Imported inputs, irreversibility, and international trade dynamics ☆

Ananth Ramanarayanan

University of Western Ontario, Department of Economics, 4071 Social Science Centre, London, Ontario N6A 5C2, Canada

ARTICLE INFO

ABSTRACT

In aggregate data, international trade volumes adjust slowly in response to relative price changes, an observation at odds with static models. This paper develops a model of trade in intermediate inputs in which heterogeneous producers face irreversibilities in adjusting their importing status. Changes in aggregate imports are accounted for by adjustment within importing plants, through reallocation between non-importers and importers, and through changes in the importing decisions of new and existing plants. When calibrated to Chilean plant-level data, the model shows that irreversibilities are important for generating aggregate and plant-level dynamics of trade flows in line with the data. In response to a permanent trade reform, increased importing at existing plants crowds out entry, raising consumption above its long-run level, and leading to welfare gains larger than a static model would imply.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Intermediate goods comprise the bulk of international merchandise trade for many of the world's industrial economies. At the level of individual producers, there is substantial heterogeneity in the use of imported intermediate inputs: relatively few producers use imported inputs, and those that do are larger and more productive than those that do not. In addition, plants switch into and out of importing over time, suggesting that importing is a dynamic decision.[1] These cross-sectional and dynamic patterns of plant-level importing are important for understanding how aggregate trade volumes respond to shocks, and for quantifying the welfare gains from trade.

This paper develops a dynamic model in which heterogeneous plants choose whether to import some of their inputs. Importing expands the variety of imperfectly substitutable inputs used in

production, as in the models of Ethier (1982) and Romer (1990), and so raises plant-level productivity, but involves paying an up-front sunk cost as well as a per-period fixed cost. Plants receive idiosyncratic, persistent shocks to their technology, so plants that receive a sufficiently good shock expect to be profitable enough to cover the sunk cost to start importing or the fixed cost to continue importing. In addition, the decision to import or not is partly irreversible. Each period, a plant faces some probability that it will be able to switch its status (importing or not importing), and otherwise it remains in its previous status. The combination of sunk and fixed costs of importing, along with the partial irreversibility, is quantitatively important for capturing the plant-level and aggregate dynamics of trade flows in the data. These features also have important welfare implications; plant-level decisions induce transition dynamics that make the welfare gain from an import price reduction higher than it would be in a static model.

In the model, movements in aggregate trade flows are shaped by four margins of adjustment. In response to a drop in the price of imports, first, importing plants purchase more imports relative to domestic goods; second, importing plants become more profitable, so they grow relative to nonimporting plants. To the extent that the price change is persistent, the third and fourth margins are that a higher fraction of previously nonimporting plants switch to importing, and a higher fraction of new entrants choose to import. Quantifying these margins provides a measure of plant-level contributions to changes in aggregate trade flows. I calibrate the model to reproduce key cross-sectional moments in Chilean plant-level data, and use a

---

[1] Detailed statistics are provided below and also in Kasahara and Lapham (2013) for Chile. Similar findings are reported in Kurz (2006) for the US; Amiti and Konings (2007) for Indonesia; Biscourp and Kramarz (2007) for France; and Halpern et al. (2015) for Hungary.

decomposition of short-run fluctuations in aggregate trade flows into these four margins to highlight the importance of irreversibilities.

In the absence of irreversibilities (plants are free to start or stop importing subject to the fixed costs), the switching margin accounts for about half of the annual fluctuations in aggregate trade flows, which is far more than in the Chilean data. This large contribution of importing decisions to trade growth cumulates over longer time horizons, and the long-run growth in trade is significantly higher than in the data: the model generates long-run trade growth about twice as large as that observed in the data in response to the persistent import price declines in Chile over the past 40 years. Introducing irreversibilities improves the predictions of the model. The gap between the model and the data in the contribution of switching to aggregate import growth is reduced by about two thirds. The long-run growth in trade flows in the model with irreversibilities matches the magnitude in the data well, since the growth in the fraction of plants importing is relatively limited.

The dynamics of trade growth and plant decisions following a permanent reduction in import prices has important consequences for welfare. A drop in the relative price of imports induces more existing plants to start importing, and fewer plants to enter. This is because it is cheaper in expected value for an existing plant to pay the cost to import than for a new plant to pay the sunk cost of entry, with some probability of importing in the future. Since importing raises the value added that plants can produce for given expenditure on intermediate inputs, the increase in importing activity raises resources available for consumption above the new long-run level, so that the welfare gain from trade liberalization is significantly larger than it would be from a static comparison of two steady states. With irreversibilities, this effect is dampened, so the gap between the welfare gain and the steady state comparison of utility is reduced, by about half.

In the presence of sunk costs, plants' decisions respond differently to temporary and permanent shocks, which, as in Ruhl (2008), generates an aggregate elasticity of substitution between imports and domestic goods (Armington elasticity) that is higher in the long-run than the short-run.[2] In the model without irreversibilities, the short-run Armington elasticity is just above 3, while adding irreversibilities reduces it to about 2.6, both within the range of estimates from the aggregate Chilean data and from the literature.[3] In response to a permanent trade liberalization, both models generate a long-run Armington elasticity that is larger than the short-run elasticity. The main contribution of this paper relative to Ruhl (2008) is to show that the partial irreversibility, in addition to sunk and fixed costs of importing, is required to bring the plant-level dynamics in line with data, and to better account for the long-run response of trade flows to relative price changes. When the model without irreversibilities is calibrated so that the average amount of plant-level switching in response to idiosyncratic shocks matches the data, there is too much variation in switching in response to aggregate shocks, and this results in overpredicting the long-run growth in trade flows.

This paper is also related to recent work on the transition dynamics of aggregate trade flows in models with heterogeneous producers but without aggregate fluctuations. Burstein and Melitz (2013) review this literature, and highlight the non-trivial transition dynamics in a model with firm-level exporting and innovation decisions, as in Atkeson and Burstein (2010). Alessandria and Choi (2014) also study the transition path following trade liberalization in a model in which producer-level efficiency evolves exogenously

over time, while Alessandria et al. (2015) model the costs of exporting in more detail to account for firm-level export growth patterns. These papers also find that the welfare gain from trade taking into account the transition differs from a comparison of steady states.

The key assumptions behind the model's prediction that only few, large plants use imported inputs are that importing raises productivity and that importing involves fixed costs. The assumption that importing raises productivity is consistent with the literature: studies estimating plant-level production functions find evidence that importing raises plant-level productivity, controlling for other sources of heterogeneity (for example, Kasahara and Rodrigue, 2008; Halpern et al., 2015; and Goldberg et al., 2010). In my model, importing expands the variety of inputs used in production, which generates a productivity gain that depends on how substitutable inputs are in production, so the estimates of this productivity gain in the literature provide guidance in choosing the elasticity of substitution at the plant level.[4] Given that there are gains to importing, then the fact that few plants use imported inputs suggests that there are costs of doing so. Although there are no direct estimates of the fixed or sunk costs firms face to use imported inputs, I calibrate the costs necessary to match the fraction of plants that import and the fractions that start and stop importing in the Chilean data.

The partial irreversibility in the importing decision is crucial for accounting for the plant-level decomposition and long-run aggregate trade growth. I model irreversibilities in importing decisions by assuming that each period, a plant can only adjust its import status with some probability less than one. This assumption is meant as a stand-in for frictions that hamper adjustment in plants' input-sourcing decisions, such as time delays in negotiating with new suppliers, frictions in matching with international suppliers, or synchronization with other input or investment decisions. For example, Kasahara (2004), in Chilean plant data, finds evidence that a large change in the ratio of imports relative to domestic inputs at the plant level is associated with a large concurrent investment in physical capital, interpreted as the adoption of a new technology. I infer the size of the irreversibilities in my model using plant-level data on the characteristics of new and continuing importing plants relative to all importing plants, since the strength of the selection effect induced by fixed costs depends on how large the irreversibilities are.

The model in this paper is related to that in Kasahara and Lapham (2013), who consider both importing and exporting at the firm level. Their focus is on estimating parameters that determine firm-level importing and exporting decisions in a stationary aggregate environment, while my focus is on quantifying the effects of heterogeneity in importing on the dynamics of aggregate trade flows in response to shocks. Also closely related is Gopinath and Neiman (2014), who develop a model in which shocks to the price of imports change both the number of firms importing and the number of goods each firm imports. They use transaction-level customs data for importing firms to quantify the importance of each of these margins for aggregate trade and welfare. This paper differs in quantifying the importance of the reallocation of resources between importing and nonimporting plants, and the entry and exit of plants, for aggregate trade and welfare.

2. Model

The model consists of a small open economy in which production takes place in plants. Plants produce a homogeneous final good

---

[2] Like Ruhl (2008), Ghironi and Melitz (2005) and Alessandria and Choi (2007) develop dynamic models with fixed costs of exporting, but focus on the business cycle properties of these models. Alessandria et al. (2012) analyze a model in which the stock of exporting plants moves slowly over time, and generates a time-varying Armington elasticity.

[3] See Ruhl (2008) for a summary of the literature.

[4] There are alternative mechanisms by which importing may raise plant level productivity; for example, imports may be of higher quality than domestic inputs (see, e.g. Kugler and Verhoogen, 2009), or imports may provide close substitutes for domestic inputs at a cheaper price. Halpern et al. (2015) provide some evidence that increased variety from importing contributes more to the productivity gain from importing than higher quality for Hungarian plants.

using labor and a continuum of intermediate goods as inputs, and receive idiosyncratic shocks to their productive efficiency. Subject to a partial irreversibility, plants choose each period whether to use imported intermediate inputs or only domestically produced ones. Importing requires paying a fixed cost that depends on the plant's previous import status. Importing inputs provides a wider variety of imperfectly substitutable goods, which raises output and measured total factor productivity (TFP) for a given level of a plant's efficiency (Throughout, I use "efficiency" to refer to the exogenous idiosyncratic shocks plants receive, to distinguish it from TFP or "productivity", which is defined further below.). The idiosyncratic shocks to efficiency as well as aggregate shocks to the exogenous price of imports change the value of importing relative to not importing, and induce some plants to switch into and out of importing. Each period, some plants exogenously die, and new plants enter. A continuum of mass one of identical consumers own the plants, consume the final good they produce, and inelastically supply labor used in production.

2.1. Consumers

The preferences of a representative consumer are represented by the expected discounted present value of utility from consumption,

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\nu}}{1-\nu},$$

where $\beta \in (0,1)$ and $\nu > 0$, and C_t denotes consumption in period t.[5] The consumer is endowed with one unit of time each period, which is supplied inelastically, and ownership of all plants in the economy. The consumer's budget constraint in period t is

$$C_t \leq w_t + \Pi_t,$$

where w_t is the wage rate in units of domestic output in period t and Π_t is the aggregate profits of all plants operating in period t. There is no trade in financial markets.

2.2. Plants

Plants produce a homogenous final good using labor and a continuum of intermediate goods. Plants receive idiosyncratic efficiency shocks, consisting of a persistent component and a temporary component,

$$a_t = z_t + u_t,$$

where u_t is drawn i.i.d. across plants and over time from a distribution with density $f_u(u)$, and z_t is drawn i.i.d. across plants from a Markov process with conditional density $f_z(z_{t+1}|z_t)$.[6] There is aggregate uncertainty over the price of imports relative to domestic goods, p_t, which follows a Markov process with conditional density $f_p(p_{t+1}|p_t)$. This section first lays out the plant's static decisions each period, then sets up plants' dynamic decision.

2.2.1. Static profit maximization

A plant with efficiency a that uses N intermediate inputs in period t can produce output y of the homogeneous final good using labor and a continuum of intermediate inputs, labeled by ω, according to:

$$y_t = (e^a)^{1-\alpha-\theta} \ell_t^\alpha \left(\int_0^N x_t(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\theta \frac{\sigma}{\sigma-1}}, \tag{1}$$

where ℓ_t denotes labor input and $x_t(\omega)$ denotes units of intermediate input ω. Intermediates are combined with the constant elasticity of substitution $\sigma > 1$, and $\alpha + \theta < 1$. Final good plants all produce the same good, but since there are decreasing returns to scale in production, the economy has a nondegenerate distribution of plants, as in Lucas (1978).

This production technology is similar to that of Kasahara and Lapham (2013), and features gains from variety, as inputs are imperfectly substitutable. Importing and nonimporting plants differ in the range of intermediate inputs they use. Specifically, if a plant is not using imported inputs, then $N = n$, and if a plant uses imported inputs, then $N = n + n^*$. Here, n denotes the mass of domestically produced inputs, and n^* is the mass of foreign-produced inputs.

Domestic intermediate goods are produced using inputs of the final good. One unit of the final good can be used to produce one unit of any of the n domestic intermediate goods, so that all these goods have a price of 1 in units of the final good. Imported inputs of all n^* varieties have price p_t.

Plants are perfectly competitive, and maximize profits by choosing labor and intermediate inputs subject to the technology (Eq. (1)), taking as given the price p_t and the wage rate w_t. Since all domestic inputs have the same price and all imported inputs have the same price, and they enter the production function symmetrically, a plant will choose to use equal quantities of all domestic inputs and, if it imports, equal quantities of all imported inputs.[7] Therefore, it is convenient to restrict attention in the plants' problems to choices of the form:

$$x_t(\omega) = \begin{cases} d_t & \text{if } \omega \in [0,n] \\ m_t & \text{if } \omega \in (n, n+n^*] \end{cases}$$

so that the per-period profit for a nonimporting plant with efficiency a can be written:

$$\pi_{dt}(a) = \max_{\ell,d} (e^a)^{1-\alpha-\theta} \ell^\alpha n^{\frac{\theta\sigma}{\sigma-1}} d^\theta - w_t \ell - nd$$

while for an importing plant:

$$\pi_{mt}(a) = \max_{\ell,d,m} (e^a)^{1-\alpha-\theta} \ell^\alpha \left(nd^{\frac{\sigma-1}{\sigma}} + n^* m^{\frac{\sigma-1}{\sigma}} \right)^{\theta\frac{\sigma}{\sigma-1}} - w_t \ell - nd - p_t n^* m$$

where the subscripts d and m refer to nonimporting and importing plants, respectively.

Let $\ell_{dt}(a), d_{dt}(a)$ and $\ell_{mt}(a), d_{mt}(a), m_t(a)$ denote the optimal input choices a nonimporting or importing plant with efficiency a,

---

respectively in period t. For nonimporting plants, these are given by:

$$\ell_{dt}(a) = e^a \frac{\alpha}{w_t} h_{dt}^{1/(\alpha+\theta-1)}$$

$$d_{dt}(a) = e^a \frac{\theta}{n} h_{dt}^{1/(\alpha+\theta-1)}$$

$$y_{dt}(a) = e^a h_{dt}^{1/(\alpha+\theta-1)} \tag{2}$$

where

$$h_{dt} = \left(n^{1/(1-\sigma)}/\theta\right)^\theta (w_t/\alpha)^\alpha \tag{3}$$

is an index of input prices common to all nonimporting plants. Profits of a nonimporting plant are given by $\pi_{dt}(a) = (1 - \alpha - \theta)y_{dt}(a)$.

For importing plants, the optimal input and output decisions are:

$$\ell_{mt}(a) = e^a \frac{\alpha}{w_t} h_{mt}^{1/(\alpha+\theta-1)}$$

$$d_{mt}(a) = e^a \frac{\theta}{n + n^* p_t^{1-\sigma}} h_{mt}^{1/(\alpha+\theta-1)}$$

$$m_t(a) = d_{mt}(a) p_t^{-\sigma}$$

$$y_{mt}(a) = e^a h_{mt}^{1/(\alpha+\theta-1)} \tag{4}$$

where the analogous index of input prices for importing plants is:

$$h_{mt} = \left((n + n^* p_t^{1-\sigma})^{\frac{1}{1-\sigma}}/\theta\right)^\theta (w_t/\alpha)^\alpha \tag{5}$$

and importing plants' profits are given by $\pi_{mt}(a) = (1 - \alpha - \theta)y_{mt}(a)$.

Plant sizes (measured by outputs or inputs) are proportional to e^a. In addition, importing plants are bigger than nonimporting plants for a given a according to any of these measures, because $h_{mt} < h_{dt}$ and $\alpha + \theta < 1$.

Plant-level gain from importing. Importing plants have a cost advantage in production because the intermediate input bundle is cheaper for an importing plant than for a nonimporting plant. The price index for a nonimporting plant to form one unit of the composite intermediate input it uses in production, $(nd^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}$, is equal to:

$$q_{dt} = n^{1/(1-\sigma)}$$

while for an importing plant to produce one unit of the composite input $\left(nd^{\frac{\sigma-1}{\sigma}} + n^* m^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$, the price index is:

$$q_{mt} = \left(n + n^* p_t^{1-\sigma}\right)^{1/(1-\sigma)}$$

For any finite p, $q_m < q_d$, because $\sigma > 1$. This gain from a higher variety of intermediate inputs is the same as the increasing return to variety considered in Ethier (1982) and Romer (1990). When input expenditures are deflated at a common price across plants – which is often the case in plant-level datasets – this cost advantage is reflected as higher TFP among importing plants compared to nonimporting plants. For a nonimporting plant, expenditures deflated by a price index q_{xt} are:

$$x_{dt}(a) = \frac{nd_{dt}(a)}{q_{xt}}$$

For an importing plant, similarly, expenditures are:

$$x_{mt}(a) = \frac{nd_{mt}(a) + p_t m_t(a)}{q_{xt}}$$

Using the fact that the cost-minimizing way to spend $x_{mt}(a)$ on the composite input is:

$$d_{mt}(a) = q_{mt}^{\sigma-1} x_{mt}(a)$$

$$m_t(a) = (q_{mt}/p_t)^{\sigma-1} x_{mt}(a)$$

output of nonimporting and importing plants can be written:

$$y_{dt}(a) = (e^a)^{1-\alpha-\theta} \ell_{dt}(a)^\alpha n^{\frac{\theta}{\sigma-1}} (q_{xt} x_{dt}(a))^\theta$$

$$y_{mt}(a) = (e^a)^{1-\alpha-\theta} \ell_{mt}(a)^\alpha \left(n + n^* p_t^{1-\sigma}\right)^{\frac{\theta}{\sigma-1}} (q_{xt} x_{mt}(a))^\theta$$

An importing plant can produce $\left(1 + \frac{n^*}{n} p_t^{1-\sigma}\right)^{\theta/(\sigma-1)}$ more units of output than a nonimporting plant with the same expenditures on labor and on intermediate inputs − that is, importing raises plant-level TFP. The magnitude of this productivity advantage depends on the share of intermediates in production, θ, and the elasticity of substitution σ. It also depends on the price p_t and the measures of goods n and n^*, but for a given ratio of expenditure on imports relative to domestic goods, $\psi_t \equiv \frac{p_t n^* m_t(a)}{nd_{mt}(a)} = \frac{n^*}{n} p_t^{1-\sigma}$, the productivity of an importing plant relative to a nonimporting plant with the same efficiency a can be written:

$$\frac{y_{mt}(a)/\left[\ell_{mt}(a)^\alpha x_{mt}(a)^\theta\right]}{y_{dt}(a)/\left[\ell_{dt}(a)^\alpha x_{dt}(a)^\theta\right]} = (1 + \psi_t)^{\frac{\theta}{\sigma-1}}$$

which is increasing in the importance of intermediate inputs in production, θ, and decreasing in the plant-level elasticity of substitution σ.[8] For $\sigma > 1$, the additional varieties of intermediate inputs gained from importing raise productivity, but as σ increases, input varieties become more substitutable and the productivity gain of importing falls. The productivity advantage of importing is (exponentially) inversely proportional to the ratio of composite input prices $\frac{q_{mt}}{q_{dt}}$, so that when p_t falls, importing plants spend relatively less per unit of inputs than nonimporting plants. Since inputs are deflated by a common price q_{xt}, this drop in import prices increases measured productivity for importing plants relative to nonimporting plants.

For the purpose of this comparison across importing and nonimporting plants, the exact choice of the price index q_{xt} is irrelevant, as long as the same price is used for all plants. Using a common deflator is consistent with methods used in plant-level datasets, and with the measurement methods in plant-level empirical studies like Kasahara and Rodrigue (2008) and Halpern et al. (2015). On the other hand, deflating inputs by plant-specific price indices would result in no effect of import price changes on measured TFP, consistent with the measurement methods in Gopinath and Neiman (2014), Burstein and Cravino (2015), and Kehoe and Ruhl (2008).

2.2.2. Plants' dynamic problem

The timing of a plant's decisions is as follows. At the beginning of period t, a plant's status (whether it imports or not) is given. The plant observes the realizations of the idiosyncratic shocks z_t and u_t, and the aggregate shock p_t, then makes input and output decisions according to the within-period problems described in the previous

---

[8] This is similar to the formula derived in Kasahara and Rodrigue (2008) and Blaum et al. (2015).

subsection. Profits in period t are $\pi_{dt}(z_t + u_t)$ if the plant is not importing or $\pi_{mt}(z_t + u_t)$ if the plant is importing. Plants then face a partial irreversibility in adjusting their import status. With probability η_d, a nonimporting plant gets the opportunity to decide whether to switch to importing in period $t + 1$ by paying a fixed cost ϕ_0 in period t. With probability $1 - \eta_d$, the plant is stuck not importing in $t + 1$. Likewise, with probability η_m, an importing plant can decide whether to switch to not importing, and with probability $1 - \eta_m$, it is stuck importing in $t + 1$. If an importing plant has the option and chooses to continue importing in $t + 1$, it pays a fixed cost ϕ_1 in period t.[9] At the end of the period, with probability δ, a plant exogenously exits.

Plants' importing decisions only depend on their forecasts of the persistent part of efficiency, z, so it is convenient to write the expected discounted value of profits from period t on averaged across realizations of u, as

$$\tilde{\pi}_{dt}(z) = \int \pi_{dt}(z + u)f_u(u)du$$

$$\tilde{\pi}_{mt}(z) = \int \pi_{mt}(z + u)f_u(u)du$$

The expected present discounted value of profits for a plant with persistent efficiency level z_t that doesn't import in period t is:

$$V_{dt}(z_t) = \lambda_t \tilde{\pi}_{dt}(z_t) + (1 - \eta_d)\beta(1 - \delta)E_t\left[V_{dt+1}(z_{t+1})|(z_t, p_t)\right]$$
$$+ \eta_d \max\left\{-\lambda_t\phi_0 + \beta(1 - \delta)E_t\left[V_{mt+1}(z_{t+1})|(z_t, p_t)\right],\right.$$
$$\left.\beta(1 - \delta)E_t\left[V_{dt+1}(z_{t+1})|(z_t, p_t)\right]\right\}$$

where $\lambda_t = C_t^{-\nu}$ is the household's marginal utility, and the expectations are taken across realizations of z_{t+1} and p_{t+1}, conditional on z_t and p_t. A nonimporting plant only makes the choice to start importing with probability η_d, and otherwise automatically continues not importing. Similarly, for a plant that imports in period t,

$$V_{mt}(z_t) = \lambda_t \tilde{\pi}_{mt}(z_t) + (1 - \eta_m)\beta(1 - \delta)E_t\left[V_{mt+1}(z_{t+1})|(z_t, p_t)\right]$$
$$+ \eta_m \max\left\{-\lambda_t\phi_1 + \beta(1 - \delta)E_t\left[V_{mt+1}(z_{t+1})|(z_t, p_t)\right],\right.$$
$$\left.\beta(1 - \delta)E_t\left[V_{dt+1}(z_{t+1})|(z_t, p_t)\right]\right\}$$

Plants value profits each period in units of the household's marginal utility to reflect the household's ownership.

Finally, new plants decide whether to enter and whether to import in their first period. A new entrant in period t pays a sunk cost κ_e to draw an initial signal of efficiency $z_t \sim g(z)$, which then evolves according to the Markov process governed by $f_z(z_{t+1}|z_t)$. An entering plant decides whether to import or only use domestic inputs starting in its first period of operation, which is the period after entry. The cost of importing for an entrant is κ_m. Expected discounted profit for an entering plant in period t with signal z_t is

$$V_{et}(z_t) = \max\left\{\beta E_t\left[V_{dt+1}(z_{t+1})|(z_t, p_t)\right],\right.$$
$$\left.-\lambda_t\kappa_m + \beta E_t\left[V_{mt+1}(z_{t+1})|(z_t, p_t)\right]\right\}$$

Plant's dynamic decisions take the form of cutoff rules, specified by three values in each period, $\hat{z}_t^e$ (for new entrants), $\hat{z}_t^0$ (for continuing plants that were not importing), and $\hat{z}_t^1$ (for continuing plants that were importing): if a plant's current z in period t is above the

cutoff, the plant chooses to pay the fixed cost to start importing in the next period. These cutoffs equate the value of the difference between expected discounted profits from importing and not importing equal to the value of the appropriate fixed cost, so they satisfy:

$$\lambda_t\kappa_m = \beta E_t\left[V_{mt+1}(z_{t+1}) - V_{dt+1}(z_{t+1})|(\hat{z}_t^e, p_t)\right]$$
$$\lambda_t\phi_0 = \beta(1 - \delta)E_t\left[V_{mt+1}(z_{t+1}) - V_{dt+1}(z_{t+1})|(\hat{z}_t^0, p_t)\right]$$
$$\lambda_t\phi_1 = \beta(1 - \delta)E_t\left[V_{mt+1}(z_{t+1}) - V_{dt+1}(z_{t+1})|(\hat{z}_t^1, p_t)\right]$$

where the expectations are taken across values of z_{t+1} conditional on the respective cutoff value in each equation, and across values of p_{t+1} conditional on p_t.

2.3. Equilibrium

The cross-section of plants at any date is summarized by two distributions, $\mu_{dt}(z_t)$ and $\mu_{mt}(z_t)$ of nonimporting and importing plants, respectively, at date t. Letting X_t denote the mass of plants that enters in period t, the distributions evolve as follows:

$$\mu_{dt+1}(z_{t+1}) = (1 - \delta)\left[\int_{-\infty}^{\hat{z}_t^0} \mu_{dt}(z_t)f_z(z_{t+1}|z_t)dz_t\right.$$
$$+ (1 - \eta_d)\int_{\hat{z}_t^0}^{\infty} \mu_{dt}(z_t)f_z(z_{t+1}|z_t)dz_t$$
$$+ \eta_m \int_{-\infty}^{\hat{z}_t^1} \mu_{mt}(z_t)f_z(z_{t+1}|z_t)dz_t\right]$$
$$+ X_t \int_{-\infty}^{\hat{z}_t^e} g(z_t)f_z(z_{t+1}|z_t)dz_t$$

$$\mu_{mt+1}(z_{t+1}) = (1 - \delta)\left[\eta_d \int_{\hat{z}_t^0}^{\infty} \mu_{dt}(z_t)f_z(z_{t+1}|z_t)dz_t\right.$$
$$+ \int_{\hat{z}_t^1}^{\infty} \mu_{mt}(z_t)f_z(z_{t+1}|z_t)dz_t$$
$$+ (1 - \eta_m)\int_{-\infty}^{\hat{z}_t^1} \mu_{mt}(z_t)f_z(z_{t+1}|z_t)dz_t\right]$$
$$+ X_t \int_{\hat{z}_t^e}^{\infty} g(z_t)f_z(z_{t+1}|z_t)dz_t$$

The value of entry satisfies:

$$\int V_{et}(z_t)g(z_t)dz_t - \lambda_t\kappa_e \leq 0$$

with equality if the mass of entrants $X_t > 0$.

Let L_{dt} denote the total labor used by nonimporting plants in period t,

$$L_{dt} = \int \int \ell_{dt}(z_t + u_t)f_u(u_t)\mu_{dt}(z_t)du_t dz_t$$

with $\ell_{dt}(a)$ given by Eq. (2). Define L_{mt} and intermediate inputs and gross outputs $D_{dt}, D_{mt}, M_t, Y_{dt}, Y_{mt}$ analogously. The labor market clearing condition is

$$L_{dt} + L_{mt} = 1$$

---

[9] An alternative assumption is that an importing plant that is forced to continue importing does not have to pay the fixed cost of importing. All the results reported in the paper are identical with this alternative assumption, which simply results in different calibrated values of the fixed cost parameters.

and the goods market clearing condition is:

$$Y_{dt} + Y_{mt} = C_t + D_{dt} + D_{mt} + p_t M_t + X_t \left[\kappa_e + (1 - G(\hat{z}_t^e)) \kappa_m \right]$$
$$+ \phi_0 \eta_d \int_{\hat{z}_t^0}^{\infty} \mu_{dt}(z_t) dz_t + \phi_1 \eta_m \int_{\hat{z}_t^1}^{\infty} \mu_{mt}(z_t) dz_t$$

Total output is equal to consumption plus purchases of all intermediate inputs, plus all fixed costs of entry and importing.

2.4. Margins of trade growth

The ratio of aggregate imports relative to domestic purchases (from hereon referred to as the "aggregate import ratio"), and the elasticity of this ratio with respect to changes in the relative price of imports – commonly referred to as the Armington elasticity – are the outcome of plant-level decisions and how they respond to shocks to p_t. The aggregate import ratio in the model is

$$\Gamma_t = \frac{\bar{p} M_t}{D_{mt} + D_{dt}}$$
$$= \frac{\int \int n^* \bar{p} m_t(z + u) f_u(u) \mu_{mt}(z) du dz}{\int n d_{mt}(z + u) f_u(u) \mu_{mt}(z) du dz + \int n d_{dt}(z + u) f_u(u) \mu_{dt}(z) du dz}$$

where $\bar{p}$, the steady state import price, is used to value imports relative to domestic goods.

Since only some plants import, aggregate imports relative to total intermediate inputs can grow over a period of time because: (i) importing plants import relatively more of their inputs; (ii) importing plants grow relative to non-importing plants; (iii) non-importing plants start importing (at a higher rate than importing plants stopping); or (iv) importing plants are more prevalent among new entrants than among exiting plants. I refer to these four margins of adjustment as within-plant, between-plant, switching, and net entry, respectively.

Using the plant-level decision rules in Eqs. (2) and (4), this ratio can be written:

$$\Gamma_t = \frac{n^* \bar{p} \tilde{m}_t}{n \tilde{d}_{mt}} \left(1 + \frac{\tilde{d}_{dt}}{\tilde{d}_{mt}} \frac{Z_{dt}}{Z_{mt}} \right)^{-1}$$
$$\equiv \omega_t (1 + b_t e_t)^{-1} \qquad (6)$$

where $\tilde{m}_t, \tilde{d}_{mt}$, and $\tilde{d}_{dt}$ are defined as the inputs used by a plant with efficiency $z + u = 1$, and Z_{dt} and Z_{mt} are given by:

$$Z_{dt} = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_{dt}(z) dz$$
$$Z_{mt} = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_{mt}(z) dz$$

When p_t changes, the effects on the terms $\omega_t = \frac{n^* \bar{p} \tilde{m}_t}{n \tilde{d}_{mt}}$, $b_t = \frac{\tilde{d}_{dt}}{\tilde{d}_{mt}}$, and $e_t = \frac{Z_{dt}}{Z_{mt}}$ correspond to the within-plant, between-plant, and the combined switching and net entry margins, respectively. I consider how these three margins contribute to short-run and long-run Armington elasticities.

The short-run elasticity is the elasticity of Γ_t with respect to the contemporaneous import price, p_t, which can be written in terms of the elasticities of the three components as:

$$\frac{d \log \Gamma_t}{d \log p_t} = \frac{d \log \omega_t}{d \log p_t} - \frac{b_t e_t}{1 + b_t e_t} \left(\frac{d \log b_t}{d \log p_t} + \frac{d \log e_t}{d \log p_t} \right)$$

The component due to the within-plant term, $\omega_t = \frac{n^*}{n} p_t^{-\sigma}$, is $\frac{d \log \omega_t}{d \log p_t} = -\sigma$, since importing plants substitute between imports and domestic goods with elasticity σ. In a version of this model in which all plants import, the aggregate import ratio would equal the within plant import ratio, and the aggregate Armington elasticity would be σ.

In my model, there are two additional margins of import growth, $b_t = \tilde{d}_{dt} / \tilde{d}_{mt}$ and $e_t = Z_{dt} / Z_{mt}$. First, the ratio $b_t = \tilde{d}_{dt} / \tilde{d}_{mt}$ is the size of a nonimporting plant relative to an importing plant (with the same productivity), measured by the domestic inputs they use: the aggregate import ratio is large when importing plants are large relative to nonimporting plants. The elasticity of b_t with respect to p_t is $\frac{d \log b_t}{d \log p_t} = \frac{\psi_t}{1 + \psi_t} \left(\frac{\theta}{1 - \alpha - \theta} - (\sigma - 1) \right)$, where $\psi_t = \frac{n^* p_t \tilde{m}_t}{n \tilde{d}_{mt}}$ is the ratio of expenditures on imports to domestic inputs at an importing plant. The sign of $\frac{d \log b_t}{d \log p_t}$ – and hence whether the between plant margin raises or lowers the aggregate Armington elasticity – depends on how large the within-plant elasticity σ is compared to $\frac{\theta}{1 - \alpha - \theta}$, the intermediate input share relative to the degree of returns to scale. If $\sigma < 1 + \frac{\theta}{1 - \alpha - \theta}$, then $\frac{d \log b_t}{d \log p_t} > 0$, and the between-plant margin reinforces the within-plant margin. In this case, when p_t increases, importing plants become relatively less profitable, so they shrink relative to nonimporting plants. If, on the other hand, $\sigma > 1 + \frac{\theta}{1 - \alpha - \theta}$, then $\frac{d \log b_t}{d \log p_t} < 0$; when goods are very substitutable, importing plants actually grow relative to nonimporting plants when p_t rises because importing plants substitute so heavily away from imports towards domestic goods. In this case, the between-plant margin counteracts the within-plant margin in determining the aggregate Armington elasticity. The contribution of the between margin to the Armington elasticity is scaled by the factor $\frac{b_t e_t}{1 + b_t e_t}$, which can be written as $\frac{1 - F_t}{R_t F_t + 1 - F_t}$, where F_t is the fraction of plants importing in period t, and R_t is the average size of importing plants relative to the average size of nonimporting plants.

Second, the ratio $e_t = Z_{dt} / Z_{mt}$ is the aggregate efficiency of nonimporting plants relative to importing plants, which captures both the mass of these plants and their average efficiency. If there are many importing plants, or they have relatively high efficiencies on average, then aggregate imports are high relative to domestic inputs. The contemporaneous effect of this margin is zero: $\frac{d \log e_t}{d \log p_t} = 0$, since Z_{dt} and Z_{mt} are determined before the realization of p_t. Therefore, the short-run Armington elasticity is

$$\frac{d \log \Gamma_t}{d \log p_t} = -\sigma - \frac{1 - F_t}{R_t F_t + 1 - F_t} \frac{\psi_t}{1 + \psi_t} \left(\frac{\theta}{1 - \alpha - \theta} - (\sigma - 1) \right) \qquad (7)$$

In the quantitative analysis below, the model is parameterized to fix steady state versions of the moments $\bar{F}, \bar{R},$ and $\bar{\psi}$, so the short-run elasticity at the steady state value of $\bar{p}$ is completely determined by the value of these moments and parameters.

Over a longer time horizon, the effects of a change in p_t on plants' dynamic switching and entry decisions affect future values of Z_{dt} and Z_{mt}. When the price of imports rises, the cutoffs for importing rise for all plants (entrants, nonimporters, and importers), so fewer plants choose to start importing. Over time, there is a larger effect on the aggregate import ratio for two reasons. First, each period, only a fraction of plants receive idiosyncratic shocks that put them above the new thresholds, and these switching plants cumulate over time; second, with $\eta_d, \eta_m < 1$, only a fraction of plants can adjust their importing status any period. These effects create a difference in the short-run and long-run Armington elasticities as in Ruhl (2008): the decisions of plants to import in response to a permanent price change have an effect that is not seen over a short time horizon. The long-run Armington elasticity is the change in the steady state

aggregate import ratio with respect to a permanent change in the import price,

$$\frac{d\log\bar{\Gamma}}{d\log\bar{p}}\Bigg| = \frac{d\log\Gamma_t}{d\log p_t}\Bigg|_{p_t=\bar{p}} - \frac{1-\bar{F}}{\bar{R}\bar{F}+1-\bar{F}}\frac{d\log\bar{e}}{d\log\bar{p}}$$

The within-plant and between-plant margins are static, in the sense that their magnitudes are the same within a period or across steady states. There is no closed-form expression for the elasticity of the entry and switching margin, but if a persistent decrease in the price of imports causes more plants to import, then $\frac{d\log\bar{e}}{d\log\bar{p}}$ is positive, so entry and switching raise (in absolute value) the long-run Armington elasticity above the short-run elasticity.

The short-run and steady state cases isolate particular ways in which the static (within-plant, between-plant) and dynamic (entry and switching) margins contribute to trade growth. Transitory price changes, if they are expected to persist, also affect the importing decisions of plants, and affect future trade volumes through movements in future values of the ratio Z_{dt}/Z_{mt}. This means that the scaling factor $\frac{1-F_t}{R_tF_t+1-F_t}$ on the between-plant contribution in the short-run elasticity depends on the history of shocks up to the current period and how plants' importing decisions have responded to those shocks. In addition, there is a gradual transition in response to permanent price changes, because the effects of the net entry and switching margins accumulate over time. In the model without any irreversibilities, i.e. $\eta_d = \eta_m = 1$, this transition is due to plant-level dynamics in efficiency, as each period only a fraction of existing plants draw idiosyncratic shocks above or below the new thresholds. In the model with η_d and η_m less than 1, there is the additional feature that only a fraction of existing plants receive opportunities to change their importing status each period. In the next section, I simulate the model to evaluate these properties quantitatively and compare the model's implications to aggregate and plant-level data from Chile.

3. Quantitative analysis

In this section, I calibrate the model to several features of the Chilean plant level and macroeconomic data, and simulate it in response to both transitory and permanent changes in the relative price of imports. I decompose the margins of trade growth in a simulated time series and compare the contributions of these margins to those in the data. Without irreversibilities in importing status, the model generates an excessively large contribution of switching to import growth, and a short-run Armington elasticity just above 3. Adding irreversibilities brings the contribution of switching to aggregate import growth closer to the data, and lowers the short-run elasticity by about 0.5. Additionally, the presence of irreversibilities is important for getting the magnitude of long-run trade growth in line with the aggregate data.

3.1. Calibration

I set some parameters to standard values in the international macro literature, and choose the remainder so that a steady state of the model matches a set of cross-sectional moments in Chilean plant-level data. Tables 1 and 2 summarize the calibration. The model period is one year, and I set the discount factor $\beta = 0.96$, which implies a real interest rate of 4% per year. I set the parameter

ν in the household's per-period utility function $C_t^{1-\nu}/(1-\nu)$ to $\nu = 2$, a standard value in international business cycle models (e.g. Backus et al., 1994).

The stochastic process for p_t is an AR(1) in logs,

$$\log p_{t+1} = (1-\rho_p)\log\bar{p} + \rho_p\log p_t + \varepsilon_{pt+1} \tag{8}$$

with $\varepsilon_{pt+1} \sim N(0,\eta_\varepsilon^2)$. I use data on Chilean import and domestic wholesale price indices from the IMF's *International Financial Statistics* to construct a series for the relative price of imports, and estimate ρ_p from the regression (Eq. (8)) over the period 1949–1996, and set η_ε to the standard deviation of the residuals. This procedure gives $\rho_p = 0.815$ for the autocorrelation of $\log p_t$ and $\eta_\varepsilon = 0.032$ for the standard deviation of the shocks. In my model, fluctuations in the relative price of imports p_t stand in for a variety of shocks such as unilateral changes in tariffs, real exchange rate movements, and commodity price fluctuations. While these different shocks would be expected to vary in their persistence and volatility, I use one aggregate shock for ease of illustration. Below, I also feed in the actual path of relative prices assuming perfect foresight, and evaluate the model's predictions for the resulting long-run dynamics in trade flows.

The remaining parameters are either calculated directly from or calibrated to match moments from Chile's annual industrial survey (*Encuesta Nacional Industrial Anual*) from the *Instituto Nacional de Estadística* (*INE*). The data includes all manufacturing plants with at least 10 employees, and spans 1979–1996.[10] Each plant reports its total intermediate input purchases and the portion of its inputs that are "direct imports". If imports are positive, I consider the plant an importer.[11] The parameters of the plant production functions that are common between non-importing plants and importing plants are α, the share of output spent on labor compensation, and θ, the share of output spent on intermediate inputs. I set θ to the average share of expenditures on intermediate goods as a fraction of gross output, which is equal to 0.525. I choose α so that the profit share, $1-\alpha-\theta$, equals 0.15, the value used in Atkeson and Kehoe (2005). In the model, labor stands in for all other variable factors of production, so I use a higher value of α (0.325) than would be implied by the average labor compensation share of gross output in the data (which is 0.17).

The parameter σ is the elasticity of substitution between different intermediate inputs at the plant level, and also the plant-level elasticity of substitution between imported and domestic inputs. This parameter also determines the productivity advantage of importing, equal to $\left(1+\bar{\psi}\right)^{\frac{\theta}{\sigma-1}}$ in a steady state, where $\bar{\psi}$ is the ratio of expenditures on imports to domestic inputs at importing plants. I choose σ so that the steady state productivity advantage in the model is equal to 20%, which gives a value of 2.05. This value is in the upper range of the estimates in Kasahara and Rodrigue (2008), who estimate the productivity advantage of importing plants in Chilean plant-level data. Several other papers, such as Halpern et al. (2015) and Muendler (2004), estimate a similar statistic in other plant- and firm-level datasets, and find a smaller advantage of importing, and Kasahara and Rodrigue's results also include lower values. I also

---

[10] The data are described in detail in Liu (1993).

[11] Under this classification, it is possible that some plants use imported inputs that come through wholesalers or retailers, and are not counted as importing plants in the data. This is a common issue with plant- or firm-level trade statistics from industrial censuses. Evidence from customs transaction data shows that wholesale and retail establishments account for significant portions of both imports and exports (e.g. Bernard et al., 2009), but more so for imports.

Table 1
Calibration: parameters externally set or calculated directly from data.

Parameter	Role	Value	Chosen to match
β	Discount factor	0.96	Annual interest rate 4%
ν	Intertemporal elasticity	2.00	Standard value
θ	Intermediate share	0.525	Average intermediate share
α	Labor share	0.325	$0.85 - \theta$
κ_e	Cost of entry	0.10	Normalization
ρ_p	p_t persistence	0.895	Chile relative import price data
η_ε	s.d. of agg. shocks	0.028	Chile relative import price data
σ	Within-plant elasticity	2.05	20% productivity gain from importing
$\bar{p}$	Steady state import price	2.191	30.5% plant-level import share
ρ_z	z persistence	0.93	Coefficient in regression (Eq. (10))
δ	Exit rate	0.029	Average exit rate 2.9%

report below the results for $\sigma = 3.0$, which corresponds to a 10% productivity gain from importing.[12]

The share of expenditures on imports at importing plants in the model, $\frac{\psi}{1+\psi}$, pins down the factor $\frac{n^*}{n}\bar{p}^{1-\sigma}$. Given a value for σ, this does not identify n^*, n, and $\bar{p}$ separately, so I set $n = n^* = 1$ and choose $\bar{p}$, the average relative import price, to match the average plant-level import share of 30.5%. I set $\delta = .029$, which is the average exit rate of plants. I normalize the cost of entry $\kappa_e = 0.1$; changing this parameter has no effect on any of the statistics I examine, since the remaining calibrated fixed cost parameters are scaled proportionally to match the remaining moments.

The persistent part of plant-level efficiency, z_t, follows an AR(1) process with mean zero,

$$z_{t+1} = \rho_z z_t + \varepsilon_{zt+1}$$

where $\varepsilon_{zt+1} \sim N(0, \sigma_z^2)$, and the transitory part $u_t \sim N(0, \sigma_u^2)$. I estimate ρ_z from the persistence of plant-level input decisions, as in Hopenhayn and Rogerson (1993), as follows. Total input expenditures at a nonimporting plant in the model are:

$$x_t = e^{z_t + u_t} \frac{\theta}{n} h_{dt}^{1/(\alpha+\theta-1)}$$

so that the evolution of x_t over time can be written:

$$\log x_{t+1} = \rho_z z_t + \varepsilon_{zt+1} + u_{t+1} + \log\left(\frac{\theta}{n} h_{dt+1}^{1/(\alpha+\theta-1)}\right)$$
$$= \rho_z \log x_t + v_{t+1} - \rho_z v_t + \xi_{t+1} \quad (10)$$

where $v_t = \log\left(\frac{\theta}{n} h_{dt}^{1/(\alpha+\theta-1)}\right)$ and v_{t+1} are common to all nonimporting plants, and $\xi_{t+1} = \varepsilon_{zt+1} + u_{t+1} - \rho_z u_t$ has variance $\sigma_\xi^2 = \sigma_z^2 + (1 + \rho_z^2)\sigma_u^2$. I estimate ρ_z from Eq. (10) with OLS using the set of plants who never use imported inputs, proxying for the $v_{t+1} - \rho_z v_t$

term with year dummies. This gives a coefficient of $\rho_z = 0.93$.[13] I then choose the standard deviation σ_z and the fixed costs κ_m, ϕ_0, ϕ_1, to jointly match four cross-sectional moments in the plant-level data: the fraction of plants importing; the average size of importing plants relative to nonimporting plants, as measured by intermediate inputs; and the two annual switching rates — the fraction of nonimporting plants that start importing and the fraction of importing plants that stop importing. Few manufacturing plants in Chile use imported intermediate inputs (23.5% on average), and they tend to be much larger than plants that do not use any imported inputs (a factor of 5.9 as measured by intermediate inputs). Each year, on average, 5.8% of nonimporting plants import the next year, and 18.8% of importing plants do not import the next year.[14] Although the four parameters jointly determine the values of these four statistics in the model, intuitively, κ_m pins down the overall fraction of plants importing, while ϕ_0 and ϕ_1 largely determine the switching rates, and σ_z affects the size ratio. A higher σ_z means shocks to persistent efficiency are larger, so the average size of importing plants relative to nonimporting plants is higher. Given a value for σ_z and an estimate of the residual variance σ_x^2 from the regression (Eq. (10)), which is $(0.47)^2$, I calculate $\sigma_u^2 = \frac{\sigma_x^2 - \sigma_z^2}{1 + \rho_z^2}$.

In the model with irreversibilities, I add two additional parameters, η_d and η_m, and two additional moments: the average size of new importers relative to all importing plants, and the average size of continuing importers relative to all importers. The values of these moments in the data are 0.64 and 1.12, respectively. The remaining parameters are also recalibrated to the moments mentioned above. The parameters η_d and η_m control the degree of the selection effect induced by the fixed costs of importing. A lower η_d means a lower probability of being able to start importing, so that among those who do receive the opportunity, the switching rate must be higher (to match the same target of 5.8%), so the cutoff $\hat{z}_0$ is lower. Similarly, a lower value of η_m raises the cutoff $\hat{z}_1$. These movements in the cutoffs mean that less productive plants start to import, and more productive plants stop importing. These effects make new importers

---

[12] An alternative to choosing σ in this way would be to relate it to the plant-level elasticity of substitution. Although the plant-level elasticity of substitution is not observed in the data, the model implies that as long as a plant continuously imports across periods, it substitutes between imports and domestic goods with elasticity σ. Therefore, the model implies that

$$\log\left(\frac{m_t(z)}{d_{mt}(z)}\right) = -\sigma \log(p_t) + b \quad (9)$$

for any importing plant. Estimating σ from a fixed-effects regression of plant-level import ratios on the relative price of imports (to capture the within-plant variation over time) yields a much lower estimate of σ, equal to 1.06. This value results in an inordinately large productivity advantage of importing – importing raises plant-level productivity by 2400% – so I use the larger elasticity calculated to match a 20% within-plant productivity gain.

[13] Considering both importing and nonimporting plants, Eq. (10) can be written:

$$\log x_{t+1} = \rho_z \log x_t + I_{mt+1} v_{mt+1} - \rho_z I_{mt} v_{mt} + v_{t+1} - \rho_z v_t + \xi_{t+1}$$

where $I_{mt} = 1$ if a plant is importing in period t and 0 otherwise, and v_{mt} is common to all importing plants. Running this alternative regression, adding dummy variables for importing and lagged importing status interacted with year fixed effects, yields $\rho_z = 0.95$. All the results reported below are essentially unchanged with this higher value for ρ_z.

[14] For comparison, Kurz (2006) reports that in 1992, about one quarter of US manufacturing plants used imported inputs, and they were on average about twice the size of the plants that did not. Using Indonesian firm-level data, Amiti and Konings (2007) report that about 20% of firms use imported inputs, and Halpern et al. (2015), show that about half of Hungarian firms import, and they are on average about five times larger than nonimporting plants.

Table 2
Calibration: jointly calibrated parameters.

Parameter	Role	Value	Chosen to match
Model with no irreversibilities			
σ_u	s.d. of transitory shocks	0.324	0.47 residual variance in regression (Eq. (10))
σ_z	s.d. of persistent shocks	0.146	5.90 importer/nonimporter size ratio
κ_m	Fixed cost for entrant	0.0150	23.5% of plants importing
ϕ_0	Nonimporter fixed cost	0.0172	5.8% nonimporter → importer switch rate
ϕ_1	Importer fixed cost	0.0166	18.8% importer → nonimporter switch rate
Model with irreversibilities			
σ_u	s.d. of transitory shocks	0.294	0.47 residual variance in regression (Eq. (10))
σ_z	s.d. of persistent shocks	0.235	5.90 importer/nonimporter size ratio
κ_m	Fixed cost for entrant	0.0180	23.5% of plants importing
ϕ_0	Nonimporter fixed cost	0.0042	5.8% nonimporter → importer switch rate
ϕ_1	Importer fixed cost	0.0150	18.8% importer → nonimporter switch rate
η_d	Friction to start importing	0.068	New importer relative average size 0.64
η_m	Friction to stop importing	0.834	Continuing importer relative average size 1.12

smaller relative to all importers, and make continuing importers larger relative to all importers.

Figs. 1 and 2 illustrate the effect of introducing the irreversibilities on the distribution of plant efficiencies and the importing decisions of existing plants. Fig. 1 shows the steady state densities μ_d and μ_m, and cutoffs $\hat{z}_0$ and $\hat{z}_1$ in the model without irreversibilities. Plants to the right of the line labeled $\hat{z}_0$ under the density μ_d switch from not importing to importing, and plants to the right of the line labeled $\hat{z}_1$ under the density μ_m continue importing. With no irreversibilities, the cutoff for continuing to import is slightly lower than the cutoff for starting to import, reflecting the calibrated value of ϕ_1 being less than ϕ_0: it is easier to remain an importer than to start importing. In Fig. 2, the fraction of plants that switch to importing is instead the plants to the right of $\hat{z}_0$ under the density labeled $\eta_d\mu_d$, since only a fraction η_d of nonimporting plants get the opportunity to start importing. Similarly, the fraction of plants that continue importing are the plants to the right of $\hat{z}_1$ under the density labeled $\eta_m\mu_m$. Since the calibrated value of η_d is so small, among those who can start importing, almost all do, so $\hat{z}_0$ is very low. The next section studies the effect of these irreversibilities on the dynamic behavior of the model: mechanically, introducing irreversibilities dampens the response of $\hat{z}_0$ to aggregate shocks, since the cutoff is so much lower than in the model without irreversibilities. A similar effect holds for importing plants, but to a lesser extent, since the calibrated value of η_m is larger than η_d.

3.2. Short-run fluctuations

I simulate the model with and without irreversibilities, with shocks to p_t drawn from the stochastic process described in the
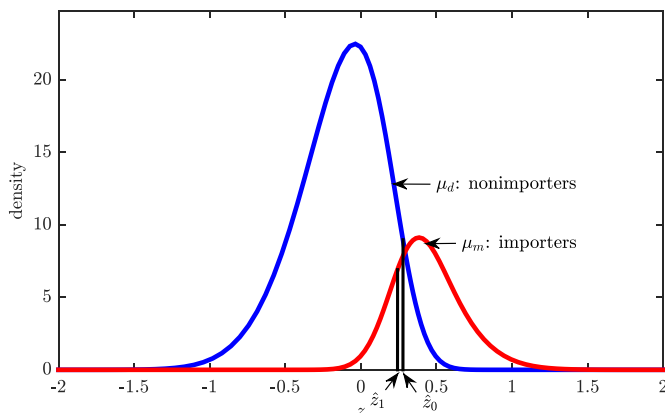

Fig. 1. Plant distributions and cutoffs without irreversibilities.

previous subsection, to evaluate the model's predictions on short-run fluctuations in trade volumes. The model without irreversibilities generates fluctuations in aggregate trade volumes that are slightly larger than in the data, and attributes an excessively large fraction of these fluctuations to plants switching into and out of importing relative to the data. Adding irreversibilities brings both these features of the model closer to the data.

I measure the magnitude of the short-run response of trade to price changes with the aggregate Armington elasticity. As Ruhl (2008) discusses, the estimates of Armington elasticities from cyclical fluctuations in prices typically imply small elasticities, mostly in the range of 1–3. I estimate short-run elasticities in the model and in the Chilean data following empirical studies such as Reinert and Roland-Holst (1992).[15] The short-run Armington elasticity is the estimated coefficient in the regression[16]:

$$\log\left(\frac{M_t}{D_t}\right) = -\hat{\sigma}\log(p_t) + b \qquad (11)$$

An alternative estimate of the short-run elasticity is the ratio of volatilities of the left hand side of Eq. (11) divided by the right hand side,

$$\hat{\sigma} = \frac{\text{std}(\log(M_t/D_t))}{\text{std}(\log(p_t))} \qquad (12)$$

Table 3 contains estimates of the short-run Armington elasticity from the Chilean data and from the model. I consider several estimates from the data that put the short-run elasticity in Chile in the range of 1–3, which is in line with the evidence from a broad set of empirical studies summarized in Ruhl (2008). There is no single series of aggregate imported and domestic purchases of intermediate inputs, so I consider two alternative data series. The first is aggregate data

---

[15] While the literature typically uses data at the quarterly (e.g. Reinert and Roland-Holst, 1992) or monthly (e.g. Gallaway et al., 2003) frequency, I use annual data because higher frequency data for Chilean manufacturing trade are unavailable.

[16] This equation is motivated by demand derived from CES preferences over aggregate imports and domestic goods. Maximizing

$$U(M_t, D_t) = \left(\omega D_t^{(\sigma-1)/\sigma} + (1-\omega)M_t^{(\sigma-1)/\sigma}\right)^{\sigma/(\sigma-1)}$$

subject to the budget constraint $D_t + p_t M_t \leq E$ for any expenditure E, gives Eq. (11), with the constant b depending on ω. In my model, the same aggregate demand function does not hold, so this is an approximation.
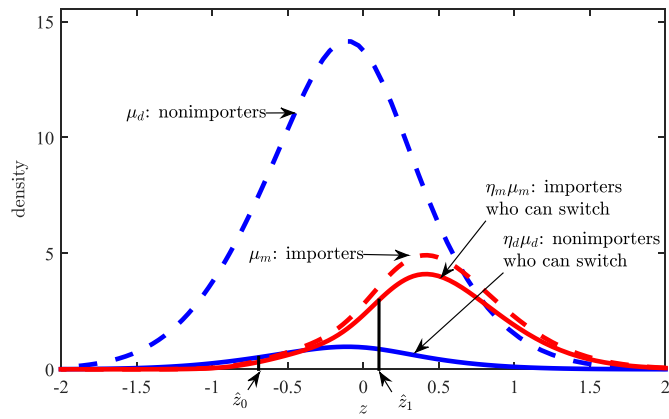
Fig. 2. Plant distributions and cutoffs with irreversibilities.

Table 3
Short-run Armington elasticity in model and data.

	Regression coefficient	Volatility ratio
Aggregate data		
1962–2010	2.86 (s.e. 0.32, R^2 0.629)	3.60
1979–1996	2.51 (s.e. 0.30, R^2 0.809)	2.79
1986–1996	1.68 (s.e. 0.19, R^2 0.894)	1.78
Aggregate of plant data		
1979–96	0.35 (s.e. 0.51, R^2 0.028)	2.07
1986–96	1.50 (s.e. 0.32, R^2 0.716)	1.78
Model, no irreversibilities	3.13 (s.e. 0.020, R^2 0.960)	3.19
Model with irreversibilities	2.63 (s.e. 0.008, R^2 0.990)	2.65

on all imported and domestically produced manufacturing goods.[17] Although this data includes more than just intermediate inputs, it has broader coverage, since the plant-level data consider just manufacturing plants above 10 employees. The second is the aggregate of all imports and domestic intermediate inputs usage in the manufacturing census. The regression estimate from the aggregate data over the period 1962–2010 is about 2.86, while the volatility ratio is 3.6. For comparison to the plant level data to which the model is calibrated, over the period 1979–1996, the elasticity in the aggregate data from the regression is about 2.5, while the volatility ratio is 2.8. And over the period 1986–1996, which is after the temporary tariff increase of the 80s, the regression coefficient is 1.68 and the volatility ratio is 1.78. In the plant-level data for the period 1979–1996, the regression estimate is 0.35, but it is not significant and the R^2 is only 0.028. The volatility ratio is about 2.07, which is more in line with the aggregate data. Over the period 1986–1996, the regression coefficient is 1.50, with a better significance and fit, and the volatility ratio is 1.78, which are again in line with the aggregate data.

The bottom of Table 3 contains the model results. In the model without irreversibilities, the short-run elasticity is 3.13, while adding irreversibilities brings the elasticity down to about 2.6. Both are at the upper end of the range of estimates from the data, and the model with irreversibilities has a short-run elasticity that is lower by about 0.5. In understanding the difference between the short-run elasticity in these two models, note that Eq. (7) applies regardless of the values of the parameters η_d and η_m. Since the models are calibrated to the same targets for the fraction of plants importing and their average size relative to nonimporting plants, the steady state $\bar{F}$ and $\bar{R}$ are identical. Hence, in each model, the elasticity of the aggregate import ratio to the import price, $\frac{d\log\Gamma_t}{d\log p_t}$, *evaluated at the steady state price* is the same. This means that the difference in the elasticities comes from the different behaviors of the fraction of importing plants and their size relative to nonimporting plants over time in the two models.

To quantify these differences, I decompose changes in aggregate imports as follows. Let $\bar{p}M_t$ and $A_t = \bar{p}M_t + D_{mt} + D_{dt}$ denote the aggregate quantities of imported inputs and total (domestic plus imported) inputs, respectively, in year t, evaluated at base-period relative prices. Let M_t^j and A_t^j denote the analogues for the subset of

plants in group j, where $j = con, start, stop, enter, exit$ denote plants that import consecutively in t and $t+1$; that start importing in $t+1$; that stop importing in t; that enter in $t+1$; and that exit in t, respectively. Then, the change in aggregate imports between periods t and $t+1$ can be decomposed as follows:

$$M_{t+1} - M_t = \underbrace{\left(\frac{M_{t+1}^{con}}{A_{t+1}^{con}} - \frac{M_t^{con}}{A_t^{con}}\right)A_{t+1}^{con}}_{\text{within}} + \underbrace{(A_{t+1}^{con} - A_t^{con})\frac{M_t^{con}}{A_t^{con}}}_{\text{between}}$$
$$+ \underbrace{M_{t+1}^{start} - M_t^{stop}}_{\text{switching}} + \underbrace{M_{t+1}^{enter} - M_t^{exit}}_{\text{net entry}} \quad (13)$$

The first term in the sum gives the change in the import share of continuously importing plants, weighted by their total inputs in period $t+1$. The second term is the growth in total inputs of continuously importing plants weighted by their initial total import share. These two terms split the growth of continuously importing plants into a first term that aggregates the within-plant adjustment of import shares and a second term that captures the changes in the size of importing plants. The next two terms in the decomposition capture the net effects of plants switching into and out of importing, and entering and exiting. Table 4 shows the components of this decomposition, labeled "within", "between", "switch", and "net entry", respectively, in the model and in the Chilean data, averaged over 1979–1996. The numbers displayed are each component as a percentage of total import growth. The figures are averages of annual changes, weighted by the absolute value of $M_{t+1} - M_t$ in each year.

In the data, a little over half of the annual changes in imports at the aggregate level are accounted for by the within margin — changes in the import ratio within continuously importing plants. About 40% is accounted for by importing plants as a whole shrinking or growing in scale. Switching and net entry each account for about 3 to 4% of aggregate import growth.

In the model without irreversibilities, the contribution of switching is an order of magnitude larger than in the data, accounting for about half of the year-to-year fluctuations in the aggregate import share. The volatility in the fraction of plants importing accounts for this large contribution of switching to fluctuations in import growth. Introducing irreversibilities improves the model's predictions on this

---

Table 4
Decomposition of short-run fluctuations in model and data.

	% of $M_{t+1} - M_t$, average			
	Within	Between	Switch	Net entry
Data, 1979–1996	53.27	39.77	3.17	3.79
Model				
No irreversibilities	36.52	11.70	50.15	1.63
Irreversibilities	48.31	27.32	18.75	5.62

decomposition: irreversibilities reduce by about two thirds the gap between the model and the data in the switching margin, and therefore also bring the rest of the decomposition closer in line with the data. This reduction in the contribution of switching occurs because the irreversibilities dampen the effect of shocks to p_t on switching. For example, when p_t falls, the value of importing rises, making some nonimporting plants switch to importing. However, part of the value of importing is the option value of switching back to not importing; when $\eta_m < 1$, this option value is reduced, so a plant is less likely to switch due to a temporary drop in p_t. A similar effect holds for importing plants considering whether to stop importing in response to an increase in p_t, due to having $\eta_d < 1$. Mechanically, the fluctuations in the cutoffs $\hat{z}_t^0$ and $\hat{z}_t^1$ brought about by aggregate fluctuations in p_t are smaller with irreversibilities than without.

Fig. 3 illustrates a sample time series to compare the dynamic behavior of the aggregate import ratio and the terms in Eq. (6). The top panel shows the path of the realized import price, and the associated movements in the aggregate import ratio. With irreversibilities, these movements are dampened compared to the model without irreversibilities, as reflected in the lower short-run Armington elasticity. The bottom panel shows the three terms in Eq. (6). The first two – the ratio of imports to domestic inputs at importing plants and the size of an importing plant relative to a nonimporting plant – behave identically with or without irreversibilities: they are static, and adjust immediately to any shock. The third term – the ratio $\frac{Z_{mt}}{Z_{dt}}$ measuring the (efficiency-weighted) mass of importing plants relative to nonimporting plants – behaves very differently in the two models. With no irreversibilities, this measure of the relative mass of importing and nonimporting plants moves rapidly following a shock, while in the model with irreversibilities, it takes several periods for this ratio to adjust, as each period new plants get the opportunity to switch. This slow movement accounts for the lower short-run Armington elasticity and the smaller contribution of switching to aggregate import growth in the model with irreversibilities.

3.3. Long-run dynamics

I now consider the model's long-run dynamic response to import price changes. I conduct two experiments: first, I consider a one-time, permanent 10% reduction in the relative price of imports, in the absence of any other shocks to p_t, starting from the calibrated steady state. I interpret this change as a unilateral trade reform, and analyze the magnitude and speed of trade growth and the welfare benefits of this trade reform. Second, I feed in the actual path of relative import prices, calculated as the ratio of the wholesale price index of imports relative to the wholesale price index of domestically produced goods, in Chile from 1974–2010, during which there were several periods of long-run decline in the price of imports.[18] The previous subsection highlighted how changes in the set of importing plants determine the dynamic behavior of aggregate trade flows in response to shocks. The fact that the aggregate measures of importing and nonimporting plants behave very differently with and without irreversibilities suggests that the two models may have very different implications over long time horizons.

Table 5 presents measures of the magnitude and speed of the growth in trade following a one-time, permanent 10% reduction in the import price. The first panel shows growth rates across steady states and growth rates one and ten years after the import price reduction, in the import ratio and the import share. In the model with no irreversibilities, both the ratio of imports to domestic goods and the share of imports in total inputs reach about 95% of their eventual growth within ten years. In the model with irreversibilities, this number is a bit lower, at 91%. Fig. 4 shows the path of the aggregate import share following the drop in p_t in the two models. Since the value of σ, the within-plant elasticity of substitution, is the same in both models, trade growth in the first year is virtually identical in the two models, with subsequent differences driven by effects of the irreversibilities on switching and entry.

Table 5 also shows the implied Armington elasticity at different time horizons following the drop in p_t. At each time $t = 1$, 10, and ∞, where ∞ denotes the new free-trade steady state, the elasticity is calculated as the percentage increase in the ratio M_t/D_t relative to the original steady state, divided by the change in the relative price, reflected in the tariff reduction. That is,

$$\tilde{\sigma}_t = \frac{\left(\frac{M_t/D_t}{\bar{M}/\bar{D}} - 1 \right)}{\left(\frac{p_t}{\bar{p}} - 1 \right)} \tag{14}$$

where $\bar{M}/\bar{D}$ is the original steady state ratio. Note that for this experiment, $p_1 = p_{10} = p_\infty = 0.90 \times \bar{p}$.

After one year, the growth in trade implies an elasticity of about 2.86, in both models, which is similar to that estimated in response to business cycle fluctuations. After 10 years, the measured elasticity is about 4.7 in the model without irreversibilities, and about 4.1 in the model with irreversibilities. Across steady states, the implied elasticities are about 5 and 4.5, respectively. Therefore, both models generate a long-run elasticity that is significantly higher than the short-run elasticity, but the irreversibilities are important in getting the short-run elasticity and the plant-level decomposition closer to the data.

3.3.1. Dynamic effects on welfare gains from trade

The gradual adjustment in aggregate quantities following trade liberalization suggests that there could be significant consequences for the welfare gains from trade reform. In particular, a drop in the
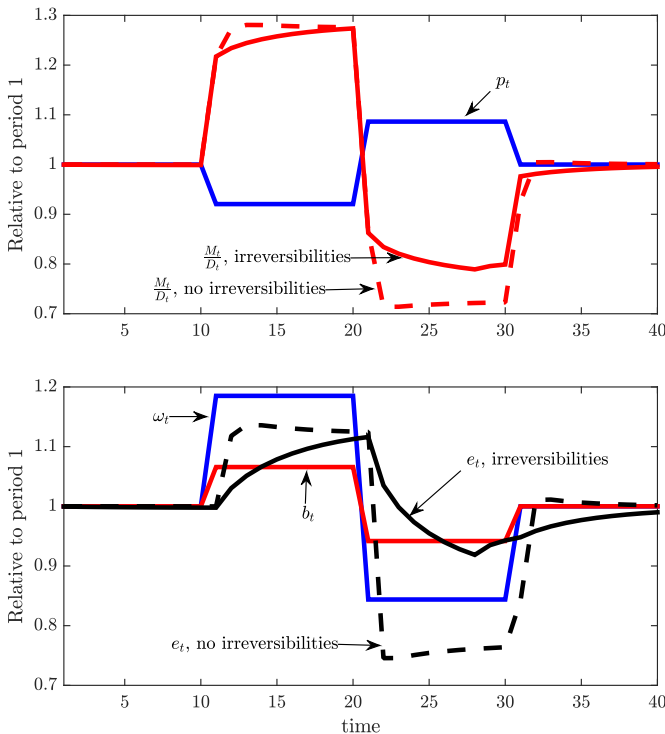

Fig. 3. Top panel: aggregate import price and aggregate import ratio. Bottom panel: components of aggregate import ratio, ω_t, b_t, and e_t, from Eq. (6).

Table 5
Dynamic response to a 10 percent reduction in the import price.

	Percent growth rate					
	No irreversibilities			Irreversibilities		
	1 year	10 years	New ss	1 year	10 years	New ss
Import share $\frac{M}{M+D}$	21.71	34.62	36.47	21.71	30.56	33.25
Armington elasticity	2.86	4.71	4.99	2.86	4.11	4.51
	Welfare gains, %					
	No irreversibilities			Irreversibilities		
Across steady states (λ_S)	2.09			2.42		
Including transition (λ_T)	3.24			3.12		

price of imports results in an increase in the fraction of plants that import (from all groups: new entrants, previous nonimporters, and previous importers), that gradually subsides as real wages rise to offset the gains form importing. Fig. 5 shows the dynamic path of aggregate consumption in the two models. In both models, there is an initial spike in consumption that gradually declines to a level that is higher than the initial steady state level of consumption.

To quantify the welfare implications of these changes in aggregate consumption, I compare two measures of welfare gains. The first measure compares lifetime utility across steady states, by calculating the percentage increase in the original steady state's consumption needed to attain the level of lifetime utility at the new steady state. This is the factor λ_S that solves:

$$U(\lambda_S \bar{C}) = U(\tilde{C})$$

where $\bar{C}$ is consumption in the original steady state, and $\tilde{C}$ is the new steady state. The second measure of welfare gains computes an analogous consumption–variation measure, comparing lifetime utility in the initial steady state to utility over the entire transition to the new steady state. That is, the second measure is the factor λ_T that solves:

$$U(\lambda_T \bar{C}) = \sum_{t=0}^{\infty} \beta^t U(C_t)$$

where C_t is consumption t periods following the trade reform.

The bottom of Table 5 shows the two measures λ_S and λ_T. In the model without irreversibilities, welfare including the transition is about 55% larger than the steady state comparison. In the model with irreversibilities, λ_T is still larger than λ_S, but by only about half as much, about 29%. These results show that the welfare calculation
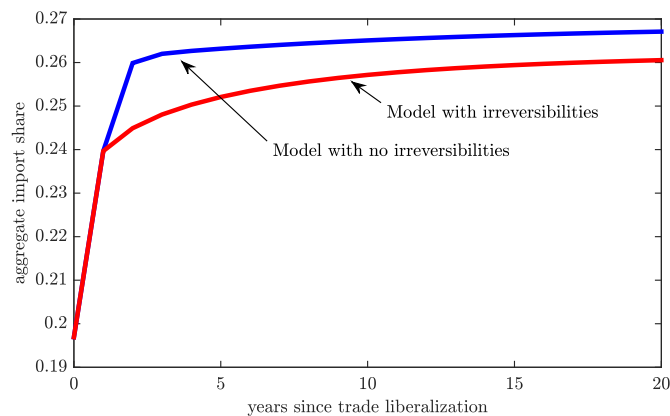

Fig. 4. Path of aggregate import share in response to permanent 10% reduction in trade cost, in models with and without irreversibilities.

based on a static model would underestimate the welfare gains, but the presence of irreversibilities mitigates this difference.

In each model, the initial increase in consumption accounts for why welfare gains taking into account the transition are higher than comparing across steady states. The dynamic behavior of consumption in both models is a result of two forces. First, the drop in the relative price of imports means that there are more resources available after paying for intermediate inputs — aggregate value-added increases. Second, these resources are used mainly for consumption and paying fixed costs for existing plants to start or continue importing, rather than investment in new plants. Fig. 6 depicts the time paths of consumption, expenditures on fixed costs of importing for existing plants, and expenditures on fixed costs of entry and importing for new plants along with aggregate value-added (GDP), relative to their initial values. Entry declines because it is more cost-effective – both upon impact and in the new steady state – for existing plants to pay the costs of importing in the next period than it is to create new plants, many of which will have low efficiency draws and not import. The sharp drop in entry accounts for the large initial spike in consumption in the model without irreversibilities. Adding irreversibilities mitigates the drop in entry and spike in consumption, because irreversibilities dampen the response of existing plants. Since only a fraction of plants get the chance to switch, the new lower price of imports induces a relatively small fraction of plants to start importing. In addition, among those that do, the increase in the value of importing is dampened by the possibility of not being able to switch back.

Comparing the welfare gains across the models with and without irreversibilities shows that irreversibilities reduce the welfare gain by a small amount, 3.12% as opposed to 3.24%. The dampened increase in consumption with irreversibilities accounts for this difference. However, the steady state level of consumption is higher in the model with irreversibilities, as can be seen from Fig. 5 and the two values of λ_S in Table 5. Plant entry is permanently lower than in the original steady state in both models, because a larger fraction of existing plants start importing. In the short-run, this raises consumption, but in the long-run the gain from importing is partly offset by the lower stock of plants. Since the drop in entry is smaller with irreversibilities, the steady state level of consumption is higher than in the model without irreversibilities. The net welfare gain, including the transition, is lower due to introducing this friction, but the difference is not as large as the difference in steady state consumption. In addition, the differences between the two models in the movements in consumption, investment, and fixed costs offset in the long-run, so that the steady state growth in GDP is the same in both models.

3.3.2. Real GDP and measured aggregate productivity

As Kehoe and Ruhl (2008) and Burstein and Cravino (2015) demonstrate, there is often a discrepancy in trade models between the theoretical welfare gains from trade and the changes in aggregate variables as defined in national income accounting methods, such as
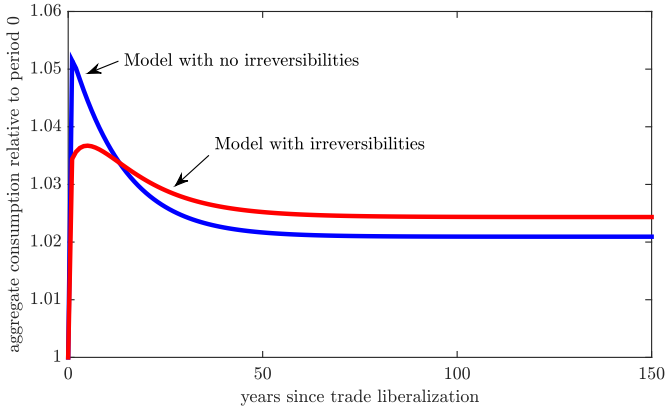
Fig. 5. Path of aggregate consumption in response to permanent 10% reduction in trade cost, in models with and without irreversibilities.

real GDP, real consumption, and aggregate total factor productivity (TFP). In this subsection, I evaluate this discrepancy in my model, and discuss how it is affected by the dynamic forces in the model.

The national accounting measure of real consumption corresponds to the current-price aggregate of consumption expenditures deflated with a consumption price index. In this model, the consumption price index is equal to one, so that real consumption is equivalent to its theoretical counterpart, C_t. The national accounting measure of real GDP (as measured from the product side) is aggregate gross output less aggregate purchases of intermediate inputs, each deflated by a producer price index and an input price index, respectively. The domestic producer price index, like the consumption price index, is equal to one, and I define the input price index P_t as a weighted average of the domestic input price (one) and the imported input price (p_t/p_0) relative to the base period $t = 0$, where

the weights are given by expenditure shares in the base period (the initial steady state),

$$P_t = \lambda_0 + (1 - \lambda_0)\frac{p_t}{p_0}$$

$$\lambda_0 = \frac{D_{d0} + D_{m0}}{D_{d0} + D_{m0} + p_0 M_0}$$

Then real GDP is given by:

$$rGDP_t = Y_{dt} + Y_{mt} - \frac{D_{dt} + D_{mt} + p_t M_t}{P_t}$$

where Y_{dt} is total gross output of nonimporting plants and Y_{mt} is total gross output of importing plants. To calculate TFP from real GDP, I construct a measure of the capital embodied in plants from cumulating investment in new plants. In each period, the resources spent on new plants are:

$$I_t = X_t \left(\kappa_e + \kappa_m \left[1 - G(\hat{z}_{mt}) \right] \right)$$

The capital stock K_t is then given by the law of motion,

$$K_{t+1} = (1 - \delta)K_t + I_t$$

with the initial capital stock defined in period 0 so that the initial steady state is consistent with this law of motion, which means $K_0 = \frac{I_0}{\delta}$. Aggregate TFP is then defined as the usual Solow residual, with the weight on labor equal to $\frac{\alpha}{1-\theta}$ (labor's share in aggregate value added) and the weight on capital equal to $1 - \frac{\alpha}{1-\theta}$. Since aggregate labor supply is fixed at one,

$$TFP_t = \frac{rGDP_t}{K_t^{1-\alpha/(1-\theta)}}$$

Figs. 7 and 8 show the time paths of real GDP, TFP and consumption, following the reduction in the import price in the model without and with irreversibilities, respectively. In each case, real GDP reflects the movements in consumption as well as investment expenditures discussed above, so the increase in real GDP is smaller than the increase in consumption. The increase in TFP reflects the aggregate impact of the increase in plant-level productivity from importing discussed in Section 2.2.1. In both versions of the model, aggregate TFP increases because importing plants become more productive due to the drop in the import price, and because a higher proportion of existing plants import. The increase in TFP is larger than the increase in real GDP, since the drop in investment leads the capital stock to decline over time, while real GDP rises. In the model
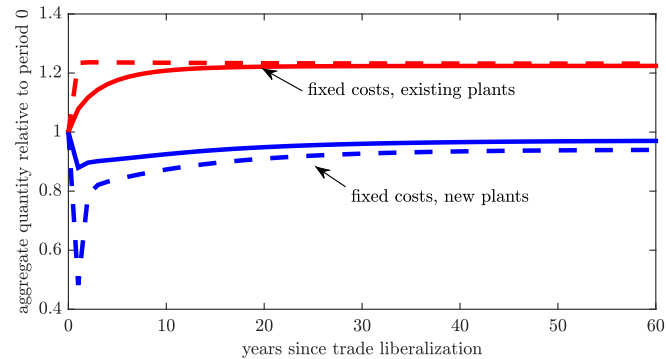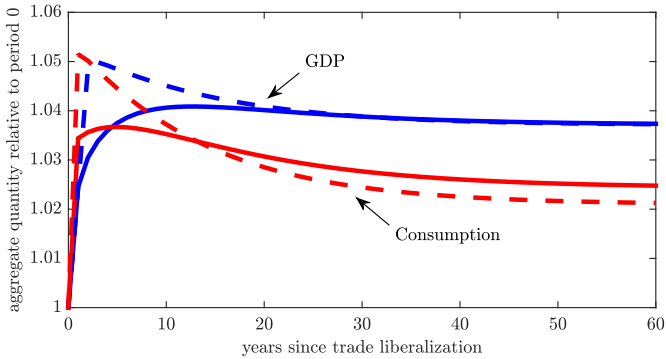

Fig. 6. GDP, aggregate consumption, and aggregate fixed costs paid by existing and new plants, in response to 10% reduction in price of imports. Dotted lines are from the model without irreversibilities and solid lines are from the model with irreversibilities.
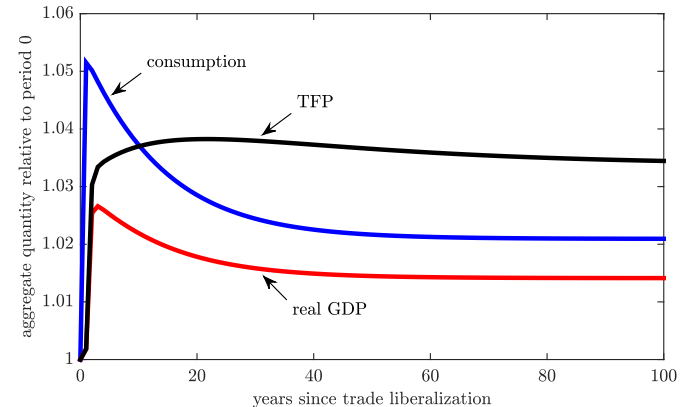

Fig. 7. Consumption, real GDP, and TFP following permanent 10% reduction in import price, in model without irreversibilities.
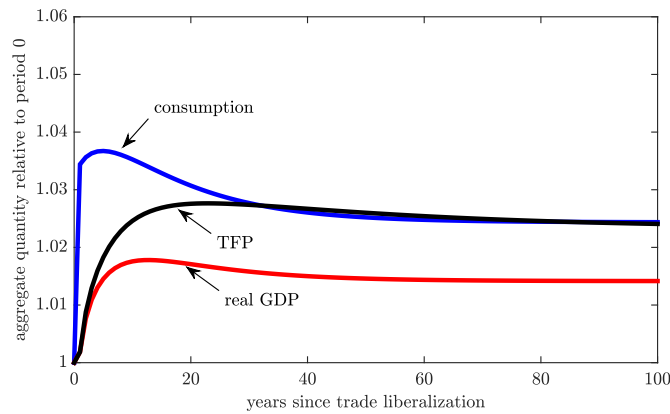
Fig. 8. Consumption, real GDP, and TFP following permanent 10% reduction in import price, in model with irreversibilities.

with irreversibilities, there is a pronounced delay in the growth of real GDP and TFP, which peak around 10 to 20 years after the price reduction. This gradual growth mirrors the growth in the import share, as irreversibilities reduce the aggregate impact of existing plants' switching decisions as discussed above.

3.3.3. Long-run trade dynamics in Chile

In extending the results to look at the actual path of relative import prices in Chile, it is relevant to note that the dynamics of trade growth, the long-run elasticity, and the welfare gains all depend on the size of the drop in the import price fed into the model. For example, a 20% reduction in the import price in the model without irreversibilities leads to a larger long-run elasticity, equal to 5.9, and a larger welfare gain, 7.87%, while the difference between λ_T and λ_S shrinks to 30%. The model with irreversibilities has a long-run elasticity of 5.5, a welfare gain of 7.48%, and a λ_S that is 15% smaller than λ_T, again about half of the difference in the model with no irreversibilities.

During the Chilean trade liberalization of the mid-1970s, average tariffs in manufacturing dropped from 94% to about 15% from 1973 to 1978. There was a temporary increase in tariffs in the mid-1980s, followed by a further gradual decline to about 5% in the mid-2000's. To capture how these tariff changes, along with other import price changes, were reflected in actual average import prices faced by plants in Chile, I feed into the model relative import prices calculated as the ratio of the wholesale import price index to the wholesale price index for domestically produced manufacturing goods. The top panel of Fig. 9 shows one plus the average tariff rate (solid line), as well as the relative import price index (dotted line), both relative to their 1979–1996 averages.[19] Although movements in the ratio of price indices since 1974 reflect both permanent changes in import tariffs associated with Chile's trade liberalization and transitory fluctuations in relative prices, I assume for purposes of solving the model that the path of p_t is perfectly foreseen, and feed the dotted line into the model.

The bottom panel of Fig. 9 shows the import share in the model with and without irreversibilities, and in the aggregate Chilean data. I compare the model results to aggregate data on all Chilean manufacturing imports and domestic purchases, because aggregate data on intermediate inputs are unavailable, and the plant-level data do not extend before 1979 or after 1996. The model without irreversibilities significantly overestimates the growth in trade, especially in the later part of the period. In particular, the import share in the data
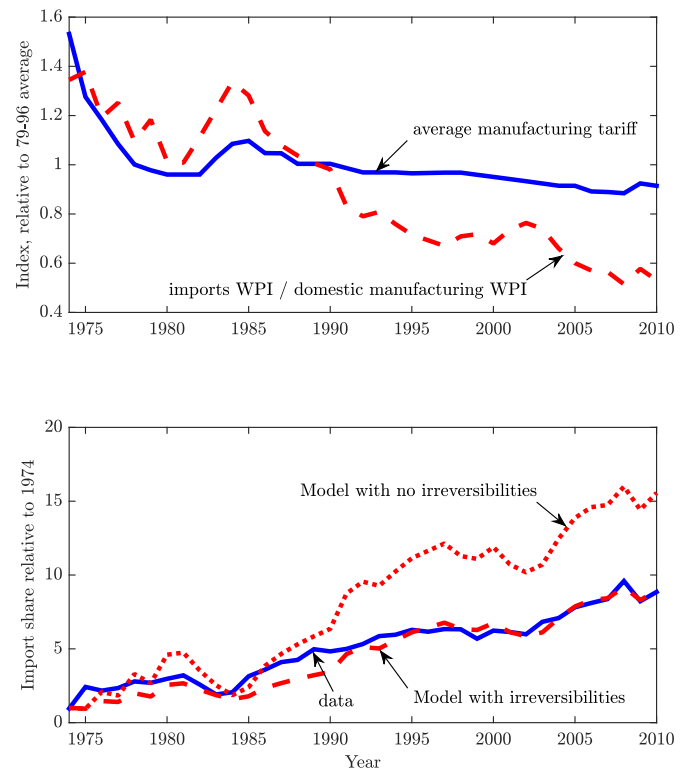

Fig. 9. Top panel: average manufacturing tariff (one plus tariff rate) and ratio of imported to domestic manufacturing wholesale price indices, Chile, 1974–2010. Bottom panel: aggregate import share in Chile, 1974–2010, and model predictions.

grew by a factor of about eight, while the model predicts growth by a factor of about 15. In contrast, the model with irreversibilities predicts a magnitude of long-run trade growth that is more in line with the data – a factor of about nine.[20] Therefore, accounting for the short-run switching behavior of plants through adding irreversibilities is important for predicting reasonable magnitudes of long-run growth in trade.

4. Conclusion

This paper has shown that a dynamic model of plant-level importing decisions, calibrated to match cross-sectional features of the distribution of imports across plants, generates short-run and long-run aggregate dynamics that are in line with data. The main motivation is the observation that a model in which the only friction to importing inputs is sunk and fixed costs of importing, calibrated to the average amount of switching into and out of importing in the data, generates far too much switching in response to aggregate shocks. This leads to overpredicting long-run growth in trade flows. Introducing an irreversibility in the importing decision in the sense that with some probability a plant cannot change its import status each period brings this feature of the model closer to the data, and impacts both short-run and long-run dynamics of aggregate trade flows.

---

[20] Calibrating the model with irreversibilities to a lower productivity gain from importing of 10%, which implies $\sigma = 3.0$, yields the following results. The short-run elasticity is 3.76, and the short-run decompositions of trade flows are within: 53.58, between: 18.65, switch: 25.23, net entry: 2.62. The long-run elasticity is 6.03, and the welfare gain from the ten percent reduction in trade costs is 2.85% (across steady states) or 3.16% (including the transition). Finally, the predicted path of the aggregate Chilean import share lies roughly halfway between the dashed and dotted lines in Fig. 6.

The model provides a framework for analyzing the dynamic effects of trade policy through changes in producer-level importing decisions. With irreversibility in these decisions, changes in trade policy have both static and dynamic effects on the allocation of resources across plants that import and plants that do not. An irreversibility in importing status stands in for other frictions that prevent plants from being able to adjust the sourcing of their inputs, such as time delays, frictions in matching with suppliers, or the synchronization of input sourcing and investment decisions. The model here has focused on the plant-level decision to import, motivated by recent empirical evidence of the importance of this decision. A large body of evidence exists as well for the importance of plant-level exporting decisions, and a useful extension would be a dynamic model that integrates the plant-level importing decisions introduced here with the exporting decisions analyzed in much of the recent trade literature.

Appendix A. Appendix

A.1. Social planner's problem

Since there are no distortions, an equilibrium solves a planning problem of maximizing the consumer's utility subject to the feasibility constraints. The planning problem is

$$\max \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\nu}}{1-\nu} \tag{15}$$

subject to:

$$C_t + D_{dt} + D_{mt} + p_t M_t + X_t \left(\kappa_e + \kappa_m \left[1 - G(\hat{z}_{mt})\right]\right) + \phi_0 \eta_d \int_{\hat{z}_{0t}}^{\infty} \mu_{dt}(z)dz + \phi_1 \eta_m \int_{\hat{z}_t^1}^{\infty} \mu_{mt}(z)dz$$

$$= (Z_{dt})^{1-\alpha-\theta} L_{dt}^{\alpha} n^{\frac{\theta}{\sigma-1}} D_{dt}^{\theta} + (Z_{mt})^{1-\alpha-\theta} L_{mt}^{\alpha} \left(n^{1/\sigma} D_{mt}^{\frac{\sigma-1}{\sigma}} + (n^*)^{1/\sigma} M_t^{\frac{\sigma-1}{\sigma}}\right)^{\theta \frac{\sigma}{\sigma-1}}$$

$$L_{dt} + L_{mt} = 1$$

$$\mu_{dt+1}(z') = (1-\delta)\left[\int_{-\infty}^{\hat{z}_{0t}} \mu_{dt}(z)fz(z'|z)dz + (1-\eta_d)\int_{\hat{z}_{0t}}^{\infty} \mu_{dt}(z)fz(z'|z)dz + \eta_m \int_{-\infty}^{\hat{z}_{1t}} \mu_{mt}(z)fz(z'|z)dz\right] + X_t \int_{-\infty}^{\hat{z}_{mt}} g(z)fz(z'|z)dz$$

$$\mu_{mt+1}(z') = (1-\delta)\left[\eta_d \int_{\hat{z}_{0t}}^{\infty} \mu_{dt}(z)fz(z'|z)dz + \int_{\hat{z}_{1t}}^{\infty} \mu_{mt}(z)fz(z'|z)dz + (1-\eta_m)\int_{-\infty}^{\hat{z}_t^1} \mu_{mt}(z_t)fz(z'|z)dz\right] + X_t \int_{\hat{z}_{mt}}^{\infty} g(z)fz(z'|z)dz$$

where Z_{dt} and Z_{mt} are given by

$$Z_{dt} = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_{dt}(z)dz \tag{16}$$

$$Z_{mt} = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_{mt}(z)dz \tag{17}$$

Letting λ_t denote the multiplier on the aggregate resource constraint; $\lambda_t w_t$ the multiplier on the labor feasibility constraint; and $\lambda_t r_{dt}(z'), \lambda_t r_{mt}(z')$ the multipliers on the laws of motion for μ_{dt} and μ_{mt}, the first order conditions of the planning problem lead to:

$$\lambda_t = u'(C_t)$$

$$L_{dt} = Z_{dt}\left(n^{\frac{\theta}{\sigma-1}} \theta^{\theta} \left(\frac{w_t}{\alpha}\right)^{\theta-1}\right)^{1/(1-\alpha-\theta)} \tag{18}$$

$$D_{dt} = w_t \frac{\theta}{\alpha} L_{dt} \tag{19}$$

$$L_{mt} = Z_{mt}\left(\left(\frac{w_t}{\alpha}\right)^{\theta-1} \theta^{\theta} n^{\frac{\theta}{\sigma-1}} \left(1 + \left(\frac{n^*}{n}\right) p_t^{1-\sigma}\right)^{\frac{\theta}{\sigma-1}}\right)^{1/(1-\alpha-\theta)} \tag{20}$$

$$D_{mt} = \frac{w_t}{\alpha} \frac{\theta}{1 + \frac{n^*}{n} p_t^{1-\sigma}} L_{mt} \tag{21}$$

$$M_t = p_t^{-\sigma} \frac{n^*}{n} D_{mt} \tag{22}$$

$$\left(\kappa_e + \kappa_m \left[1 - G(\hat{z}_{mt})\right]\right) = \int_{-\infty}^{\infty} r_{dt}(z')\left[\int_{-\infty}^{\hat{z}_{mt}} g(z)fz(z'|z)dz\right]dz' + \int_{-\infty}^{\infty} r_{mt}(z')\left[\int_{\hat{z}_{mt}}^{\infty} g(z)fz(z'|z)dz\right]dz'$$

$$\kappa_m = \int_{-\infty}^{\infty} \left[r_{mt}(z') - r_{dt}(z')\right] fz\left(z'|\hat{z}_{mt}\right) dz'$$

$$\phi_0 = (1-\delta)\int_{-\infty}^{\infty}[r_{mt}(z') - r_{dt}(z')]fz(z'|\hat{z}_{0t})dz'$$

$$\phi_1 = (1-\delta)\int_{-\infty}^{\infty}[r_{mt}(z') - r_{dt}(z')]fz(z'|\hat{z}_{1t})dz'$$

$$r_{dt}(z') = \beta\frac{\lambda_{t+1}}{\lambda_t}\left[(1-\alpha-\theta)Z_{dt+1}^{-\alpha-\theta}e^{\sigma_u^2}e^{z'}L_{dt+1}^{\alpha}n^{\frac{\theta}{\sigma-1}}D_{dt+1}^{\theta} - \phi_0\eta_d\mathbb{I}_{\{z'\geq\hat{z}_{0t+1}\}}\right]$$
$$+ \beta(1-\delta)\left[\eta_d\mathbb{I}_{\{z'\geq\hat{z}_{0t+1}\}}\int_{-\infty}^{\infty}r_{mt+1}(z'')fz(z''|z')dz'' + \left(\mathbb{I}_{\{z'<\hat{z}_{0t+1}\}} + (1-\eta_d)\mathbb{I}_{\{z'\geq\hat{z}_{0t+1}\}}\right)\int_{-\infty}^{\infty}r_{dt+1}(z'')fz(z''|z')dz''\right]$$

$$r_{mt}(z') = \beta\frac{\lambda_{t+1}}{\lambda_t}\left[(1-\alpha-\theta)Z_{mt+1}^{-\alpha-\theta}e^{\sigma_u^2}e^{z'}L_{mt+1}^{\alpha}\left(n^{1/\sigma}D_{mt+1}^{\frac{\sigma-1}{\sigma}} + (n^*)^{1/\sigma}M_{t+1}^{\frac{\sigma-1}{\sigma}}\right)^{\theta\frac{\sigma}{\sigma-1}} - \phi_1\left(\eta_m\mathbb{I}_{\{z'\geq\hat{z}_{1t+1}\}} + 1 - \eta_m\right)\right]$$
$$+ \beta(1-\delta)\left[\left(\mathbb{I}_{\{z'\geq\hat{z}_{1t+1}\}} + (1-\eta_m)\mathbb{I}_{\{z'<\hat{z}_{1t+1}\}}\right)\int_{-\infty}^{\infty}r_{mt+1}(z'')fz(z''|z')dz'' + \eta_m\mathbb{I}_{\{z'<\hat{z}_{1t+1}\}}\int_{-\infty}^{\infty}r_{dt+1}(z'')fz(z''|z')dz''\right]$$

where $\mathbb{I}_{\{Q\}}$ equals 1 if Q is true and 0 otherwise.

To solve the steady state and the transition path following a permanent change in p, I solve the social planner's problem, by approximating the distributions μ_d and μ_m by their values on a finely spaced grid. This is feasible for the steady state and deterministic path, but infeasible for solving the model subject to fluctuations in p_t.

A.2. Recursive problem and solution method for model with fluctuations

I solve the model with fluctuations in p_t by adapting the Krusell and Smith (1998) method, by proxying the endogenous distributions μ_d and μ_m with a state variable of finite dimension, and approximating the aggregate variables in plants' decision problems with log-linear functions of the state. Khan and Thomas (2003) and Ruhl (2008) are examples of models with heterogeneity in production that use similar methods.

Formulated recursively, the state variable for a plant's decision problem is (z, p, μ_d, μ_m) where p is the current price of imports, and $\mu_d(z), \mu_m(z)$ are the current distributions of nonimporting and importing plants, respectively, across values of z. Call $\mu = (\mu_d, \mu_m)$ the aggregate endogenous state variable and let $V_d(z,p,\mu)$ and $V_m(z,p,\mu)$ be the expected present discounted value of profits for a nonimporting plant and an importing plant, respectively, with persistent efficiency level z. These are given by:

$$V_d(z,p,\mu) = \lambda(p,\mu)\tilde{\pi}_d(z,p,\mu) + (1-\eta_d)\beta(1-\delta)\int\int V_d(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp'$$
$$+ \eta_d\max\left\{-\lambda(p,\mu)\phi_0 + \beta(1-\delta)\int\int V_m(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp',\right.$$
$$\left.\beta(1-\delta)\int\int V_d(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp'\right\}$$

$$V_m(z,p,\mu) = \lambda(p,\mu)\tilde{\pi}_m(z,p,\mu) + (1-\eta_m)\beta(1-\delta)\int\int V_m(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp'$$
$$+ \eta_m\max\left\{-\lambda(p,\mu)\phi_1 + \beta(1-\delta)\int\int V_m(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp',\right.$$
$$\left.\beta(1-\delta)\int\int V_d(z',p',\mu')f_z(z'|z)f_p(p'|p)dz'dp'\right\}$$

where, in each equation, plants take as given the law of motion for the endogenous aggregate state variable, $\mu' = H(p,\mu)$, and the function $\lambda(p,\mu) = C(p,\mu)^{-\nu}$.

$$\mu_d'(z') = (1-\delta)\left[\int_{-\infty}^{\hat{z}_0(p,\mu)}\mu_d(z)fz(z'|z)dz + (1-\eta_d)\int_{\hat{z}_0(p,\mu)}^{\infty}\mu_d(z)fz(z'|z)dz + \eta_m\int_{-\infty}^{\hat{z}_1(p,\mu)}\mu_m(z)fz(z'|z)dz\right] + X(p,\mu)\int_{-\infty}^{\hat{z}_m(p,\mu)}g(z)fz(z'|z)dz$$

$$\mu_m'(z') = (1-\delta)\left[\eta_d\int_{\hat{z}_0(p,\mu)}^{\infty}\mu_d(z)fz(z'|z)dz + \int_{\hat{z}_1(p,\mu)}^{\infty}\mu_m(z)fz(z'|z)dz + (1-\eta_m)\int_{-\infty}^{\hat{z}_1(p,\mu)}\mu_m(z)fz(z'|z)dz\right] + X(p,\mu)\int_{\hat{z}_m(p,\mu)}^{\infty}g(z)fz(z'|z)dz$$

The value of entry satisfies:

$$\int V_e(z,p,\mu)g(z)dz - C(p,\mu)^{-\nu}\kappa_e \leq 0$$

with equality if $X(p,\mu) > 0$.

Let $L_d(p,\mu)$ denote the total labor used by nonimporting plants in period t,

$$L_d(p,\mu) = \int\int \ell_d(z+u,p,\mu)h(u)\mu_d(z)dudz$$

with $\ell_d(a, p, \mu)$ given by Eq. (2) evaluated at $p_t = p$ and $w_t = w(p, \mu)$. Define L_m and intermediate inputs and gross outputs D_d, D_m, M, Y_d, Y_m analogously. The labor market clearing condition is

$$L_d(p, \mu) + L_m(p, \mu) = 1$$

and the goods market clearing condition is:

$$Y_d(p, \mu) + Y_m(p, \mu) = C(p, \mu) + D_d(p, \mu) + D_m(p, \mu) + pM(p, \mu) + \phi_0 \eta_d \int_{\hat{z}_0(p,\mu)}^{\infty} \mu_d(z)dz + \phi_1 \left[\int_{\hat{z}_1(p,\mu)}^{\infty} \mu_m(z)dz + (1 - \eta_m) \int_{-\infty}^{\hat{z}_1(p,\mu)} \mu_m(z)dz \right]$$
$$+ X(p, \mu) \left[\kappa_e + (1 - G(\hat{z}_m(p, \mu))) \phi_0 \right]$$

The algorithm I use is as follows.

1. Select a finite set of moments to summarize the distributions μ_d and μ_m. Given how these distributions enter the aggregate feasibility conditions, I use the two moments $Z = (Z_d, Z_m)$ defined by:

$$Z_d = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_d(z)dz$$
$$Z_m = e^{\sigma_u^2} \int_{-\infty}^{\infty} e^z \mu_m(z)dz$$

2. Guess a set of coefficients in the approximate laws of motion for $H(p, Z) = (Z'_d(p, Z), Z'_m(p, Z))$ and $C(p, Z)$:

$$\log Z'_d(p, Z) = b_{d0}^0 + b_{dp}^0 \log p + b_{dd}^0 \log Z_d + b_{dm}^0 \log Z_m$$
$$\log Z'_m(p, Z) = b_{m0}^0 + b_{mp}^0 \log p + b_{md}^0 \log Z_d + b_{mm}^0 \log Z_m$$
$$\log C(p, Z) = b_{C0}^0 + b_{Cp}^0 \log p + b_{Cd}^0 \log Z_d + b_{Cm}^0 \log Z_m$$

Denote these coefficients (b_d^0, b_m^0, b_C^0), where $b_i^0 = \left(b_{i0}^0, b_{ip}^0, b_{id}^0, b_{im}^0 \right)$ for each $i = d, m, C$. The equilibrium wage $w(p, Z)$ can then be explicitly calculated using the labor market clearing condition $1 = L_d + L_m$, evaluated at the aggregate moments Z_d and Z_m, which gives

$$w(p, Z) = \left[Z_d \left(n^{\frac{\theta}{\sigma-1}} \theta^\theta \alpha^{1-\theta} \right)^{1/(1-\alpha-\theta)} + Z_m \left(\theta^\theta n^{\frac{\theta}{\sigma-1}} \alpha^{1-\theta} \left(1 + \left(\frac{n^*}{n} \right) p^{1-\sigma} \right)^{\frac{\theta}{\sigma-1}} \right)^{1/(1-\alpha-\theta)} \right]^{\frac{1-\alpha-\theta}{1-\theta}}$$

3. Solve the plants' problems by value function iteration on a grid of values for (z, p, Z_d, Z_m). I discretize the Markov processes for z and p using Rouwenhorst's method, and for Z_d and Z_m I use equally spaced grids centered around their steady state values. I use bilinear interpolation in the (Z_d, Z_m) dimensions to evaluate the future value functions off the grid.

4. Simulate a time series $\{p_t\}_{t=0}^T$ starting from the steady state $\bar{p}$. Starting from the steady state distributions $\bar{\mu}_d(z)$ and $\bar{\mu}_m(z)$, solve for sequences of equilibrium variables, $\hat{z}_{mt}, \hat{z}_{0t}, \hat{z}_{1t}, C_t, w_t, X_t, \mu_{dt+1}(z), \mu_{mt+1}(z), L_{dt}, D_{dt}, L_{mt}, D_{mt}, M_t, Z_{dt}, Z_{mt}$, for $t = 0, \ldots, T$, using the system of equations given by the 4 constraints on the planning problem (Eq. (15)), plus Eq. (16) through Eq. (22), and

$$C_t^{-\nu} \kappa_m = \beta \int \int [V_m(z', p', Z_{t+1}) - V_d(z', p', Z_{t+1})] f_z(z'|\hat{z}_{mt}) f_p(p'|p_t) dz'dp'$$
$$C_t^{-\nu} \phi_0 = \beta(1 - \delta) \int \int [V_m(z', p', Z_{t+1}) - V_d(z', p', Z_{t+1})] f_z(z'|\hat{z}_{0t}) f_p(p'|p_t) dz'dp'$$
$$C_t^{-\nu} \phi_1 = \beta(1 - \delta) \int \int [V_m(z', p', Z_{t+1}) - V_d(z', p', Z_{t+1})] f_z(z'|\hat{z}_{1t}) f_p(p'|p_t) dz'dp'$$
$$C_t^{-\nu} \kappa_e = \int V_e(z, p, Z_t) g(z)dz$$

In this step, I use numerical quadrature to integrate μ_{dt} and μ_{mt}, and I use the probabilities associated with the discretized Markov chains for z and p to integrate the value functions.

5. From the simulated series, calculate new coefficients $(b_d^1), (b_m^1), (b_C^1)$ by linear regression,

$$\log Z_{dt+1} = b_{d0}^1 + b_{dp}^1 \log p_t + b_{dd}^1 \log Z_{dt} + b_{dm}^1 \log Z_{mt}$$
$$\log Z_{mt+1} = b_{m0}^1 + b_{mp}^1 \log p_t + b_{md}^1 \log Z_{dt} + b_{mm}^1 \log Z_{mt}$$
$$\log C_t = b_{C0}^1 + b_{Cp}^1 \log p_t + b_{Cd}^1 \log Z_{dt} + b_{Cm}^1 \log Z_{mt}$$

6. If $\max \{ |b_d^1 - b_d^0|, |b_m^1 - b_m^0|, |b_C^1 - b_C^0| \} < 10^{-5}$, stop. Otherwise set $b_i^0 = b_i^1$ for each $i = d, m, C$, and go back to step 3.

The R^2's of the three converged forecasting rules in each of the models are: for $\eta_d = \eta_m = 1$, 0.9173, 0.9240, and 0.9954; and for $\eta_d, \eta_m < 1$, 0.9781, 0.9854, and 0.9997.

References

Alessandria, G., Choi, H., 2007. Do sunk costs of exporting matter for net export dynamics? Q. J. Econ. 122 (1), 289–336.

Alessandria, G., Choi, H., 2014. Establishment heterogeneity, exporter dynamics, and the effects of trade liberalization. J. Int. Econ. 94 (2), 207–223.

Alessandria, G., Choi, H., Ruhl, K., 2015. Trade adjustment dynamics and the welfare gains from trade. Working Paper. University of Rochester.

Alessandria, G., Pratap, S., Yue, V., 2012. Export dynamics in large devaluations. Working Paper. Federal Reserve Bank of Philadelphia, Hunter College, and Federal Reserve Board.

Amiti, M., Konings, J., 2007. Trade liberalization, intermediate inputs, and productivity: evidence from Indonesia. Am. Econ. Rev. 97 (5), 1611–1638.

Atkeson, A., Burstein, A., 2010. Innovation, firm dynamics, and international trade. J. Polit. Econ. 118 (3), 433–484.

Atkeson, A., Kehoe, P., 2005. Modeling and measuring organization capital. J. Polit. Econ. 113 (5), 1026–1053.

Backus, D., Kehoe, P., Kydland, F., 1994. Dynamics of the trade balance and the terms of trade: the J-curve? Am. Econ. Rev. 84 (1), 84–103.

Bernard, A.B., Jensen, J.B., Schott, P.K., 2009. Importers, exporters and multinationals: a portrait of firms in the U.S. that trade goods. In: Dunne, T., Jensen, J.B., Roberts, M.J. (Eds.), Producer Dynamics: New Evidence From Micro Data. University of Chicago Press.

Biscourp, P., Kramarz, F., 2007. Employment, skill structure and international trade: firm-level evidence for France. J. Int. Econ. 72 (1), 22–51.

Blaum, J., Lelarge, C., Peters, M., 2015. The gains from input trade in firm-based models of importing. NBER Working Paper 21504.

Burstein, A., Cravino, J., 2015. Measured aggregate gains from international trade. Am. Econ. J. Macroecon. 7 (2), 181–218.

Burstein, A., Melitz, M.J., 2013. Trade liberalization and firm dynamics. In: Acemoglu, D., Arellano, M., Dekel, E. (Eds.), Advances in Economics and Econometrics: Tenth World Congress. Cambridge University Press, New York, NY, pp. 283–328.

Ethier, W.J., 1982. National and international returns to scale in the modern theory of international trade. Am. Econ. Rev. 72 (3), 389–405.

Ffrench-Davis, R., Saez, R.E., 1995. Comercio y desarollo industrial en chile. Coleccion Estud. CIEPLAN 41 (1), 67–96.

Gallaway, M.P., McDaniel, C.A., Rivera, S.A., 2003. Short-run and long-run industry-level estimates of U.S. Armington elasticities. N. Am. J. Econ. Financ. 14 (1), 49–68.

Ghironi, F., Melitz, M., 2005. International trade and macroeconomic dynamics with heterogeneous firms. Q. J. Econ. 120 (3), 865–915.

Goldberg, P.K., Khandelwal, A.K., Pavcnik, N., Topalova, P., 2010. Imported intermediate inputs and domestic product growth: evidence from India. Q. J. Econ. 125 (4), 1727–1767.

Gopinath, G., Neiman, B., 2014. Trade adjustment and productivity in large crises. Am. Econ. Rev. 104 (3), 793–831.

Halpern, L., Koren, M., Szeidl, A., 2015. Imported inputs and productivity. Am. Econ. Rev. 105 (12), 3660–3703.

Hopenhayn, H., Rogerson, R., 1993. Job turnover and policy evaluation: a general equilibrium analysis. J. Polit. Econ. 101 (5), 915–938.

Kasahara, H., 2004. Technology adoption under relative factor price uncertainty: the putty-clay investment model. working paper. University of British Columbia.

Kasahara, H., Lapham, B., 2013. Productivity and the decision to import and export: theory and evidence. J. Int. Econ. 89 (2), 297–316.

Kasahara, H., Rodrigue, J., 2008. Does the use of imported intermediates increase productivity? Plant-level evidence. J. Dev. Econ. 87 (1), 106–118.

Kehoe, T.J., Ruhl, K.J., 2008. Are shocks to the terms of trade shocks to productivity? Rev. Econ. Dyn. 11 (4), 804–819.

Khan, A., Thomas, J.K., 2003. Nonconvex factor adjustments in equilibrium business cycle models: do nonlinearities matter? J. Monet. Econ. 50 (2), 331–360.

Krusell, P., Smith, A.A., 1998. Income and wealth heterogeneity in the macroeconomy. J. Polit. Econ. 106 (5), 867–896.

Kugler, M., Verhoogen, E., 2009. Plants and imported inputs: new facts and an interpretation. Am. Econ. Rev. Pap. Proc. 99 (2), 501–507.

Kurz, C.J., 2006. Outstanding outsourcers: a firm-and plant-level analysis of production sharing. FEDS Discussion Paper 2006-4.

Liu, L., 1993. Entry-exit, learning, and productivity change: evidence from Chile. J. Dev. Econ. 42 (2), 217–242.

Lu, D., Mariscal, A., Mejía, L.-F., 2016. How firms accumulate inputs: evidence from import switching. Working Paper. University of Rochester.

Lucas, R.E., 1978. On the size distribution of business firms. Bell J. Econ. 9 (2), 508–523.

Muendler, M.-A., 2004. Trade, technology, and productivity: a study of Brazilian manufacturers, 1986–1998. Working Paper. University of California-San Diego.

Ramanarayanan, A., 2012. Imported inputs and the gains from trade. Working Paper. University of Western Ontario.

Reinert, K., Roland-Holst, D., 1992. Armington elasticities for United States manufacturing sectors. J. Policy Model. 14 (5), 631–639.

Romer, P.M., 1990. Endogenous technological change. J. Polit. Econ. 98 (5), S71–S102.

Ruhl, K.J., 2008. The elasticity puzzle in international economics. Working Paper. University of Texas at Austin.