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Costs of Starting to Trade and Costs of Continuing to Trade

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ABSTRACT

Costs of international trade are increasingly modeled as fixed costs paid by individual firms. In a dynamic setting, these fixed costs may take two different forms: costs of starting to trade and costs of continuing to trade. The distinction matters when firms experience idiosyncratic shocks to productivity over time. We develop an analytically tractable dynamic model of firms' import decisions. In the model, there are costs of developing relationships with foreign input suppliers and costs of continuing these relationships. The benefit of using imported inputs lies in a combination of the relative price and the technology embodied in the inputs. Our model quantitatively captures many important features of plant-level manufacturing data, including the dynamics of import status, entry and exit rates, the size distribution, and the large performance advantage associated with using imported intermediate inputs.

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Introduction

Models of international trade increasingly emphasize the trade decisions of individual firms or plants. Following Melitz (2003), these models typically feature heterogeneous firms that face fixed costs of exporting their goods to foreign markets. (See Helpman (2006) for a survey of this literature.) For simplicity, these models are typically static or, if dynamic, hold fixed each firm's technological efficiency over time. Our modeling approach here also involves heterogeneous firms making trade decisions subject to fixed costs, but we differ from the literature in two important ways: by emphasizing the decision to use imported intermediate goods and by taking firm dynamics seriously.

Modeling the decision to import rather than the decision to export may at first seem to be of little consequence, but the two decisions involve entirely different considerations by firms. In deciding whether to export its good, a firm considers the characteristics of a foreign market and weighs the expected profits from exporting to that market against the costs of entering it. The emphasis is on foreign demand. In deciding whether to use an imported intermediate good, a firm considers how using that input will affect its production process and weighs the additional expected profits against the costs of developing a trade relationship with a foreign input supplier. The emphasis is on technology. Consistent with this, we model a firm's decision to import as a choice between two technologies: a technology that uses only domestic inputs and a technology that uses both domestic and foreign inputs. In a broader sense, we develop a dynamic general equilibrium model of technology adoption when there are adoption and continuation costs.

By taking firm dynamics seriously, we can analyze the relative importance of two types of fixed costs: costs of starting to trade and costs of continuing to trade. With respect to importing intermediate goods, we think of these fixed costs as the costs of developing and maintaining relationships with foreign input suppliers. As Melitz (2003) points out, in a stationary equilibrium with no shocks to firms' technological efficiencies, the distinction between fixed costs of starting to trade and fixed costs of continuing to trade is without consequence: a firm's trade status is fixed over time and only the expected discounted present value of the fixed costs matters. By contrast, when we allow for idiosyncratic shocks to firms' efficiencies over time, start-up and continuation costs have different implications, even in a stationary equilibrium. With sunk costs of starting to trade, uncertainty about future shocks discourages firms from investing in trade relationships even when, from a purely static point of view, they would prefer to be engaged in trade. Costs of continuing to trade imply that firms may stop trading even after having paid the start-up costs. Together, these costs allow us to capture the dynamics of firms' trade status over time.

Our model is motivated by the data. Distinguishing between importers and non-importers perhaps would not be of much importance if the two types of producers appeared similar in the data. But this is not the case. Only a small fraction of plants choose to use imported intermediate inputs and plants that do use imported intermediate inputs are much larger than plants that do not. We document this phenomenon using recent surveys of Chilean manufacturing plants. In the Chilean data, plants that use imported intermediate inputs are 3.6 times larger in terms of gross output and 1.2 times more productive in terms of value added per worker than are non-importers. Despite the apparent advantage of importing, most plants do not. Moreover, plants switch important status over time. In our data, 25 percent of plants import at some point, with 12 percent importing for the entire period and 13 percent switching import status at least once.

Our interpretation of the data is that plants would prefer to use imported intermediate inputs but that there are barriers to doing so that take the form of fixed costs. This is the approach taken by Gibson and Graciano (2010) in a static setting. Due to these fixed costs, only the largest, most efficient plants choose to import. Plants start importing if their efficiency increases enough to cover the additional costs and stop importing if their efficiency decreases. Our model formalizes the role imported intermediate inputs play in firm performance by giving each firm a choice between two technologies, one that uses only domestic inputs, and another that uses both domestic and imported inputs.

Firms receive a performance increase from using the importing technology but it requires the payment of an additional fixed cost to operate. Most of the literature focuses on selection effects, while we allow for both a selection effect and a technology upgrade effect. Therefore, only the most efficient firms choose to import. Sunk costs ensure that the barrier to start importing is greater than the barrier to stop importing, first by adding additional costs to importing and second by providing firms with an incentive to continuously import to avoid having to repay start-up costs. As a result, trade status becomes history-dependent. That is, there is a band of firm efficiency levels where two firms with the same efficiency draw may be using different technologies.

Quantitatively, the model captures many important features of the data including the dynamics of import status, entry and exit rates, the size distribution, and the large performance advantage associated with using imported intermediate inputs.

Our paper connects to three strands of the literature: the first concerns the characteristics of producers that engage in trade relative to those that do not, the second emphasizes producers' decisions regarding importing rather than exporting, and the third seeks to develop better dynamic models of producers' trade decisions.

A large literature establishes a connection between firm trade status and firm performance. This has been done by Bernard et al. (2003); Bernard, Jensen, and Schott (2005); Eaton, Kortum, and Kramarz (2008); and others. It is a stylized fact that firms that trade are larger and more productive than those that are not. This is particularly true for exporters. For the United States, Bernard and Jensen (1999) find that exceptional performers become exporters, and exporting can further increase plant performance. Bernard et al. (2003) and Bernard, Jensen, and Schott (2005) find similar differences between U.S. exporters and non-exporters. Using Chilean data Pavcnik (2002) finds empirical evidence to support the correlation between export status and plant performance. Eaton, Kortum, and Kramarz (2008) show that, for French firms, efficiency differences account for a large part of export decisions. Empirically, Kasahara and Rodrigue (2008) demonstrate that importers are exceptional performers.

Analysis of firms' import decisions is much less common than analysis of firms' export decisions, despite the fact that a large and growing share of trade is trade in intermediate goods (Hummels, Ishii, and Yi, 2001; Helpman, 2006). Gibson and Graciano (2010) analyze a static version of the model here. Kugler and Verhoogen (2009) use a model where firms with high ability capture larger gains from using high quality inputs. When high quality inputs are imported, the most efficient firms become importers. Amiti and Konings (2007), examining data from Indonesia, find that lowering tariffs on imported inputs can increase plant productivity through learning, variety, and quality effects. Halpern, Koren, and Szeidl (2005) find using Hungarian data that imported inputs increase plant productivity through complementarity and quality channels. Perhaps the work most closely related to ours is Kasahara and Lapham (2005), who model import choice when firms face stochastic fixed costs.

If firm efficiency is subject to idiosyncratic shocks, then sunk costs cause trade decisions to become history-dependent since it will be less costly for some firms to continuously trade than to start and stop. A similar motivation for history dependence can be found in Alessandria and Choi (2007). Other dynamic models of trade decisions include Arkolakis (2010), Ramanarayanan (2007), Irarrazabal and Opromolla (2009), and Das, Roberts, and Tybout (2007).

Data

In order to motivate our model and, later, to calibrate it, we consider plant-level data from a tradable sector, manufacturing, in a small open economy, Chile. We use data from the annual census of Chilean manufacturing plants (Encuesta Nacional Industrial Anual, or ENIA), collected by Chile’s Instituto Nacional de Estadísticas, from 2001 to 2006. An earlier version of this census was used by Liu (1993), Levinsohn (1999), and Pavcnik (2002), among others. We use a more recent, revised version of the census (Navarro (2008) also uses this version).

The unit of observation in the data is the plant. The census covers a total of 8,014 different plants over the period 2001 to 2006. The data include detailed information on each plant’s inputs, employment, and expenditures. Expenditure on imported raw materials represents a significant outlay for importing plants, on average 7 percent of their gross output, making it a non-trivial part of importing behavior. For each survey, we divide the plants into those that do not report any use of imported raw materials, which we refer to as *non-importers*, and those that do, which we refer to as *importers*. Since our model is concerned with long-run effects, when we calculate statistics we average over the sample period, 2001 to 2006. On average, importers are 20 percent of plants. We consider how importers differ from non-importers and how plants change their import status over time.

Differences between importers and non-importers

First we consider how importers differ from non-importers. Even though most plants do not import, those that do are much larger and more productive than plants that do not. Table 1 summarizes these findings. Differences between importers and non-importers in this data are robust to a variety of statistical controls (see Gibson and Graciano (2011) for details).

Plant dynamics

The Chilean manufacturing sector is characterized by simultaneous plant entry and exit. The average exit rate over the sample period, 2001 to 2006, is 12.1 percent of active plants. The average entry rate is 12.8 percent. Importers tend to be larger and more efficient than non-importers and are therefore less likely to exit than non-importers, as documented by Lopez (2006). The difference between exit rates for importers and non-importers is about 4 percent. Table 2 summarizes the transition probabilities found in the data.[1]

Importers are less likely to exit than non-importers and therefore on average have longer life spans. On average, 11 percent of operating plants switch trade status each year. On average 14 percent of importers stop importing every year. While on average only 3 percent of non-importers start importing each year. The transition probabilities for importers show a higher level of history dependence than those of non-importers which is consistent with the presence of an entry cost similar to what is found in the model. Plant entry, exit, and import status display no noticeable trend over the sample period.

Model

Consider a small open economy in a stationary competitive equilibrium. (Due to the assumption of stationarity, we omit time from the notation that follows whenever

[1] We interpret zero expenditure on imported raw materials to mean that a plant is no longer importing, but we cannot tell whether these plants are drawing from stockpiles. Stockpiling behavior is most likely small due to the annual frequency of our data, and the aggregate variable we use to indicate importing status. Less than 3 percent of reported expenditure on imported raw materials is more than two standard deviations above the mean (which may suggest a particularly large outlay). In the six years of data that we consider, 5 percent of plants switch import status more than once.

possible.) The economy produces a single output good. The price of the output good is normalized to one. The good may be used in four different ways: for consumption, for export, as an intermediate good, or for payment of fixed costs.

There is no international borrowing and lending, but there is trade in goods. The small open economy exports some of its good and imports a single intermediate good from the rest of the world. Since the economy is small, it takes the relative price of the two goods — the terms of trade — as given. The small open economy may impose an *ad valorem* tariff on imports.

The single output good is produced by a continuum of single-plant firms. The firms are heterogeneous in technological efficiency. There are decreasing returns to scale in production, so each firm produces output at its optimal level, with more efficient firms producing more output. Each firm, after learning its efficiency level, has a choice of two technologies. One technology uses labor and the domestically produced intermediate good as inputs. The other technology uses labor, the domestically produced intermediate good, and the imported intermediate good as inputs. The choice of technology separates firms into non-importers and importers. Firms' efficiency levels evolve stochastically over time. Firms make endogenous decisions regarding entry, exit, and choice of technology. Each firm also faces an exogenous probability of death each instant.

In this section, we specify the consumer's problem, the static decisions of firms, the dynamic decisions of firms, firm entry, and the distribution of firms. We then define a stationary competitive equilibrium and provide an algorithm for calculating it.

Consumer

In the small open economy, there is a representative consumer who is endowed with quantity of labor $\bar{L}$ and ownership of the firms. At each instant, the consumer maximizes consumption, C, subject to the budget constraint

$$C = w\bar{L} + \mathrm{T} + \Pi \,. \tag{1}$$

The consumer's three sources of income are labor income, $w\bar{L}$, where w is the wage; transfers from the government, T; and the profits of firms, Π. The consumer's subjective discount rate is ρ, $\rho > 0$.

Firms' static decisions

Given a firm's efficiency level and its choice of technology, the firm's optimal decisions regarding inputs and output are simple static decisions at each instant. Let technology N (where N stands for *non-importer*) be the technology that does not use the imported intermediate good as an input. Let technology I (where I stands for *importer*) be the technology that uses the imported intermediate good as an input. Let η be the efficiency of technology I relative to technology N.

Consider a firm with efficiency x operating technology N. The firm's output is given by

$$y_N(x) = x^{1-\nu}\Omega_N\left(\ell_N(x), d_N(x)\right)^{\nu}, \tag{2}$$

where Ω_N is a standard production function with constant returns to scale, $\ell_N(x)$ is the input of labor, $d_N(x)$ is the input of the domestically produced intermediate good, and $0<\nu<1$. The firm's profits are

$$\pi_N(x) = y_N(x) - w\ell_N(x) - d_N(x) - \phi_N, \tag{3}$$

where ϕ_N is the fixed cost of operating. The firm chooses $\ell_N(x)$ and $d_N(x)$ to satisfy the profit-maximization conditions

$$\nu x^{1-\nu}\Omega_N\left(\ell_N(x), d_N(x)\right)^{\nu-1}\Omega_{N\ell}\left(\ell_N(x), d_N(x)\right) - w = 0 \tag{4}$$

$$\nu x^{1-\nu}\Omega_N\left(\ell_N(x), d_N(x)\right)^{\nu-1}\Omega_{Nd}\left(\ell_N(x), d_N(x)\right) - 1 = 0, \tag{5}$$

where $\Omega_{Nk} = \partial\Omega_N / \partial k$, $k = \ell, d$.

Now consider a firm with efficiency x operating technology I. The firm's output is given by

$$y_I(x) = (x\eta)^{1-\nu}\Omega_I\left(\ell_I(x), d_I(x), f_I(x)\right)^{\nu}, \tag{6}$$

where Ω_I is a standard production function with constant returns to scale, $\ell_I(x)$ is the input of labor, $d_I(x)$ is the input of the domestically produced intermediate good, $f_I(x)$ is the input of the imported intermediate good, and $\eta > 0$. The firm's profits are

$$\pi_I(x) = y_I(x) - w\ell_I(x) - d_I(x) - (1+\tau)pf_I(x) - \phi_I, \tag{7}$$

where p is the relative price of the imported intermediate good, τ is the *ad valorem* tariff on imports, and ϕ_I is the fixed cost of operating. The firm chooses $\ell_I(x)$, $d_I(x)$, and $f_I(x)$ to satisfy the profit-maximization conditions

$$\nu(x\eta)^{1-\nu}\Omega_I\left(\ell_I(x), d_I(x), f_I(x)\right)^{\nu-1}\Omega_{I\ell}\left(\ell_I(x), d_I(x), f_I(x)\right) - w = 0 \qquad (8)$$

$$\nu(x\eta)^{1-\nu}\Omega_I\left(\ell_I(x), d_I(x), f_I(x)\right)^{\nu-1}\Omega_{Id}\left(\ell_I(x), d_I(x), f_I(x)\right) - 1 = 0 \qquad (9)$$

$$\nu(x\eta)^{1-\nu}\Omega_I\left(\ell_I(x), d_I(x), f_I(x)\right)^{\nu-1}\Omega_{If}\left(\ell_I(x), d_I(x), f_I(x)\right) - (1+\tau)p = 0, \qquad (10)$$

where $\Omega_{Ik} = \partial\Omega_I / \partial k$, $k = \ell, d, f$.

Firms' dynamic decisions

Each firm's efficiency evolves stochastically according to a continuous Markov process. In addition, at each instant each firm faces exogenous probability of death δ, $0 \le \delta < 1$. A firm's operating and technology decisions are dynamic, or forward-looking, decisions in the sense that they take into account the firm's expectations for the future.

To remain in operation, a firm must continuously operate either technology N or technology I by paying the relevant fixed cost, ϕ_N or ϕ_I. If a firm ever fails to pay the relevant fixed cost, it exits forever. Because of these fixed costs, a firm will endogenously choose to exit when its efficiency gets sufficiently low. We let b denote the cutoff to operate technology N and let c denote the cutoff to operate technology I.

If a firm chooses to operate, it must choose which technology to use. This decision is forward-looking because switching from technology N to technology I involves a sunk cost of ϕ_{SI} units of output. A firm can costlessly switch from technology I to technology N, but if the firm ever wants to switch back to technology I it must pay the sunk cost ϕ_{SI} again. Given this sunk cost, a non-importer will only switch to using technology I if its efficiency is sufficiently high. We let B denote the cutoff to start importing. Thus non-importers have efficiencies in the range $x \in [b, B)$ and importers have efficiencies in the range $x \in [c, \infty)$.

Before specifying the dynamic programming problems of firms, we define some notation that we use throughout the paper. We specify the dynamic problems of firms using Bellman equations. (Stokey (2009) refers to this as the direct approach. The indirect approach, which is equivalent, uses Hamilton-Jacobi-Bellman equations. See Stokey (2009) and Dixit and Pindyck (1994) for details.) Consider a firm with efficiency $x \in [z, Z)$ that faces lower cutoff z and upper cutoff Z. Eventually the firm will face an *adjustment*, by which we mean that one of the following three events will occur: (i) the firm's efficiency will reach z, (ii) the firm's efficiency will reach Z, or (iii) the firm will exogenously die. We allow $Z = \infty$, in which case event (ii) never occurs. Denote the first time that (i) or (ii) occurs by the random variable $T(x, z, Z)$. Define the probability that adjustment (i) occurs first as

$$\psi(x, z, Z) = E\left(e^{-\delta T(x,z,Z)}\right) \Pr\left(X\left(T(x, z, Z)\right) = z\right). \tag{11}$$

Define the probability that adjustment (ii) occurs first as

$$\Psi(x, z, Z) = E\left(e^{-\delta T(x,z,Z)}\right) \Pr\left(X\left(T(x, z, Z)\right) = Z\right). \tag{12}$$

Since the consumer owns the firms, we will also need counterparts to (11) and (12) that take into account the consumer's rate of time preference, ρ. Define the expected discounted value of the indicator function for the event of adjustment (i) occurring first as

$$\tilde{\psi}(x, z, Z) = E\left(e^{-\rho T(x,z,Z)}\right) \psi(x, z, Z). \tag{13}$$

Define the expected discounted value of the indicator function for the event of adjustment (ii) occurring first as

$$\tilde{\Psi}(x, z, Z) = E\left(e^{-\rho T(x,z,Z)}\right) \Psi(x, z, Z). \tag{14}$$

Define the expected time until an adjustment occurs as

$$\overline{T}(x, z, Z) = E\left(e^{-\delta T(x,z,Z)} T(x, z, Z)\right). \tag{15}$$

Finally, we introduce the concept of local time. For $\xi \in (z, Z)$, let $L(\xi; x, z, Z)$ be the expected amount of time that a firm starting from efficiency x will have efficiency ξ before adjustment. Let $\tilde{L}(\xi; x, z, Z)$ be the expected discounted amount of time that a firm starting from efficiency x will have efficiency ξ before adjustment, where the discounting reflects the consumer's rate of time preference, ρ.

The relationship between the above formulas and our particular framework is as follows. A non-importer with efficiency $x \in [b, B)$ will remain a non-importer until one of three adjustments occurs: (i) its efficiency reaches b and it chooses to exit, (ii) its efficiency reaches B and it chooses to become an importer, or (iii) it exogenously dies. For an importer with efficiency $x \in [c, \infty)$, case (ii) is not relevant, but the other two cases are. The firm will remain an importer until its efficiency reaches c and it switches back to being a non-importer or it exogenously dies.

Consider a non-importer with efficiency $x \in [b, B)$. The firm's expected discounted returns from operating technology N until adjustment are given by

$$r_N(x,b,B) = E_{X(0)=x} \int_0^{T(x,b,B)} e^{-(\rho+\delta)t} \pi_N\left(X(t)\right) dt. \tag{16}$$

Future returns are discounted at rate $\rho + \delta$. This reflects both the consumer's rate of time preference and the exogenous probability of firm death. Now consider an importer with efficiency $x \in [c, \infty)$. The firm's expected discounted returns from operating technology I until adjustment are given by

$$r_I(x,c) = E_{X(0)=x} \int_0^{T(x,c,\infty)} e^{-(\rho+\delta)t} \pi_I\left(X(t)\right) dt. \tag{17}$$

Using the expected discounted local time function, we can eliminate the stochastic integrals in (16) and (17) by expressing the return functions more directly as

$$r_N(x,b,B) = \int_b^B \tilde{L}(\xi; x,b,B) \pi_N(\xi) d\xi \tag{18}$$

$$r_I(x,c) = \int_c^\infty \tilde{L}(\xi; x,c,\infty) \pi_I(\xi) d\xi. \tag{19}$$

The cutoffs b, c, and B are endogenous choices of firms, but first we define the value functions of firms taking the cutoffs as given. Given the cutoffs b, c, and B, the expected discounted value of being a non-importer with efficiency x, $x \in [b, B)$, is

$$\overline{v}_N(x;b,c,B) = r_N(x,b,B) + \tilde{\Psi}(x,b,B)\left(\overline{v}_I(B;b,c,B) - \phi_{SI}\right) \tag{20}$$

and the expected discounted value of being an importer with efficiency x, $x \in [c, \infty)$, is

$$\overline{v}_I(x;b,c,B) = r_I(x,c) + \tilde{\psi}(x,c,\infty)\overline{v}_N(c;b,c,B). \tag{21}$$

The second term on the right side of (20) is the net present value of the option to become an importer. The second term on the right side of (21) is the present value of the option to return to being a non-importer. After substitution, we can express (20) and (21) more directly as

$$\overline{v}_N(x;b,c,B) = r_N(x,b,B) + \tilde{\Psi}(x,b,B)\frac{r_I(B,c) + \tilde{\psi}(B,c,\infty) r_N(c,b,B) - \phi_{SI}}{1 - \tilde{\psi}(B,c,\infty)\tilde{\Psi}(c,b,B)} \tag{22}$$

$$\overline{v}_I(x;b,c,B) = r_I(x,c) + \tilde{\psi}(x,c,\infty)\frac{r_N(c,b,B) + \tilde{\Psi}(c,b,B)\left(r_I(B,c) - \phi_{SI}\right)}{1 - \tilde{\psi}(B,c,\infty)\tilde{\Psi}(c,b,B)}. \tag{23}$$

Now we can define the value functions with the cutoffs as endogenous choices of each firm. The expected discounted value of a firm with efficiency x operating technology N is

$$v_N(x) = \max\left\{\max_{b,c,B} \overline{v}_N(x;b,c,B),\ v_I(x) - \phi_{SI},\ 0\right\} \tag{24}$$

and the expected discounted value of a firm with efficiency x operating technology I is

$$v_I(x) = \max\left\{\max_{b,c,B} \overline{v}_I(x;b,c,B),\ v_N(x),\ 0\right\}. \tag{25}$$

As the outer maximization of (24) shows, a non-importer chooses among remaining a non-importer, paying the sunk cost ϕ_{SI} to become an importer, or exiting. As the outer maximization of (25) shows, an importer chooses among remaining an importer, becoming a non-importer, or exiting. In both value functions, the cutoffs b, c, and B are endogenous decisions of each firm. The optimal cutoffs are independent of a firm's current efficiency and its import status. Thus they satisfy the first-order conditions from every firm's dynamic problem:

$$\overline{v}_{jk}(x;b,c,B) = 0, \tag{26}$$

for all x, $j = N, I$, $k = b, c, B$, where $\overline{v}_{jk} = \partial\overline{v}_j / \partial k$.

Firm entry

The cost of firm entry is ϕ_{En} units of output. Paying the cost of entry entitles a firm to enter as a non-importer with efficiency x_0, $x_0 \in (b,B)$. (It is straightforward to allow for a probability distribution over initial efficiency draws, but this is not important for our analysis.) Free entry requires that the value of entry equals the cost of entry:

$$v_N(x_0) = \phi_{En}. \tag{27}$$

Firm distributions

Here we characterize the stationary distributions over firm efficiency. We break up the characterization into two parts. First, we specify the probability distributions over firm efficiency for each type. We let $g_N(x)$ denote the probability density function over non-importers' efficiencies with support $x \in [b, B)$. We let $g_I(x)$ denote the probability density function over importers' efficiencies with support $x \in [c, \infty)$. Second, we specify the measure of each firm type. We denote the measure of non-importers by M_N, the measure of importers by M_I, the measure of entrants by M_{En}, the measure of firms switching from technology N to technology I by M_{SI}, the measure of firms switching from technology I to technology N by M_{SN}, and the measure of firms that endogenously exit by M_{Ex}. The measure of firms that exogenously exit every instant is $\delta(M_N + M_I)$.

Now we are ready to specify the distributions of firms. We start with the distribution of importers because it is simpler. Entry into the distribution of importers only occurs at efficiency level B. The expected local time function for an importer with efficiency B is $L(x; B, c, \infty)$. If we normalize the expected local time function by the expected time to adjustment, $\overline{T}(B, c, \infty)$, then we obtain the stationary distribution over importers' efficiencies as the probability density function

$$g_I(x) = \frac{L(x; B, c, \infty)}{\overline{T}(B, c, \infty)}. \tag{28}$$

Entry into the distribution of non-importers occurs at two different efficiency levels. New firms enter with efficiency x_0, while firms that are switching from technology I to technology N enter with efficiency c. The total distribution of non-importers is therefore a weighted average of the two types:

$$g_N(x) = \frac{M_{En}}{M_{En} + M_{SN}} \frac{L(x; x_0, b, B)}{\overline{T}(x_0, b, B)} + \frac{M_{SN}}{M_{En} + M_{SN}} \frac{L(x; c, b, B)}{\overline{T}(c, b, B)}. \tag{29}$$

Now we turn to specifying the measures of each firm type. Measure M_{En} of non-importers enter with efficiency x_0 every instant. In a stationary equilibrium, the measure of these firms that are adjusting every instant is $M_{En} / \overline{T}(x_0, b, B)$. Applying the relevant probabilities, the measure of these firms that are endogenously exiting every instant is $M_{En}\psi(x_0, b, B) / \overline{T}(x_0, b, B)$, the measure that are adopting technology I every instant is $M_{En}\Psi(x_0, b, B) / \overline{T}(x_0, b, B)$, and the measure that are exogenously dying every instant is $M_{En}\left(1-\psi(x_0, b, B) - \Psi(x_0, b, B)\right) / \overline{T}(x_0, b, B)$. Similarly, every instant measure M_{SN} of firms will switch from being importers to become non-importers with efficiency c. For these firms, the adjustment probabilities are, respectively, $\psi(c, b, B)$, $\Psi(c, b, B)$, and $1-\psi(c, b, B) - \Psi(c, b, B)$ and the expected time until adjustment is $\overline{T}(c, b, B)$. Thus the total measure of firms that choose to exit every instant is

$$M_{Ex} = M_{En} \frac{\psi(x_0, b, B)}{\overline{T}(x_0, b, B)} + M_{SN} \frac{\psi(c, b, B)}{\overline{T}(c, b, B)} \tag{30}$$

and the total measure of firms that switch to being importers every instant is

$$M_{SI} = M_{En} \frac{\Psi(x_0, b, B)}{\overline{T}(x_0, b, B)} + M_{SN} \frac{\Psi(c, b, B)}{\overline{T}(c, b, B)}. \tag{31}$$

Firms only enter the importer distribution with efficiency B. The only forms of adjustment are (i) switching back to being a non-importer and (ii) exogenous exit and the respective probabilities of these events are $\psi(B, c, \infty)$ and $1-\psi(B, c, \infty)$, with expected time to adjustment being $\overline{T}(B, c, \infty)$. Thus every instant the measure of firms switching from being importers to being non-importers is

$$M_{SN} = M_{SI} \frac{\psi(B, c, \infty)}{\overline{T}(B, c, \infty)}. \tag{32}$$

In a stationary equilibrium, the measure of non-importers and the measure of importers must be constant over time. Thus total entry into distribution N must equal total exit from distribution N,

$$M_{En} + M_{SN} = \delta M_N + M_{SI} + M_{Ex}, \tag{33}$$

and total entry into distribution I must equal total exit from distribution I,

$$M_{SI} = \delta M_I + M_{SN}. \tag{34}$$

This implies that the total measure of each type is the difference between the entry and exit rates divided by δ. We assume that parameter values are such that all of the above measures are strictly positive.

Market-clearing conditions

Define aggregate use of the domestic input as

$$D = M_N \int_b^B d_N(x) g_N(x) dx + M_I \int_c^\infty d_I(x) g_I(x) dx . \tag{35}$$

Define aggregate use of the foreign input as

$$F = M_I \int_c^\infty f_I(x) g_I(x) dx . \tag{36}$$

Define aggregate output as

$$Y = M_N \int_b^B y_N(x) g_N(x) dx + M_I \int_c^\infty y_I(x) g_I(x) dx . \tag{37}$$

International balance of payments requires that

$$E = pF , \tag{38}$$

where E is the quantity of output that is exported. Tariff revenue is rebated to the consumer as a lump-sum transfer, so

$$\mathrm{T} = \tau pF . \tag{39}$$

Aggregate profits are

$$\Pi = M_N \int_b^B \pi_N(x) g_N(x) dx + M_I \int_c^\infty \pi_I(x) g_I(x) dx - \phi_{En} M_{En} - \phi_{SI} M_{SI} . \tag{40}$$

Clearing in the labor market requires that

$$M_N \int_b^B \ell_N(x) g_N(x) dx + M_I \int_c^\infty \ell_I(x) g_I(x) dx = \bar{L} . \tag{41}$$

Finally, clearing in the goods market requires that

$$C + D + E + \phi_N M_N + \phi_I M_I + \phi_{En} M_{En} + \phi_{SI} M_{SI} = Y . \tag{42}$$

Equilibrium

A *stationary competitive small open economy equilibrium* is a list of aggregate measures $\hat{C}$, $\hat{E}$, $\hat{F}$, $\hat{D}$, $\hat{Y}$, $\hat{M}_N$, $\hat{M}_I$, $\hat{M}_{En}$, $\hat{M}_{Ex}$, $\hat{M}_{SI}$, and $\hat{M}_{SN}$; a transfer $\hat{\mathrm{T}}$; profits $\hat{\Pi}$; a wage $\hat{w}$; firm decision rules $\hat{y}_N(x)$, $\hat{\pi}_N(x)$, $\hat{\ell}_N(x)$, $\hat{d}_N(x)$, $\hat{y}_I(x)$, $\hat{\pi}_I(x)$, $\hat{\ell}_I(x)$,

$\hat{d}_I(x)$, $\hat{f}_I(x)$, $\hat{b}$, $\hat{c}$, $\hat{B}$, $\hat{v}_N(x)$, $\hat{v}_I(x)$, $\hat{r}_N(x,b,B)$, $\hat{r}_I(x,c)$, $\hat{\bar{v}}_N(x;b,c,B)$, $\hat{\bar{v}}_I(x;b,c,B)$; and stationary distributions $\hat{g}_N(x)$ and $\hat{g}_I(x)$ such that (1)-(17), (20)-(21), and (24)-(42) hold.

The following is an algorithm to calculate the equilibrium. Taking w as given, solve for $\hat{\ell}_N(x)$ and $\hat{d}_N(x)$ using (4) and (5); solve for $\hat{\ell}_I(x)$, $\hat{d}_I(x)$, and $\hat{f}_I(x)$ using (8)-(10); calculate $\hat{y}_N(x)$, $\hat{\pi}_N(x)$, $\hat{y}_I(x)$, and $\hat{\pi}_I(x)$ using (2), (3), (6), and (7); calculate $\hat{r}_N(x,b,B)$ and $\hat{r}_I(x,c)$ using (16) and (17); solve for $\hat{\bar{v}}_N(x;b,c,B)$ and $\hat{\bar{v}}_I(x;b,c,B)$ using (20) and (21); solve for $\hat{b}$, $\hat{c}$, and $\hat{B}$ using (26); and solve for $\hat{v}_N(x)$ and $\hat{v}_I(x)$ using (24) and (25). Then solve for $\hat{w}$ using (27). Taking M_{En} as given, solve for $\hat{M}_{Ex}$, $\hat{M}_{SI}$, and $\hat{M}_{SN}$ using (30)-(32); solve for $\hat{M}_N$ and $\hat{M}_I$ using (33) and (34); and solve for $\hat{g}_N(x)$ and $\hat{g}_I(x)$ using (28) and (29). Then solve for $\hat{M}_{En}$ using (41). Finally, calculate $\hat{C}$, $\hat{Y}$, $\hat{E}$, $\hat{F}$, $\hat{D}$, $\hat{\mathrm{T}}$, and $\hat{\Pi}$ using (1), (35)-(39), and (40). By Walras's Law, the remaining market-clearing condition (42) holds.

Further assumptions

Here we specify the stochastic process, functional forms for the production technologies, and restrictions on the costs and benefits of importing.

Stochastic process

We let each firm's efficiency evolve as a geometric Brownian motion with drift:

$$\frac{dX(t)}{X(t)} = \mu dt + \sigma dW(t). \tag{43}$$

Here $dX(t)/X(t)$ is the percentage change in a firm's efficiency at time t. It is the sum of a deterministic trend, μdt, and a stochastic shock, $\sigma dW(t)$. The parameter σ, $\sigma > 0$, determines the relative magnitude of the shock and $W(t)$ is a Weiner process satisfying

$$W(t) = \varepsilon\sqrt{t}, \tag{44}$$

where ε is a standard normal random variable. The first two moments of a Weiner process are $E\left(W(t)\right)=0$ and $E\left(W(t)^2\right)=t$, so $dX(t)/X(t)$ is normally distributed with mean μdt and variance $\sigma^2 dt$. In order to obtain a stationary distribution, we assume that $\rho+\delta>\mu$.

Geometric Brownian motion is a continuous-time Markov process with independent relative increments. That is, for any times t and s, $t>s$, $dX(t)/X(t)-dX(s)/X(s)$ is an independent random variable that is normally distributed with mean $\mu(t-s)$ and variance $\sigma^2(t-s)$. An advantage of using geometric Brownian motion is that it generates simple analytic expressions for the functions $\psi(x,z,Z)$, $\Psi(x,z,Z)$, $\tilde{\psi}(x,z,Z)$, $\tilde{\Psi}(x,z,Z)$, $\overline{T}(x,z,Z)$, $L(\xi;x,z,Z)$, and $\tilde{L}(\xi;x,z,Z)$. We provide the formulas in Appendix 1.

Functional forms for production technologies

Here we specify functional forms for the constant-returns-to-scale components of the production functions, Ω_N in (2) and Ω_I in (6). Let

$$\Omega_N(\ell,d)=\ell^{\alpha}d^{1-\alpha} \tag{45}$$

$$\Omega_I(\ell,d,f)=\ell^{\alpha}\left(\omega d^{\theta}+(1-\omega)f^{\theta}\right)^{\frac{1-\alpha}{\theta}}, \tag{46}$$

where $0<\alpha<1$, $0<\omega<1$, and $\theta<1$. With this specification, the elasticity of substitution between labor and intermediate goods is one for all firms, with α being the share of expenditure on labor.[2] For importers, the elasticity of substitution between domestically produced intermediate goods and imported intermediate goods is $1/(1-\theta)$. We can think of an importer with efficiency x as using a composite intermediate good, the quantity of which is given by

$$z_I(x)=\left(\omega d_I(x)^{\theta}+(1-\omega)f_I(x)^{\theta}\right)^{1/\theta}. \tag{47}$$

The composite intermediate good has price

[2] In the manufacturing plant data used in this paper, the share of expenditure devoted to labor is roughly constant over the sample period, 2001 to 2006. This is consistent with our choice of Cobb-Douglas production functions.

$$P=\left(\omega^{\frac{1}{1-\theta}}+(1-\omega)^{\frac{1}{1-\theta}}\left((1+\tau)p\right)^{-\frac{\theta}{1-\theta}}\right)^{-\frac{1-\theta}{\theta}}. \quad (48)$$

Given these functional forms, the static decisions of firms have simple analytic expressions. We provide them in Appendix 2.

Costs and benefits of importing

Here we discuss the costs and benefits of importing and place further restrictions on parameters. In the model, the costs of importing are fixed costs, while the benefits of importing depend on a firm's scale of operation.

First consider the benefits of importing. We suppose that, in the absence of any additional fixed costs of importing, every firm would choose to be an importer. With functional forms (45) and (46), we define the *benefit of importing* as

$$\beta=\eta P^{-\frac{(1-\alpha)\nu}{1-\nu}}, \quad (49)$$

where $\beta>1$. A firm that operates technology I has employment, output, expenditure on intermediate goods, and variable profits greater by a factor of β than if it operated technology N at the same efficiency level. As (49) shows, the benefit of importing is determined by a combination of the relative efficiency of technology I, as given by η, and the relative cost of intermediate inputs, as given by P.

Now consider the costs of importing. We assume that ϕ_I is sufficiently greater than ϕ_N that $b<c$. We also assume that $\phi_{SI}>0$, so $c<B$. The value functions then imply that

$$v_N(b)=0 \quad (50)$$

$$v_N(c)=v_I(c) \quad (51)$$

$$v_N(B)=v_I(B)-\phi_{SI}. \quad (52)$$

For a firm with efficiency $x\in(c,B)$, the optimal choice of technology is *history-dependent*, or exhibits *hysteresis*.

Extreme cases

In order to evaluate the relative importance of start-up and continuation costs of trade, we also consider two extreme cases. In the first extreme case, we suppose that there is a start-up cost of trade but no additional continuation cost of trade. That is, $\phi_{SI} > 0$ and $\phi_N = \phi_I = \phi$. In this case, the endogenous ordering of cutoffs is $c < b < B$.

In the second extreme case, we suppose that the fixed cost of operating technology I is greater than that of operating technology N, but that there is no start-up cost of trade. That is, $\phi_{SI} = 0$ and $\phi_I > \phi_N$. In this case, $c = B$. We assume that ϕ_I is sufficiently greater than ϕ_N that the ordering of cutoffs is $b < B$.

These extreme cases also have advantages in that we can obtain certain analytic expressions for cutoffs that we cannot in the benchmark model, where the dynamics are more complex. In the first extreme case, we can obtain an analytic expression for c, the cutoff for operating as an importer. Once a firm starts using technology I it will never switch back to using technology N. The value function of an importer with efficiency x is simply

$$v_I(x) = \max_c r_I(x,c). \tag{53}$$

We can analytically solve $\partial r_I / \partial c = 0$ to obtain

$$c = \frac{\tilde{\lambda}_2 - 1}{\tilde{\lambda}_2} \frac{A\phi}{\beta}, \tag{54}$$

where $\tilde{\lambda}_2$, $\tilde{\lambda}_2 > 1$, and A are defined in the appendices. It is worthwhile to compare this cutoff to the cutoff that would arise in the absence of uncertainty. If firms' efficiencies were held fixed over time, the operating cutoff for importers would be given by the solution to $\pi_I(c) = 0$, which is $c = A\phi / \beta$. Comparing this with (54), we see that, since $(\tilde{\lambda}_2 - 1)/\tilde{\lambda}_2 < 1$, in the presence of uncertainty a firm is willing to operate with negative profits for awhile in the hope that its efficiency will eventually increase. As we would expect, the cutoff given by (54) is decreasing in σ.

In the second extreme case, we can obtain an analytic expression for B, as the cutoff for importing is no longer a dynamic decision but a simple static decision. At every instant, a firm simply compares the profits from operating technology N with those from operating technology I. We solve $\pi_N(B) = \pi_I(B)$ to get the cutoff for importing:

$$B = \frac{A(\phi_I - \phi_N)}{\beta - 1}. \tag{55}$$

In this case, whether technology N or I is used depends only on x and is not history-dependent.

Quantitative analysis

In this section we examine the extent to which the model can quantitatively capture important features of the data, particularly the data on Chilean manufacturing plants discussed above. We calibrate the model and use it to quantitatively analyze the effects of unilateral trade liberalization.

Calibration

We calibrate the model to closely match important facts from the Chilean manufacturing data discussed above. Some parameters are simply normalized or are taken from the literature, while others we specifically choose to match particular facts. We set the length of one unit of time as one year.

Since we are primarily interested in relative comparisons, we normalize a number of parameters. We normalize the labor endowment, $\bar{L}$, to one. We normalize the cost of entry, ϕ_{En}, to one so that all other fixed costs are relative to the cost of entry. We choose the terms of trade, p, so that $P = 1$. We set the initial efficiency draw, x_0, equal to one.

Some parameters we take from the literature. Following Atkeson and Kehoe (2005), we set the degree of diminishing returns faced by both technologies, ν, equal to 0.85. They find that this value closely matches plant-level data on U.S. manufacturing. We choose θ such that the elasticity of substitution between domestic and foreign intermediate inputs is 2 (Ruhl, 2004). We set the consumer's rate of time preference at 4 percent, a standard value for the real interest rate.

The World Bank estimates that Chile's average tariff rate in 2001 was 8 percent. We set τ accordingly. Among plants that import, expenditure on imported intermediate goods as a share of total expenditure on intermediate goods is 34 percent. We set the parameter ω to match this. In the model, α is expenditure on labor as a share of expenditure on both labor and intermediate goods. In the data this share is 0.35. In the data, the rate of exit for importers is 9 percent. In our model, this corresponds to the rate of exogenous exit, so we set $\delta = 0.09$.

Then, given a value for η, we can simultaneously choose the values of μ, σ, b, c, and B to match the following five facts: (i) the averge rate of entry and exit is 12.45 percent, (ii) the total rate at which firms switch import status is 5.2 percent; (iii) the share of firms that import is 20 percent, (iv) the average importer has output of 3.6 times that of the average non-importer, and (v) the coefficient of variation for gross output is 6.0. Since b, c, and B are equilibrium objects, we use the first-order conditions from a firm's problem to find the corresponding parameter values for ϕ_N, ϕ_I, and ϕ_{SI}. To obtain a value for η, we iterate using the above procedure until importers have value added per worker of 1.2 times that of non-importers. Table 3 summarizes the entire calibration, while Table 4 shows the extent to which the model captures the above six targets. Tables 5 and 6 revisit the data discussed earlier and make comparisons with the model.

Experiments using the benchmark calibration

We consider two forms of trade liberalization: a decrease in the *ad valorem* tariff rate and an improvement in the terms of trade. Comparing stationary equilibria allows us to analyze the long-term effects of trade liberalization. Decreases in τ and p have similar qualitative effects. The main difference is in how they affect government revenue. A decrease in τ or p (i) increases the cutoff to operate, b; (ii) decreases the cutoff to start importing, B; (iii) decreases the cutoff to stop importing, c; (iv) decreases the measure of entrants, M_{En}; (v) increases the wage, w; (vi) increases social welfare, C; and (vii) increases output, Y.

A decrease in τ or p both increase the benefit to importing. First, we lower the tariff rate from 8 percent to 7 percent. Next we consider an equivalent improvement in the terms of trade (an approximately 1 percent decrease in p). Table 7 reports percentage changes for statistics of interest. Both experiments have similar quantitative effects. While both forms of trade liberalization increase social welfare the increase is greater for the terms of trade improvement. Reductions in the tariff rate decrease the percentage of revenue that is rebated back to the consumer. In both experiments 30 percent of firms choose to import. Both experiments result in a large increase in trade: the quantity of imports increases by 28.2 percent. The majority of this increase is due to changes in the extensive margin.

The third experiment reduces the cost of importing ϕ_I ,while leaving the benefit unchanged. To make this experiment comparable to the previous two we reduced the fixed cost of importing such that the same share of firms choose to import as in the trade liberalization experiments. This involves a 2 percent reduction in the fixed cost of importing. The start-up cost was left unchanged. Table 7 reports percentage changes for statistics of interest. Reductions in the cost to import generally have smaller impacts than an increase in the benefit of importing. However, the increase in real GDP is larger for a reduction in the fixed costs, since a smaller portion of output required for payment of fixed costs.

Trade liberalization reallocates resources from non-importers to importers. As a result, importers become larger on average and the least efficient firms are forced to exit. Greater output per unit of labor leads to an increase in average efficiency. Trade liberalization drives out the least efficient firms because they can no longer profitably operate at the higher wage, while the most efficient non-importers upgrade to the superior technology, since the benefit of using it has increased.

Conclusion

We have developed a dynamic general equilibrium model of importing by firms. More broadly, we have developed a model of the dynamics of technology adoption when there are start-up and continuation costs. The model is analytically tractable and easily generalizable. The model qualitatively and quantitatively captures the dynamics of importing by firms and the effects of trade liberalization.

The framework developed here could be extended in many ways. We only consider a stationary equilibrium, but the role of sunk costs in the presence of aggregate shocks is a fruitful area for future research. We consider only a firm's decision to import, but adding the decision to export would be an interesting extension. Given that firms use imported intermediate goods with varying intensities, allowing for more than one import technology would also be a worthwhile extension.

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Table 1. Importer premia

Statistic	Ratio of average importer to average non-importer
Gross output	3.6
Total materials	3.4
Employment	3.1
Value added	3.9
Value added per worker	1.3

Table 2. Transition probabilities (%)

	Importer	Non-importer	Exit
Importer	77	14	9
Non-importer	3	84	13
Exit	0	0	100

Table 3. Summary of the calibration

Parameters	Values	Explanations
$\bar{L}$	1	Normalization
ϕ_{En}	1	Normalization
p	0.1	Normalization to get $P = 1$
x_0	1	Normalization
ρ	0.04	Real interest rate of 4%
ν	0.85	Atkeson and Kehoe (2005)
θ	0.5	Ruhl (2004)
τ	0.08	World Bank's World dataBank
δ	0.09	Rate of exit of importers
α	0.35	Expenditure on labor as a share of total expenditure on labor and intermediate goods
ω	0.81	Importers' expenditure on imported intermediate goods as a share of total expenditure on intermediate goods of 0.34
μ, σ, η, ϕ_N, ϕ_I, ϕ_{SI}	-0.1, 0.54, 1.15, 0.25, 0.33, 0.01	Jointly chosen to minimize discrepancy with the set of facts in Table 4

Table 4. Calibration targets

Statistic	Data	Model
Total rate of exit (%)	12.45	12.45
Share of plants that import (%)	20	20
Gross output of average importer relative to gross output of average non-importer	3.6	3.6
Total rate at which plants switch import status (%)	5.2	5.2
Coefficient of variation for gross output	6.0	6.0
Value-added per worker of average importer relative to value-added per worker of average non-importer	1.2	1.2

Table 5. Model vs. data (static)

Statistic	Ratio of average importer to average non-importer	
	Data	Model
Gross output	3.6	3.6
Total materials	3.4	3.6
Employment	3.1	3.6
Value added	3.9	4.3
Value added per worker	1.2	1.2

Table 6. Model vs. data (dynamic)

Data

	Importer	**Non-importer**	**Exit**
Importer	77	14	9
Non-importer	3	84	13

Model

	Importer	**Non-importer**	**Exit**
Importer	83	9	9
Non-importer	4	83	13

Table 7. Three experiments

Statistic	**Tariff reduction** (% change)	**Terms-of-trade improvement** (% change)	**Fixed-cost reduction** (% change)
Welfare	2.4	2.7	2.5
Wage	0.4	0.4	0.2
Measure of entrants	−4.5	−4.5	−4.7
Output	0.4	0.4	0.2
Tariff revenue	12.2	27.0	24.7
Real GDP	1.5	1.5	1.9
Price of composite intermediate	−0.3	−0.3	0.0
Imports	28.2	28.2	24.7
Technological efficiency	10.5	10.5	9.5
Benefit of importing	1.2	1.2	0.0

Figure 1. Firm distributions

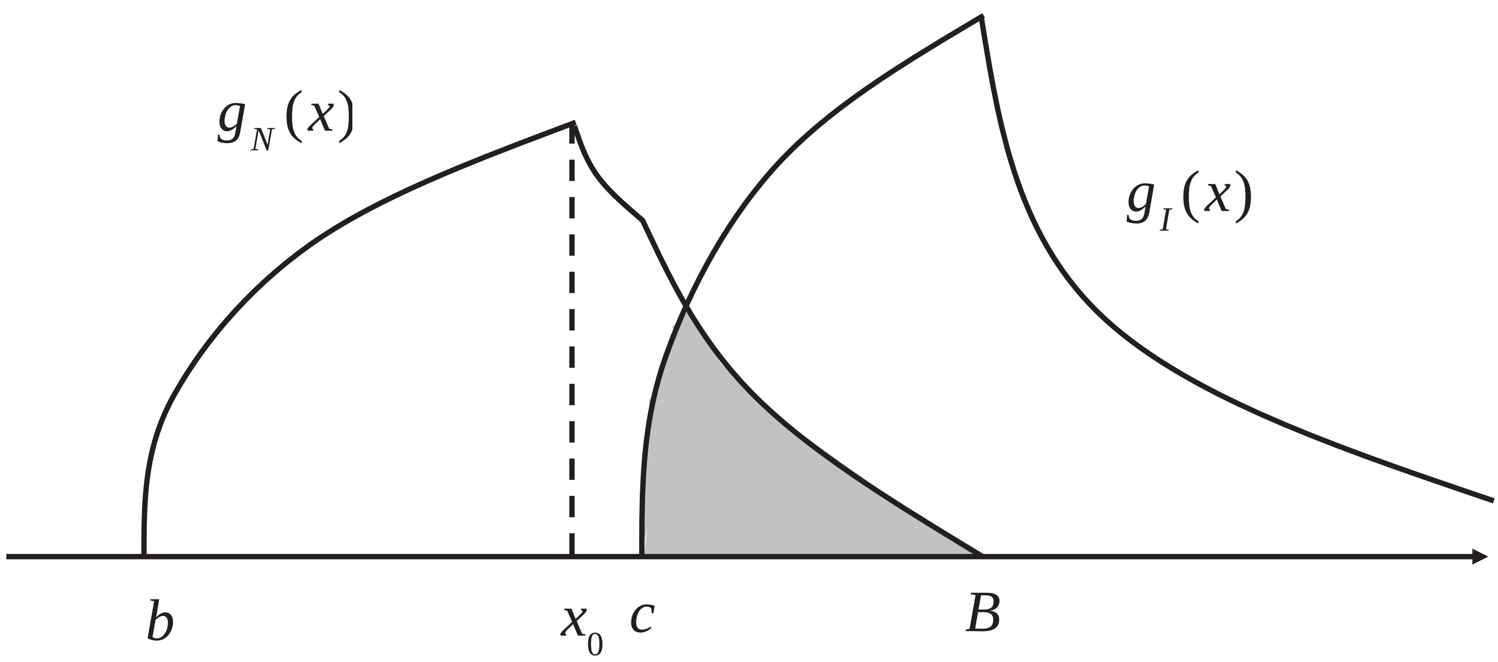
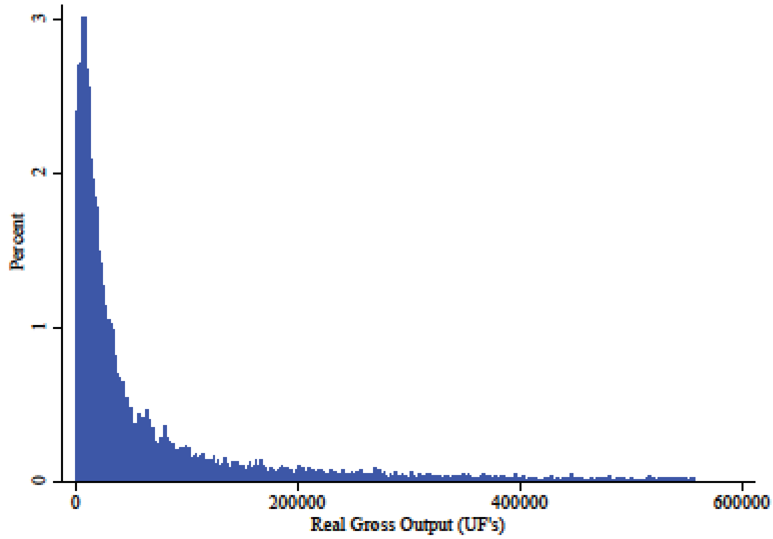


Figure 2. Firm size distribution in the data



Appendix 1. Formulas with geometric Brownian motion

Consider a firm with efficiency $x \in (z, Z)$. Suppose that the firm's efficiency evolves according to a geometric Brownian motion $X(t)$, where

$$\frac{dX(t)}{X(t)} = \mu dt + \sigma dW(t), \tag{56}$$

where $\mu \neq \sigma^2 / 2$. Eventually the firm will face an adjustment, meaning that one of three events will occur: (i) the firm's efficiency will reach z, (ii) the firm's efficiency will reach Z, or (iii) the firm will exogenously die. Let $T(x, z, Z)$ be the random variable for the first time that adjustment (i) or (ii) occurs. Let

$$J = \sqrt{(\mu - \sigma^2 / 2)^2 + 2\delta\sigma^2} \tag{57}$$

$$\lambda_1 = -\frac{(\mu - \sigma^2 / 2) + J}{\sigma^2} \tag{58}$$

$$\lambda_2 = \frac{-(\mu - \sigma^2 / 2) + J}{\sigma^2} \tag{59}$$

$$\tilde{J} = \sqrt{(\mu - \sigma^2 / 2)^2 + 2(\rho + \delta)\sigma^2} \tag{60}$$

$$\tilde{\lambda}_1 = -\frac{(\mu - \sigma^2 / 2) + \tilde{J}}{\sigma^2} \tag{61}$$

$$\tilde{\lambda}_2 = \frac{-(\mu - \sigma^2 / 2) + \tilde{J}}{\sigma^2}. \tag{62}$$

The probability that adjustment (i) occurs first is

$$\begin{aligned} \psi(x, z, Z) &= E\left(e^{-\delta T(x,z,Z)}\right) \Pr\left(X\left(T(x, z, Z)\right) = z\right) \\ &= \frac{x^{\lambda_1} Z^{\lambda_2} - Z^{\lambda_1} x^{\lambda_2}}{z^{\lambda_1} Z^{\lambda_2} - Z^{\lambda_1} z^{\lambda_2}} \end{aligned}. \tag{63}$$

The probability that adjustment (ii) occurs first is

$$\begin{aligned} \Psi(x, z, Z) &= E\left(e^{-\delta T(x,z,Z)}\right) \Pr\left(X\left(T(x, z, Z)\right) = Z\right) \\ &= \frac{z^{\lambda_1} x^{\lambda_2} - x^{\lambda_1} z^{\lambda_2}}{z^{\lambda_1} Z^{\lambda_2} - Z^{\lambda_1} z^{\lambda_2}} \end{aligned}. \tag{64}$$

Taking into account the consumer's subjective discount factor, the expected discounted value of the indicator function for the event of adjustment (i) occurring first is

$$\tilde{\psi}(x,z,Z) = E\left(e^{-\rho T(x,z,Z)}\right)\psi(x,z,Z) = \frac{x^{\tilde{\lambda}_1}Z^{\tilde{\lambda}_2} - Z^{\tilde{\lambda}_1}x^{\tilde{\lambda}_2}}{z^{\tilde{\lambda}_1}Z^{\tilde{\lambda}_2} - Z^{\tilde{\lambda}_1}z^{\tilde{\lambda}_2}}. \tag{65}$$

The expected discounted value of the indicator function for the event of adjustment (ii) occurring first is

$$\tilde{\Psi}(x,z,Z) = E\left(e^{-\rho T(x,z,Z)}\right)\Psi(x,z,Z) = \frac{z^{\tilde{\lambda}_1}x^{\tilde{\lambda}_2} - x^{\tilde{\lambda}_1}z^{\tilde{\lambda}_2}}{z^{\tilde{\lambda}_1}Z^{\tilde{\lambda}_2} - Z^{\tilde{\lambda}_1}z^{\tilde{\lambda}_2}}. \tag{66}$$

The expected time until adjustment is

$$\bar{T}(x,z,Z) = E\left(e^{-\delta T(x,z,Z)}T(x,z,Z)\right) = \frac{1}{\delta}\left(1 + \frac{x^{\lambda_1}z^{\lambda_2} - x^{\lambda_1}Z^{\lambda_2} + Z^{\lambda_1}x^{\lambda_2} - z^{\lambda_1}x^{\lambda_2}}{z^{\lambda_1}Z^{\lambda_2} - Z^{\lambda_1}z^{\lambda_2}}\right). \tag{67}$$

For $\xi \in (z,Z)$, the expected local time function is

$$L(\xi;x,z,Z) = \begin{cases} \frac{1}{\xi J}\left(\left(\frac{x}{\xi}\right)^{\lambda_1} - \Psi(x,z,Z)\left(\frac{Z}{\xi}\right)^{\lambda_1} - \psi(x,z,Z)\left(\frac{z}{\xi}\right)^{\lambda_2}\right) & \text{if } z \le \xi \le x \\ \frac{1}{\xi J}\left(\left(\frac{x}{\xi}\right)^{\lambda_2} - \Psi(x,z,Z)\left(\frac{Z}{\xi}\right)^{\lambda_1} - \psi(x,z,Z)\left(\frac{z}{\xi}\right)^{\lambda_2}\right) & \text{if } x \le \xi \le Z \end{cases}. \tag{68}$$

The expected discounted local time function is the counterpart to (69) after taking into account the consumer’s rate of time preference. It is given by

$$\tilde{L}(\xi;x,z,Z) = \begin{cases} \frac{1}{\xi \tilde{J}}\left(\left(\frac{x}{\xi}\right)^{\tilde{\lambda}_1} - \tilde{\Psi}(x,z,Z)\left(\frac{Z}{\xi}\right)^{\tilde{\lambda}_1} - \tilde{\psi}(x,z,Z)\left(\frac{z}{\xi}\right)^{\tilde{\lambda}_2}\right) & \text{if } z \le \xi \le x \\ \frac{1}{\xi \tilde{J}}\left(\left(\frac{x}{\xi}\right)^{\tilde{\lambda}_2} - \tilde{\Psi}(x,z,Z)\left(\frac{Z}{\xi}\right)^{\tilde{\lambda}_1} - \tilde{\psi}(x,z,Z)\left(\frac{z}{\xi}\right)^{\tilde{\lambda}_2}\right) & \text{if } x \le \xi \le Z \end{cases}. \tag{69}$$

Appendix 2. Analytic expressions for equilibrium objects

Taking as given the cutoffs, b, c, and B; the wage, w; and the measure of entrants, M_{En}, we analytically solve for the rest of the equilibrium objects. Let

$$P = \left(\omega^{\frac{1}{1-\theta}} + (1-\omega)^{\frac{1}{1-\theta}} \left((1+\tau) p \right)^{-\frac{\theta}{1-\theta}} \right)^{-\frac{1-\theta}{\theta}} \tag{70}$$

$$\beta = \eta P^{-\frac{(1-\alpha)\nu}{1-\nu}} \tag{71}$$

$$A = \frac{w^{\frac{\alpha\nu}{1-\nu}}}{\alpha^{\frac{\alpha\nu}{1-\nu}} (1-\alpha)^{\frac{(1-\alpha)\nu}{1-\nu}} \nu^{\frac{\nu}{1-\nu}} (1-\nu)} . \tag{72}$$

Taking the wage as given, firms' static decisions are

$$\ell_N(x) = \frac{x\alpha\nu}{A(1-\nu)w} \tag{73}$$

$$d_N(x) = \frac{x(1-\alpha)\nu}{A(1-\nu)} \tag{74}$$

$$y_N(x) = \frac{x}{A(1-\nu)} \tag{75}$$

$$\pi_N(x) = \frac{x}{A} - \phi_N \tag{76}$$

$$\ell_I(x) = \frac{x\beta\alpha\nu}{A(1-\nu)w} \tag{77}$$

$$d_I(x) = \frac{x\beta(1-\alpha)\nu\omega^{\frac{1}{1-\theta}} P^{\frac{\theta}{1-\theta}}}{A(1-\nu)} \tag{78}$$

$$f_I(x) = \frac{x\beta(1-\alpha)\nu(1-\omega)^{\frac{1}{1-\theta}} \left((1+\tau) p \right)^{-\frac{1}{1-\theta}} P^{\frac{\theta}{1-\theta}}}{A(1-\nu)} \tag{79}$$

$$y_I(x) = \frac{x\beta}{A(1-\nu)} \tag{80}$$

$$\pi_I(x) = \frac{x\beta}{A} - \phi_I . \tag{81}$$

Taking the cutoffs, wage, and measure of entrants as given, it is straightforward to calculate the rest of the equilibrium objects using the formulas in Appendix 1:

$$r_N(x,b,B) = \int_b^B \tilde{L}(\xi; x,b,B)\pi_N(\xi)d\xi \tag{82}$$

$$r_I(x,c) = \int_c^\infty \tilde{L}(\xi; x,c,\infty)\pi_I(\xi)d\xi \tag{83}$$

$$\overline{v}_N(x;b,c,B) = r_N(x,b,B) + \tilde{\Psi}(x,b,B)\frac{r_I(B,c) + \tilde{\psi}(B,c,\infty)r_N(c,b,B) - \phi_{SI}}{1 - \tilde{\psi}(B,c,\infty)\tilde{\Psi}(c,b,B)} \tag{84}$$

$$\overline{v}_I(x;b,c,B) = r_I(x,c) + \tilde{\psi}(x,c,\infty)\frac{r_N(c,b,B) + \tilde{\Psi}(c,b,B)\left(r_I(B,c) - \phi_{SI}\right)}{1 - \tilde{\psi}(B,c,\infty)\tilde{\Psi}(c,b,B)} \tag{85}$$

$$M_{SI} = \frac{M_{En}\dfrac{\Psi(x_0,b,B)}{\overline{T}(x_0,b,B)}}{1 - \dfrac{\psi(B,c,\infty)}{\overline{T}(B,c,\infty)}\dfrac{\Psi(c,b,B)}{\overline{T}(c,b,B)}} \tag{86}$$

$$M_{SN} = M_{SI}\frac{\psi(B,c,\infty)}{\overline{T}(B,c,\infty)} \tag{87}$$

$$M_{Ex} = M_{En}\frac{\psi(x_0,b,B)}{\overline{T}(x_0,b,B)} + M_{SN}\frac{\psi(c,b,B)}{\overline{T}(c,b,B)} \tag{88}$$

$$M_N = \frac{M_{En} + M_{SN} - M_{SI} - M_{Ex}}{\delta} \tag{89}$$

$$M_I = \frac{M_{SI} - M_{SN}}{\delta} \tag{90}$$

$$g_N(x) = \frac{M_{En}}{M_{En} + M_{SN}}\frac{L(x;x_0,b,B)}{\overline{T}(x_0,b,B)} + \frac{M_{SN}}{M_{En} + M_{SN}}\frac{L(x;c,b,B)}{\overline{T}(c,b,B)} \tag{91}$$

$$g_I(x) = \frac{L(x;B,c,\infty)}{\overline{T}(B,c,\infty)}. \tag{92}$$