	(.155)	(.014)
25	*Coffee products* (OP: 655, FE: 843 observations)										
	-*.094*	*.04*	*.047*	*.066*	.205	.294	.324	-*.1*	*.04*	-*.811*	.188
	(.142)	(.037)	(.035)	(3.043)	(.025)	(.036)	(.042)	(.292)	(.029)	(1.422)	(.016)
26	*Processed edible products* (OP: 2,233, FE: 2,927 observations)										
	-.322	.072	.048	.208	.246	.2	.332	-.318	.072	-.394	.224
	(.136)	(.018)	(.024)	(.082)	(.011)	(.018)	(.018)	(.151)	(.016)	(.086)	(.008)
27	*Meat and poultry* (OP: 896, FE: 1,194 observations)										
	.032	*.039*	*.01*	*.821*	.336	.152	.306	-*.079*	*.041*	-*.691*	.324
	(.179)	(.02)	(.025)	(.574)	(.04)	(.036)	(.062)	(.258)	(.024)	(.471)	(.016)
28	*Processed dairy products* (OP: 582, FE: 766 observations)										
	-.422	-.073	*.017*	*.793*	.276	.203	.332	-*.428*	-.073	-*.701*	.236
	(.202)	(.032)	(.028)	(1.225)	(.026)	(.03)	(.04)	(.237)	(.034)	(.696)	(.017)

κ^f: share of foreign equipment, k: log of total equipment, s: log of other structures goods, μ^f: share of foreign intermediates, m: log of total intermediates, l^{wh}: log of number of white-collar workers, l^{bl}: log of number of blue-collar workers.

Standard errors: Estimates from 250 bootstraps.

Source: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG* (as documented in Muendler 2002).

Table 10: Production Functions, continued

	Olley-Pakes and further treatments							FE			
Nív.50	κ^f	k	s	μ^f	m	l^{wh}	l^{bl}	κ^f	k	μ^f	m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
29	*Sugar* (OP: 336, FE: 757 observations)										
	-*.778*	.122	-*.02*	*1.669*	.304	.109	.158	-*.619*	.125	-*2.136*	.328
	(.434)	(.029)	(.027)	(7.152)	(.028)	(.02)	(.022)	(.339)	(.029)	(3.351)	(.017)
30	*Vegetable oil* (OP: 439, FE: 567 observations)										
	-.642	.075	.151	-*.344*	.356	.152	.257	-.702	.089	*.282*	.354
	(.26)	(.028)	(.037)	(.914)	(.035)	(.048)	(.044)	(.313)	(.028)	(.754)	(.021)
31	*Beverages and other food products* (OP: 2,468, FE: 3,236 observations)										
	-*.049*	.075	.04	*.29*	.213	.2	.396	-*.044*	.075	-.299	.188
	(.083)	(.013)	(.014)	(.151)	(.011)	(.015)	(.031)	(.132)	(.013)	(.134)	(.008)

κ^f: share of foreign equipment, k: log of total equipment, s: log of other structures goods, μ^f: share of foreign intermediates, m: log of total intermediates, l^{wh}: log of number of white-collar workers, l^{bl}: log of number of blue-collar workers.

Standard errors: Estimates from 250 bootstraps.

Source: *Pesquisa Industrial Anual* 1986-98, deflated with *IPA-OG* (as documented in Muendler 2002).

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