Imported Inputs and the Gains from Trade[*]

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Abstract

Empirical studies find that trade liberalization raises productivity at plants that use imported inputs. This paper develops a model to illustrate and quantify how these productivity gains shape the aggregate welfare gains from trade. Countries differ in their costs of producing intermediates. Plants in each country choose a fraction of inputs to optimally source from the lowest cost supplier country, with the rest purchased domestically. Sourcing more inputs requires higher up-front fixed costs, but reduces variable input costs. Consistent with a broad set of studies with plant-level data, not all plants import; import shares vary among those that do; importers are larger than nonimporters; and importing more leads to higher productivity. Import decisions amplify productivity differences across plants, with higher within-plant productivity gains at larger plants. When calibrated to Chilean data, this concentration of productivity gains raises the aggregate welfare gain from trade by sixty percent.

1 Introduction

Intermediate inputs comprise the bulk of international trade in goods for industrialized countries. A recent literature examining firm- and plant-level data finds that imported inputs are concentrated among relatively few producers, and there is substantial heterogeneity among them in the share of input expenditures spent on imports.[1] In addition, imported inputs raise plant-level productivity, and trade liberalization results in within-plant productivity gains at importing plants.[2] These facts suggest that the distribution of imported inputs across different plants matters for the aggregate welfare gains from trade. However, until recently, most work on intermediate goods in international trade has employed models in which all producers use an identical bundle of imported and domestic goods.[3]

This paper develops a model to examine how the distribution of imported inputs and the resulting within-plant productivity gains shape the aggregate welfare gains from trade. I develop a general equilibrium model with heterogeneous plants in which imported inputs raise plant-level productivity, but it is increasingly costly to import a large fraction of inputs. The aggregate welfare gain from opening to trade is driven by the distribution of within-plant gains: larger plants import more, as in the data, so productivity gains are concentrated at these plants, raising aggregate gains from trade. This result contrasts with Arkolakis, Costinot, and Rodriguez-Clare (2012), who show that in a broad class of models, heterogeneity in plant-level decisions has no effect on the welfare gains from trade. In a version of my model calibrated to Chilean plant-level data, the welfare gain from trade is 60 percent higher than in an economy with the same aggregate trade volume, but without heterogeneity in import shares.

In my model, plants producing a final good use a continuum of intermediate inputs, any of which can be produced domestically or abroad. Intermediate goods are produced in different countries at different unit cost, as in the Ricardian model of Eaton and Kortum (2002). For each input, a plant chooses whether to pay a fixed cost to "source" the input – buy it from the cheapest location – or to buy it domestically. A plant therefore faces a tradeoff between paying a higher fixed cost to source more inputs in order to reduce its marginal cost. Plants differ in their underlying productive efficiency, and more efficient plants find

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[1]Kasahara and Lapham (2007) have documented these facts for Chile, while similar facts can be found in Kurz (2006) and Bernard, Jensen, and Schott (2009) for the US, Biscourp and Kramarz (2007) for France, Amiti and Konings (2007) for Indonesia, and Halpern, Koren, and Szeidl (2009) for Hungary.

[2]See, for example, Kasahara and Rodrigue (2008) on the first result and Amiti and Konings (2007) on the second.

[3]Trade in intermediate goods plays a role in, among others, Sanyal and Jones (1982), Ethier (1982), Krugman and Venables (1995), and Eaton and Kortum (2002). In addition, Grossman and Helpman (1990) and Rivera-Batiz and Romer (1991) use models of trade in intermediate inputs to study the relationship between trade and growth.

it profitable to source – and hence import – more inputs than relatively inefficient plants. Sourcing more inputs lowers input prices, so a plant that sources (and hence imports) more inputs appears more productive – it produces more output with the same expenditure on inputs – than a plant that sources fewer inputs. Importing plants, therefore, are larger and more productive than nonimporting plants, both because they tend to be more efficient producers, and because importing amplifies efficiency differences. In addition, liberalizing trade generates within-plant productivity gains at importing plants, as they reduce their marginal costs by sourcing and importing more inputs.

To quantitatively evaluate the aggregate impact of these within-plant productivity gains, I calibrate the model to a set of facts from Chilean plant-level data over the period 1986-1996. In particular, I use the model to analytically map parameters governing the costs of importing and productivity heterogeneity to key moments of the endogenous cross-sectional distributions of import shares and plant size.

The main results invove two sets of counterfactuals, one involving the calibrated model, and one involving an alternative model in which all plants import the same share of inputs, calibrated to generate the same level of trade as the original model. Comparing these two models tells us how the distribution of gains from importing across plants affects the aggregate welfare gain from trade. In each model, I compare the economy with trade to the economy with autarky to compute the welfare gain from trade. In the model with heterogeneous import shares, trade at the level in the Chilean data generates close to a three percent increase in the levels of both aggregate welfare and total factor productivity (TFP). This number is about 60 percent higher than in the model with no heterogeneity in import shares.

These results show that heterogeneity in import shares provides additional gains from trade which are quantitatively significant. This result differs from those in Arkolakis, Costinot, and Rodriguez-Clare (2012), who show that plant-level heterogeneity does not provide a new source of gains from trade in the models they consider. This difference is because the distribution of within-plant productivity gains from trade matters in my model. These within-plant productivity gains translate into bigger aggregate gains when they are concentrated in large plants that import and produce a lot. In particular, a plant-level decomposition of the change in aggregate productivity from opening to trade shows that the covariance between plant output growth and within-plant productivity growth accounts for the bulk of the aggregate gains. Ignoring this channel would result in understating the gains from trade.

This paper builds on recent empirical and theoretical work examining producer-level heterogeneity in the use of imported inputs. Amiti and Konings (2007), Kasahara and Rodrigue (2008), and Halpern, Koren, and Szeidl (2009) provide evidence that imported

inputs raise plant-level productivity. Goldberg, Khandelwal, Pavcnik, and Topalova (2010) also measure the benefits of imported inputs using data on firms, though they measure the effects on the number of products firms produce.

Most related to this paper are Gopinath and Neiman (2011) and Antràs, Fort, and Tintelnot (2014). Gopinath and Neiman show that heterogeneity in the adjustment of the number of inputs imported by Argentinean firms contributes to high-frequency movements in aggregate productivity. They use detailed customs data to decompose product-level changes in imports, which requires excluding non-importing producers from the analysis. In contrast, I use plant-level data that reports input expenditures at a higher level of aggregation than the product level, but includes information on non-importing manufacturing plants.[4] Gopinath and Neiman also emphasize how imperfect competition is necessary for their model to generate the productivity movements they consider, while market power plays no role in my analysis of welfare gains from imported inputs. Overall, this paper reinforces Gopinath and Neiman's result that the distribution of importing decisions matters for the aggregate gains from trade. In Antràs, Fort, and Tintelnot (2014), a firm chooses the countries from which to source inputs, and sourcing from more countries requires paying a higher fixed cost. They focus on the margin of the number of source countries in accounting for import flows.

Section 2 below sets out the model. Section 3 discusses how to map parameters to the cross-sectional distribution of import shares and plant size, and performs a numerical simulation of the model calibrated to Chilean plant-level data. Section 3 also quantifies the gains from trade in the calibrated model.

2   Model

The model economy consists of $J \geq 2$ countries in which production takes place in two stages: internationally tradeable intermediate goods are produced with labor, and a final, nontradable good is produced using labor and intermediate goods. The final good is produced by heterogeneous plants that differ in their efficiency and in the fraction of goods they choose to import. All producers are perfectly competitive.

2.1   Production and prices of intermediate goods

Intermediate goods production is similar to the Ricardian models of Dornbusch, Fischer, and Samuelson (1977) and Eaton and Kortum (2002). Producers in each country have

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[4] About three quarters of manufacturing plants in Chile do not use any imported inputs. Excluding these plants from my analysis would overstate the aggregate gains from trade.

technologies to produce a continuum of intermediate goods labelled $\omega \in [0,1]$. Good ω can be produced with labor in country i with efficiency $Z_i(\omega)$. Denoting the wage rate in country i as w_i, the cost of producing a unit of good ω is $\frac{w_i}{Z_i(\omega)}$. As in Eaton and Kortum (2002), $Z_i(\omega)$ is the realization of a random variable drawn independently and identically across ω and i from a Frechet distribution,

$$\Pr(Z_i(\omega) \leq Z) = e^{-T_i Z^{-\theta}}$$

Here, T_i controls the level and θ the dispersion of efficiency within country i.

Intermediate goods are tradeable, but producers face proportional trade costs when selling internationally: in order to sell one unit of any good ω in country j, a producer in country i must produce τ_{ij} units, where $\tau_{ij} > 1$ if $i \neq j$ and $\tau_{ii} = 1$. Since producers are perfectly competitive, the price of a good sold from i to j is

$$p_{ij}(\omega) = \frac{\tau_{ij} w_i}{Z_i(\omega)}$$

The distribution of prices of goods that country j can potentially buy from country i is:

$$\Pr(p_{ij}(\omega) \leq p) = 1 - e^{-T_i(\tau_{ij} w_i)^{-\theta} p^{\theta}}$$

2.2 Input sourcing and final good production

A continuum of mass one of heterogeneous plants produce the final good in each country using labor ℓ and a composite x of intermediates, according to:

$$y = z^{1-\alpha-\eta} \ell^{\alpha} x^{\eta}$$

where $\alpha + \eta < 1$. Although plants are perfectly competitive and produce a homogeneous final good, plants with different efficiencies coexist because of decreasing returns to scale. Plants' efficiencies z are distributed in country j according to a Pareto distribution with density

$$h_j(z) = \zeta \underline{z}_j^{\zeta} z^{-\zeta-1} \tag{1}$$

The composite intermediate input is given by the Cobb-Douglas aggregate:

$$x = \exp\left(\int_0^1 \log \tilde{x}(\omega) \, d\omega\right)$$

where $\tilde{x}(\omega)$ refers to units of good ω and x is units of the composite input.

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2.2.1 Two extremes

If a plant bought each intermediate good from the cheapest country, then, as Eaton and Kortum (2002) show, the fraction of country j plants' intermediate input expenditures that is spent on goods from country i would be:

$$\lambda_{ij} = \frac{T_i \left(\tau_{ij} w_i\right)^{-\theta}}{\sum_k T_k \left(\tau_{kj} w_k\right)^{-\theta}} \tag{2}$$

and the price of a unit of the composite input in country j would be:

$$p_j^s = \left(\sum_i T_i \left(\tau_{ij} w_i\right)^{-\theta}\right)^{-1/\theta} \tag{3}$$

In contrast, if a plant purchased all intermediate goods domestically, then the composite input bundle price p_j^d would equal the country j term in equation (3),

$$p_j^d = \left(T_j w_j^{-\theta}\right)^{-1/\theta} \tag{4}$$

which is higher than p_j^s for any $\theta > 0$.

2.2.2 Costly sourcing of imports

In contrast with the standard Ricardian model, I assume it is costly to source each input from the cheapest location (hereafter referred to simply as "sourcing") rather than buy it from domestic suppliers. This cost is a stand-in for the costs of searching for and maintaining a relationship with a foreign supplier and the costs of testing and finding out whether an imported product is an appropriate substitute for a domestic one. Specifically, if a plant sources a fraction n of its inputs, it has to pay $g(n) = b(f^n - 1)$ units of labor. I assume $f > 1$, so that the total cost a plant pays is increasing and convex in the fraction of goods sourced. In addition $g(0) = 0$, so the fixed cost associated with sourcing nothing and purchasing everything from domestic suppliers is normalized to zero. Introducing this fixed cost function generates differences in importing behavior across plants, as seen in the data.

The benefit of sourcing a larger fraction of inputs is that it lowers the price index of the input bundle: if a plant in country j sources n inputs, the price index among those n goods is given by p_j^s as defined in (3), while the price index for the remainder of the inputs is given by p_j^d, in (4).[5] So, the price for a unit of the overall input bundle if a plant sources n of the

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[5]Although this model is static, there is an implicit timing assumption: plants choose the fraction n of inputs to source before the realization of intermediate good producers' efficiencies $z_i(\omega)$. This assumption

inputs is

$$p_j(n) = \left(p_j^s\right)^n \left(p_j^d\right)^{1-n} \tag{5}$$

Since $p_j^s < p_j^d$, $p_j(n)$ is decreasing in n: plants that source a higher fraction of their inputs face lower per-unit input costs. Using (3) and (4),

$$p_j(n) = (\lambda_{jj})^{n/\theta} T_j^{-1/\theta} w_j \tag{6}$$

where λ_{jj} (see equation (2)) is the fraction of expenditures on the n *sourced* inputs purchased domestically, and $1 - \lambda_{jj}$ is the fraction spent on imports. Overall, a plant that sources n inputs spends a fraction $n(1 - \lambda_{jj})$ on imported inputs, and $n\lambda_{jj} + 1 - n$ on domestic goods.

The input sourcing and production choices of plants can be separated into two steps: first choose input quantities to maximize variable profit, given a sourcing policy (i.e., given an n), then choose n to maximize overall profits given the optimal quantity decisions. The variable profit of a plant in country j with efficiency z that has chosen to source n of its inputs is given by:

$$\tilde{\pi}_j(z, n) = \max_{\ell, x} P_j z^{1-\alpha-\eta} \ell^\alpha x^\eta - w_j \ell - p_j(n) x$$

where P_j is the price of the final good in country j. The profit-maximizing inputs and outputs can be written:

$$\ell_j(z, n) = \frac{\alpha}{w_j} z v_j \gamma_j^n \tag{7}$$

$$x_j(z, n) = \frac{\eta}{p_j(n)} z v_j \gamma_j^n \tag{8}$$

$$y_j(z, n) = \frac{1}{P_j} z v_j \gamma_j^n \tag{9}$$

where

$$v_j = \left(P_j \left(\frac{\alpha}{w_j}\right)^\alpha \left(T_j^{1/\theta} \frac{\eta}{w_j}\right)^\eta \right)^{1/(1-\alpha-\eta)}$$

$$\gamma_j = \lambda_{jj}^{\frac{-\eta}{\theta(1-\alpha-\eta)}}$$

Maximized variable profit given n is then $\tilde{\pi}_j(z, n) = (1 - \alpha - \eta) z v_j \gamma_j^n$.

Since $\lambda_{jj} \leq 1$, $\gamma_j \geq 1$, so given n, a plant with higher z is larger in terms of labor, intermediate expenditure, and outputs, and has higher profits.

Now, the choice of n and total profit of a plant with efficiency z in country j are deter-

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generates the formula for the price index $p_j(n)$ in (5), and allows the closed-form solution to plants' optimal choice of n below.

mined by

$$\pi_j(z) = \max_{n \in [0,1]} \tilde{\pi}_j(z, n) - w_j b(f^n - 1)$$

Variable profit rises exponentially with n, at rate γ_j, while the fixed cost of sourcing inputs also rises exponentially at rate f. As shown in the appendix, (i) a sufficient condition for the existence of a unique solution to this problem is $f > \gamma_j$; and (ii) if that is the case, then the optimal choice of n for a plant with efficiency z in country j is:

$$n_j(z) = \begin{cases} 0 \text{ if } z \leq z_j^0 \\ \psi_j \log z + \phi_j \text{ if } z \in (z_j^0, z_j^1) \\ 1 \text{ if } z \geq z_j^1 \end{cases} \tag{10}$$

where

$$\psi_j = \frac{1}{\log f_j - \log \gamma_j}$$

$$\phi_j = \psi_j \log \left(\frac{(1 - \alpha - \eta) v_j \log \gamma_j}{w_j b_j \log f_j} \right)$$

and

$$z_j^0 = \exp \left(\frac{-\phi_j}{\psi_j} \right)$$

$$z_j^1 = \exp \left(\frac{1 - \phi_j}{\psi_j} \right)$$

The solution takes the form of two cutoffs, z_j^0 and z_j^1, with $z_j^0 < z_j^1$: plants with efficiency below z_j^0 source none of their inputs globally and purchase everything from domestic suppliers, while plants with efficiency above z_j^1 source all of their inputs, and purchase a fraction λ_{jj} of these inputs domestically. Between these two thresholds, the fraction of inputs sourced is linear in the log of efficiency, with slope $\psi_j = \frac{1}{\log f - \log \gamma_j}$. Notice that the sufficient condition for existence and uniqueness of this solution ($f > \gamma_j$) also implies that $n_j(z)$ is increasing in z: more efficient plants source a higher share of their inputs. In this range, the import share, $n_j(z)(1 - \lambda_{jj})$, is increasing with z, so more efficient plants import a larger share of their intermediate inputs. Also, since size – measured by either labor, output, or total intermediate expenditures – is increasing in efficiency z (from (7)-(9)), size and import share are positively related. In practice, when calibrating this model, the moments I match relating size and importing behavior guarantee that $f > \gamma_j$.

2.2.3 Heterogeneity in import shares

Figure 1 illustrates the functional form of $n_j(z)$, juxtaposed against the distribution of efficiency levels $h_j(z)$ (the parameters for the figure are those calibrated below). The interaction of the exogenous heterogeneity in efficiency and the choice of n generates a distribution for import shares, $s_j(z) = (1 - \lambda_{jj}) n_j(z)$. Among those plants that import a positive amount, ignoring for a moment the restriction that $n_j(z) \le 1$,

$$
\begin{aligned}
\Pr\left(s_j(z) \ge s \mid s_j(z) \ge 0\right) &= \frac{\Pr\left((1 - \lambda_{jj})\left(\psi_j \log z + \phi_j\right) \ge s\right)}{\Pr\left((1 - \lambda_{jj})\left(\psi_j \log z + \phi_j\right) \ge 0\right)} \\
&= \exp\left(-\zeta \frac{s}{(1 - \lambda_{jj})\psi_j}\right)
\end{aligned}
$$

Therefore, the cumulative distribution function of import shares, for $s > 0$, is:

$$
\begin{aligned}
G_j(s) &\equiv \Pr\left(s_j \le s \mid s_j \ge 0\right) \\
&= \begin{cases} 1 - \exp\left(-\zeta \frac{s}{(1 - \lambda_{jj})\psi_j}\right) & \text{if } 0 < s < 1 - \lambda_{jj} \\ 1 \text{ if } s \ge 1 - \lambda_{jj} \end{cases}
\end{aligned}
\tag{11}
$$

The distribution of import shares is an exponential distribution with parameter $\frac{\zeta}{(1 - \lambda_{jj})\psi_j}$ up to the point $1 - \lambda_{jj}$, where there is a mass point, equal to the fraction of plants that source all of their intermediate inputs (those with z above z_j^1).

2.3 Market clearing and equilibrium

A representative consumer in each country j values consumption of the final good, inelastically supplies labor at the level $\bar{L}_j$, and receives the profits of all final good plants. The consumer spends this income on consumption of the final good produced by plants, so the budget constraint is

$$
P_j C_j = w_j \bar{L}_j + \int \pi_j(z) h_j(z) \, dz
$$

The market clearing condition for labor requires that the labor used by intermediate goods producers plus the labor used by final good plants in each country j adds up to $\bar{L}_j$. Since intermediate goods producers are perfectly competitive, their total payments to labor
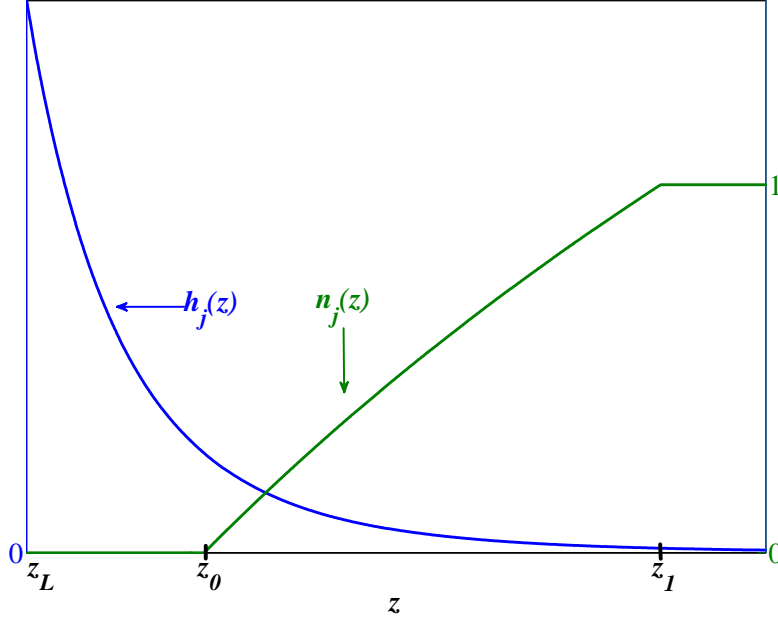
Figure 1: Heterogeneity in efficiency and import shares. $h_j(z)$ (left axis) is the density of efficiency draws in country j, and $n_j(z)$ (right axis) is the optimal sourcing decision of a plant with efficiency z in country j.

equal their sales, which are:

$$\sum_k \left(\int \lambda_{jk} n_k(z) p_k(n_k(z)) x_k(z, n_k(z)) h_k(z) \, dz \right) \qquad (12)$$
$$+ \int (1 - n_j(z)) p_j(n_j(z)) x_j(z, n_j(z)) h_j(z) \, dz$$

The first line in (12) is total sales to plants in all countries sourcing intermediate goods from country j. Plants in each country k with efficiency z spend a fraction $\lambda_{jk} n_k(z)$ of their intermediate expenditures $p_k(n_k(z)) x_k(z, n_k(z))$ on j's goods, and there is mass $h_k(z)$ of plants with each efficiency z. The second line is additional sales to final good plants within j of the goods that they decide not to source, and hence must purchase from country j's intermediate good producers. Each plant in j with efficiency z spends a fraction $1 - n_j(z)$ of its intermediate expenditures on its own country's intermediates in this way.

Payments to labor by final good plants (both for production and for fixed costs) is given by:

$$w_j \int [\ell_j(z, n_j(z)) + g(n_j(z))] h_j(z) \, dz \qquad (13)$$

So the labor market clearing condition states that (12) and (13) equal total payments to

labor:

$$
\begin{aligned}
w_j \bar{L}_j &= \sum_k \left(\int \lambda_{jk} n_k (z) \, p_k (n_k (z)) \, x_k (z, n_k (z)) \, h_k (z) \, dz \right) \\
&\quad + \int (1 - n_j (z)) \, p_j (n_j (z)) \, x_j (z, n_j (z)) \, h_j (z) \, dz \\
&\quad + w_j \int [\ell_j (z, n_j (z)) + g (n_j (z))] \, h_j (z) \, dz
\end{aligned}
$$

Finally, balanced trade requires that country j's exports,

$$
\sum_{k \neq j} \left(\int \lambda_{jk} n_k (z) \, p_k (n_k (z)) \, x_k (z, n_k (z)) \, h_k (z) \, dz \right)
$$

equal its imports,

$$
\int (1 - \lambda_{jj}) \, n_j (z) \, p_j (n_j (z)) \, x_j (z, n_j (z)) \, h_j (z) \, dz
$$

which, rearranging, gives

$$
\begin{aligned}
&\sum_k \left(\int \lambda_{jk} n_k (z) \, p_k (n_k (z)) \, x_k (z, n_k (z)) \, h_k (z) \, dz \right) \\
&= \int n_j (z) \, p_j (n_j (z)) \, x_j (z, n_j (z)) \, h_j (z) \, dz
\end{aligned}
$$

An equilibrium is a set of wages w_j and final good prices P_j such that, given the plant-level decisions characterized in the previous subsection, market clearing for labor and trade balance hold for each country.

Using the plant-level input decisions in (7)-(8) and (10), the labor market clearing condition and trade balance condition in each country j can be written in terms of three moments of the distribution of z,

$$
w_j \bar{L}_j = \alpha \mu_{Yj} + \sum_k \lambda_{jk} \eta \mu_{Mk} + \eta \left(\mu_{Yj} - \mu_{Mj} \right) + w_j \mu_{Hj} \tag{14}
$$

and

$$
\sum_k \lambda_{jk} \mu_{Mk} = \mu_{Mj} \tag{15}
$$

where

$$
\mu_{Yj} = v_j \int z \gamma_j^{n_j (z)} h_j (z) \, dz
$$

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$$\mu_{Mj} = v_j \int z n_j(z) \gamma_j^{n_j(z)} h_j(z) \, dz$$

$$\mu_{Hj} = b_j \left(\int \left(f^{n_j(z)} - 1 \right) h_j(z) \, dz \right)$$

These three terms are related to aggregate revenue of final-good producing plants (which is equal to μ_{Yj}), aggregate imports of intermediate goods (which is equal to $(1 - \lambda_{jj}) \eta \mu_{Mj}$), and aggregate payments for fixed costs (which is equal to $w_j \mu_{Hj}$). Total final consumption C_j is then equal to the value of total labor income plus profits,

$$C_j = \frac{w_j \bar{L}_j + (1 - \alpha - \eta) \mu_{Yj} - w_j \mu_{Hj}}{P_j} \tag{16}$$

2.4 The link between importing and productivity

In this model, importing raises plant-level productivity when input expenditures are measured across plants using common price deflators, as is standard in plant-level data sets. Sourcing some inputs (and importing a fraction of those inputs sourced) lowers the prices on average that a plant pays for its input bundle. Productivity then appears higher at plants that import some of their inputs because they produce more output with the same expenditures on inputs, compared to plants that purchase all of their inputs domestically.

The output of a plant in country j with efficiency z can be written:

$$\hat{y}_j(z) = z^{1-\alpha-\eta} \hat{\ell}_j(z)^{\alpha} \hat{X}_j(z)^{\eta} p_j(n_j(z))^{-\eta}$$

where $\hat{y}_j(z) = y_j(z, n_j(z))$ is the output of a plant with efficiency z (who chooses to source a fraction $n_j(z)$ of inputs), with other variables defined similarly. $\hat{X}_j(z)$ are *expenditures* on intermediate goods by the plant,

$$\hat{X}_j(z) = p_j(n_j(z)) x_j(z, n_j(z))$$

Deflating intermediate expenditures by any common price index P_I, total factor productivity (TFP) measured at the plant level is

$$\frac{\hat{y}_j(z)}{\hat{\ell}_j(z)^{\alpha} \left(\hat{X}_j(z) / P_I \right)^{\eta}} = z^{1-\alpha-\eta} p_j(n_j(z))^{-\eta} P_I^{\eta}$$

Therefore, plants who choose higher n, and hence pay a lower input price $p_j(n_j(z))$, appear

more productive that those that choose a lower n.[6]

As a function of the import expenditure share, $s_j(z) = n_j(z)(1 - \lambda_{jj})$, the gain (in logs) in productivity for a plant relative to sourcing none of its inputs (and buying them all from domestic suppliers) is, using $p_j(n)$ from (6):

$$\log\left(\frac{p_j(n_j(z))}{p_j(0)}\right)^{-\eta} = \frac{s_j(z)}{1 - \lambda_{jj}}\frac{\eta}{\theta}\log\left(\frac{1}{\lambda_{jj}}\right)$$

Since $\frac{\log(1/\lambda_{jj})}{1-\lambda_{jj}}\frac{\eta}{\theta} > 0$, the productivity gain of importing is increasing in a plant's import share. The magnitude of this productivity effect depends directly on two parameters – η, the share of intermediate inputs in total costs, and θ, the degree of heterogeneity in the prices of intermediate inputs – as well as the fraction of sourced inputs that are optimally purchased domestically in equilibrium, λ_{jj}. The lower is θ, the greater the dispersion in prices of intermediate inputs, so the greater is the incentive to exploit comparative advantage by sourcing inputs. Also, $\frac{\log(1/\lambda_{jj})}{1-\lambda_{jj}}$ is decreasing in λ_{jj}, so that the less open a country is, the lower is the productivity gain from sourcing inputs.

3   Quantitative Analysis

In this section, I analyze the model's quantitative implications for productivity and welfare in a setting with two countries. I calibrate several parameters to cross-sectional facts from Chilean plant-level data, so I take the two countries to be Chile (country 1) and the rest of the world (country 2). The goal of these exercises is to quantify the welfare gains from trade through imported inputs, and to illustrate how these gains depend on the distribution of plant-level import shares.

3.1   Calibration

Table 1 summarizes the parameter values. I choose the share parameters in production, $\eta = 0.5$ and $\alpha = 0.35$, so that 50% of gross output goes to intermediate input expenditures,

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[6]An alternative way to define the labor input is to include the fixed costs of sourcing. Plants that import a higher fraction of goods require more resources in the form of the fixed cost for sourcing, which offsets some of the gain in output. In the quantitative analysis, I also report the following measure of TFP in terms of total labor input, $\hat{L}_j(z) = \hat{\ell}_j(z) + g(n_j(z))$:

$$\frac{\hat{y}_j(z)}{\hat{L}_j(z)^\alpha\left(\hat{X}_j(z)/P_I\right)^\eta} = z^{1-\alpha-\eta}p_j(n_j(z))^{-\eta}\left(\frac{\hat{\ell}_j(z)}{\hat{L}_j(z)}\right)^\alpha P_I^\eta$$

and 70% of value-added (gross output net of intermediate expenditures) is paid to labor. I assume that the lower bound of productivity draws in the final good, $\underline{z}_j$, the labor endowment $\bar{L}_j$, and the level parameter of the Frechet distribution T_j are all equal within a country, $\underline{z}_j = \bar{L}_j = T_j$. Alvarez and Lucas (2007) use a similar assumption that labor force and the technology level are proportional within each country. Additionally, I set $\underline{z}_1 = \bar{L}_1 = T_1 = 1$ as a normalization. Given the rest of the parameters, the levels of T_2 and τ_{12} determine the share of Chile in world GDP and aggregate Chilean imports as a share of Chilean GDP.

The remaining parameters determine the levels and dispersion of importing and size among importing and nonimporting plants in the model. These are the variable importing cost, τ_{21}, the dispersion in intermediate good efficiencies θ, the shape parameter ζ for the Pareto distribution of final good efficiencies, and the parameters of the fixed cost function b and f. I choose these five parameters so that the model matches averages of moments in Chilean manufacturing plant-level data over the period 1987-1996, as described in the following subsections.

Table 1: Calibration: Parameters

parameter	value	role
η	0.50	intermediate share of gross output
α	0.35	labor share of gross output
T_1	1.00	technology / labor force in Chile
T_2	187.59	technology / labor force in ROW
τ_{12}	0.96	per-unit variable cost to ship from Chile to ROW
τ_{21}	1.64	per-unit variable cost to ship from ROW to Chile
θ	3.72	shape parameter in distribution of intermediate efficiencies
ζ	11.20	shape parameter of distribution of final good efficiencies
b	0.09	level parameter in importing fixed cost function
f	16.63	curvature parameter in importing fixed cost function

3.1.1 Average and standard deviation of import shares

Given the distribution of import shares $G_1(s)$ derived in (11), the average import share in country 1 (Chile) is

$$
\begin{aligned}
\bar{s}_1 &= \int_0^1 s \, dG_1(s) \\
&= (1 - \lambda_{11}) \frac{\psi_1}{\zeta} \left(1 - e^{-\zeta/\psi_1} \right)
\end{aligned}
$$

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The variance of import shares, similarly, is

$$
\begin{aligned}
\sigma_1^2 &= \int_0^1 s^2 dG_1(s) - (\mu_1^s)^2 \\
&= (1 - \lambda_{11})^2 \frac{2\psi_1}{\zeta} \left(\frac{\psi_1}{\zeta} - e^{-\zeta/\psi_1} \left(\frac{\psi_1}{\zeta} + 1 \right) \right) - (\bar{s}_1)^2
\end{aligned}
$$

These two statistics pin down the two factors $\frac{\psi_1}{\zeta} = \frac{1}{\zeta(\log f_1 - \log \gamma_1)}$ and λ_{11}.

3.1.2 The dispersion in imports among importers

For a given import share s, a high efficiency plant would be larger than a low efficiency plant, measured by labor or inputs purchased. But high efficiency plants also choose high import shares. Therefore, the dispersion in size from the exogenous variation in z is amplified through the dispersion in import shares generated by the curvature of the fixed cost function. The relationship between dispersion in size and the curvature parameter f can be seen in percentiles of the distribution of imports among importing plants.

Let $z_j^{(q)}$ be the qth percentile of the conditional distribution of efficiencies among plants with nonzero import shares in country j, that is, the level above which there are $(100 - q)\%$ of the importing plants:

$$
\begin{aligned}
\Pr \left(z \geq z_j^{(q)} | z \geq z_j^0 \right) &= 1 - \frac{q}{100} \\
z_j^{(q)} &= \left(z_j^0 \right) \left(1 - \frac{q}{100} \right)^{-1/\zeta}
\end{aligned}
$$

Since total import purchases $M_j(z) = (1 - \lambda_{jj}) n_j(z) p_j(n_j(z)) x_j(z, n_j(z))$ are a monotonically nondecreasing function of z, the qth percentile of the distribution of imports among importing plants is given by $M_j^{(q)} = M_j \left(z_j^{(q)} \right)$. As long as q small enough that $z_j^{(q)} < z_j^1$ (so that the import share for the qth percentile plant is interior), this quantity is given by:

$$
\begin{aligned}
M_j^{(q)} &= (1 - \lambda_{jj}) n_j \left(z_j^{(q)} \right) p_j \left(n_j \left(z_j^{(q)} \right) \right) x_j \left(z_j^{(q)}, n_j \left(z_j^{(q)} \right) \right) \\
&= \left(z_j^{(q)} \right)^{1 + \psi_j \log \gamma_j} v_j \eta (1 - \lambda_{jj}) \left(\psi_j \log z_j^{(q)} + \phi_j \right) \gamma_j^{\phi_j}
\end{aligned}
$$

Now, consider the ratio of two percentiles, q and r:

$$\frac{M_j^{(q)}}{M_j^{(r)}} = \left(\frac{z_j^{(q)}}{z_j^{(r)}}\right)^{1+\psi_j \log \gamma_j} \frac{\psi_j \log z_j^{(q)} + \phi_j}{\psi_j \log z_j^{(r)} + \phi_j}$$

$$= \left(\frac{100-r}{100-q}\right)^{(1+\psi_j \log \gamma_j)/\zeta} \frac{\log\left(\frac{100-q}{100}\right)}{\log\left(\frac{100-r}{100}\right)}$$

So given two percentiles of the distribution of imports, their ratio pins down the factor:

$$\frac{1 + \psi_j \log \gamma_j}{\zeta} = \frac{\log f}{\zeta \left(\log f - \log \gamma_j\right)}$$

Given a mean import share for Chile, $\bar{s}_1$, which determines $\zeta \left(\log f - \log \gamma_1\right)$, the ratio of any two interior percentiles of the distribution of import expenditures, $\frac{M_1^{(q)}}{M_1^{(r)}}$, can be used to uniquely identify f.

For given mean and dispersion of the import share, a larger f makes the ratio $\frac{M_1^{(q)}}{M_1^{(r)}}$ larger for any two percentiles, $q > r$. A larger f makes it more costly for large plants to raise their import ratio, so dispersion in size grows without increasing the dispersion in import shares.

3.1.3 The fraction of plants importing

Plants with efficiency draws above z_j^0 use imported inputs. The fraction of plants doing so, $F_j^{im} \in [0, 1]$, is:

$$F_j^{im} = \Pr\left(z \geq z_j^0\right)$$

$$= \underline{z}_j^\zeta e^{\zeta \phi_j / \psi_j}$$

With the average import share pinning down the ratio $\frac{\zeta}{\psi_1}$, a target for F_1^{im} yields $\phi_1 = \psi_1 \log\left(\frac{(1-\alpha-\eta)v_1 \log \gamma_1}{w_1 b \log f}\right)$.

3.1.4 The average size of importing relative to nonimporting plants

The total expenditures on inputs by a plant with efficiency z are:

$$X_j(z) = p_j(n_j(z)) x_j(z, n_j(z))$$

$$= \eta z v_j \gamma_j^{n_j(z)}$$

The average size, measured by total inputs, of importing plants is

$$\bar{X}_j^m = \frac{1}{1 - \underline{z}_j^\zeta \left(z_j^0\right)^{-\zeta}} \int_{z_j^0}^\infty \eta z v_j \gamma_j^{n_j(z)} h_j(z)\, dz$$

while the average size of nonimporting plants is

$$\bar{X}_j^d = \frac{1}{\underline{z}_j^\zeta \left(z_j^0\right)^{-\zeta}} \int_{\underline{z}_j}^{z_j^0} \eta z v_j h_j(z)\, dz$$

The ratio of these two can be written (see appendix):

$$
\begin{aligned}
\frac{\bar{X}_j^m}{\bar{X}_j^d} &= \frac{1 - F_j^{im}}{F_j^{im}} \frac{1}{\left(F_j^{im}\right)^{(1-\zeta)/\zeta} - 1} \\
&\times \left(\frac{\zeta - 1}{\zeta} \frac{1}{\varsigma_{2j} - 1} \left(e^{\left(\varsigma_{2j} - 1\right)\varsigma_{1j}} - 1 \right) + \lambda_{jj}^{\frac{-\eta}{\theta(1-\alpha-\eta)}} e^{\varsigma_{1j}(1-\zeta)/\zeta} \right)
\end{aligned}
\tag{17}
$$

where F_j^{im} is the fraction of plants importing, $\varsigma_{1j} = \zeta/\psi_j$ and $\varsigma_{2j} = \left(1 + \psi_j \log \gamma_j\right)/\zeta$ are parameter combinations that are pinned down by the average import share and the ratio of import percentiles derived above, and λ_{jj} is determined from the average and standard deviation of import shares.

Therefore, given targets for the other moments, the ratio of the average size of importing plants relative to nonimporting plants in Chile, $\frac{\bar{X}_1^m}{\bar{X}_1^d}$, identifies ζ through equation (17).

3.1.5 Chilean Manufacturing Data and Model Fit

I choose the seven parameters $T_2, \tau_{12}, \tau_{21}, \theta, f, \zeta$, and b to match five moments in the model – the average import share among importing plants, the standard deviation of the import share among importing plants, the fraction of plants importing, the 75/25 percentile ratio of imports among importing plants, and the average size of importers relative to nonimporters – to data from Chile's manufacturing census, as well as two aggregate moments, Chile's share of world GDP and Chile's import/GDP ratio.[7] I use the averages over 1987-1996 of each moment as calibration targets (see Table 2).

On average, about 23% of plants report purchasing positive amounts of imported inputs. Among these plants, the average import share is 33% of total intermediate input expendi-

---

Table 2: Chilean Manufacturing Plant Data Moments, 1987-1996

year	fraction importing	avg. import share	s.d. import share	75/25 import ratio	size ratio	Chile GDP / World GDP (%)	Chile imports / Chile GDP (%)
1987	0.244	0.334	0.268	16.0	6.9	0.205	27.22
1988	0.237	0.315	0.258	13.8	4.6	0.212	27.25
1989	0.212	0.316	0.261	16.6	4.7	0.228	30.65
1990	0.204	0.329	0.263	13.0	4.4	0.233	30.55
1991	0.212	0.323	0.268	13.6	4.2	0.251	27.77
1992	0.234	0.331	0.267	15.8	3.7	0.279	28.17
1993	0.243	0.338	0.267	14.9	3.9	0.296	28.62
1994	0.264	0.335	0.276	17.3	4.4	0.308	26.57
1995	0.239	0.345	0.283	16.1	4.0	0.331	27.10
1996	0.242	0.338	0.275	17.0	4.4	0.344	28.97
average	0.233	0.330	0.269	15.4	4.5	0.269	28.29

tures, and the standard deviation of import shares across plants is about 27%. The average 75/25 ratio indicates that the importer at the 75th percentile imports about 15.4 times as much as the importer at the 25th percentile of the distribution of import expenditures. And relative to nonimporting plants, importing plants are on average 4.5 times as large as measured by their total expenditures on intermediate inputs.

Figures 2 and 3 show the cumulative distributions of the import share and (de-meaned) log imports for each year in the data, along with the model's predictions. Choosing parameters to match the moments discussed above does a fairly good job at fitting the cross-sectional distribution in import shares and import expenditures among importers in the data, except that the model generates too many plants who source all their inputs (resulting in an import share of $1 - \lambda_{11} = 0.94$). Among these plants, there is one less source of heterogeneity in import expenditures, hence the abrupt compression in the model's distribution at the right end of Figure 3.[8]

3.1.6 The productivity advantage of importing

In my model, plants gain by importing through lowering the price index for the input bundle they purchase. Looking across plants within a period, plants that import a higher share of their inputs appear more productive, even aside from the fact that plants with inherently higher efficiency z have higher import shares. Although calibrated to match moments on heterogeneity in size and import shares (and not productivity measures), the model's structure

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[8]The maximum absolute differences between the model and data distributions, averaged across years, are 0.053 (import shares) and 0.042 (log imports).
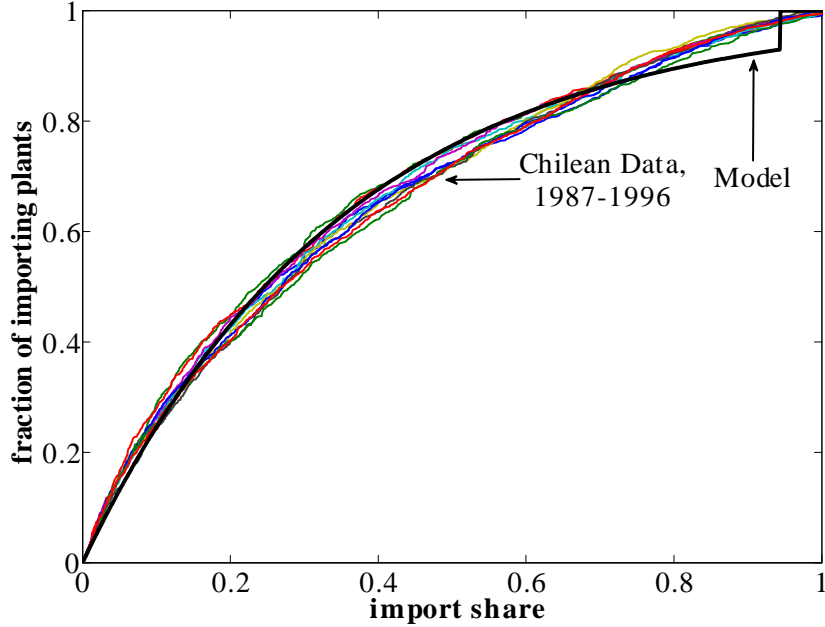
Figure 2: Cumulative distribution of import share

links the calibrated parameters to an implied gain in productivity from importing.

Several recent empirical studies have estimated this kind of productivity advantage of importing in plant-level data, including Amiti and Konings (2007) using Indonesian data, Halpern, Koren, and Szeidl (2009) using Hungarian data, and Kasahara and Rodrigue (2008) using a subset of the Chilean data considered here.[9] These papers all estimate production functions that relate a plant's output to its factor inputs and intermediate expenditures, along with indicators of whether the plant imports any of its inputs, or its import expenditure share (or both). In my model, as described in subsection 2.4, the plant-level production technology can be represented as a function of inputs ℓ and X and a plant's import share s as follows:

$$\log y\left(z\right) = \log z + \alpha \log \ell\left(z\right) + \theta \log X\left(z\right) + s\left(z\right) \frac{\eta}{\theta\left(1-\lambda_{11}\right)} \log\left(\frac{1}{\lambda_{11}}\right) \qquad (18)$$

The log gain in productivity for a plant with productivity z that uses imported inputs relative to not using imported inputs is given by the factor $s\left(z\right) \frac{\eta}{\theta(1-\lambda_{11})} \log\left(\frac{1}{\lambda_{11}}\right)$. With

---

[9]Although they do not estimate the direct producer-level productivity gain from importing, Goldberg, Khandelwal, Pavcnik, and Topalova (2010), using data on Indian firms, find that lower input tariffs, and hence higher expenditures on imported inputs, lead firms to create more new products. They argue that this is because the cost of production decreases (which similar to the increase in productivity considered here), so that producing new products becomes profitable.
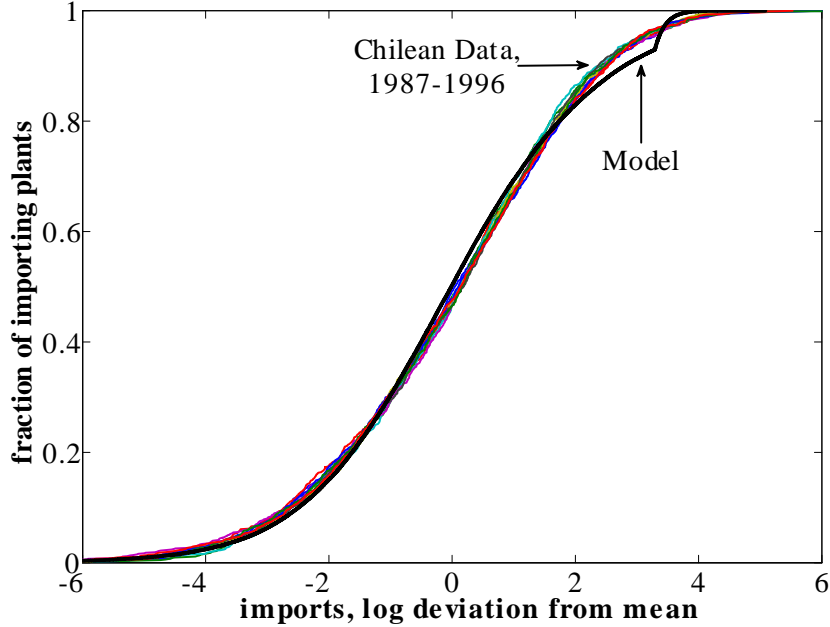
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Figure 3: Cumulative distribution of log imports, relative to mean

the calibrated parameters, $\frac{\eta}{\theta(1-\lambda_{11})} \log\left(\frac{1}{\lambda_{11}}\right) = 0.41$, which implies that a plant gains 4.1% in productivity by increasing its import share by 10 percentage points. The average productivity gain across all importing plants is given by $\bar{s}_1 \frac{\eta}{\theta(1-\lambda_{11})} \log\left(\frac{1}{\lambda_{11}}\right) = 0.135$, so an importing plant on average is 13.5% more productive than a nonimporting plant, controlling for differences in their exogenous efficiency. These numbers are in line with those reported by Kasahara and Rodrigue (2008) in their analysis of Chilean plant data. Using a continuous import share variable, their range of estimates imply that raising the import share by 10 percentage points raises productivity by 0.5% to 2.7%. Using a discrete import status variable, they find that importing raises productivity on average by between 18% and 21%. Similar magnitudes are reported in Halpern, Koren, and Szeidl (2009) and Amiti and Konings (2007).

3.2   The gains from trade

The welfare gain from trade in this model result from the productivity-improving effect of plants optimally sourcing inputs. When open to trade, plants are able to purchase inputs cheaper, and produce more for the same expenditure of resources. This raises plant-level productivity as well as the aggregate level of welfare, as measured by the value of final output for consumption. This subsection shows how the magnitude of this welfare gain depends critically on the distribution of import shares across plants: welfare gains in the calibrated model are substantially higher than in a model in which all plants import the

same share that is consistent with the same aggregate moments.

To quantitatively evaluate the gains from trade, I solve the model in autarky, i.e. $\tau_{21} = \infty$, meaning $\lambda_{11} = 1$. The measure of welfare is the value of final consumption in country 1, or equivalently, the real value of income, from (16). The welfare gain from trade is then the difference in real income, or final consumption, in the equilibrium with trade relative to the autarky equilibrium. The first number in Table 3 contains the results from this welfare calculation. The welfare gain from trade is equivalent to 2.68 percent of consumption. Since this is a static model, this should be interpreted as a permanent increase in consumption of 2.68 percent in perpetuity. The second and third numbers in the first column of Table 3 decompose this welfare gain in terms of real labor income and profits. Moving from autarky to trade raises the real wage paid to labor, since importing raises total factor productivity at some plants; however, the fixed costs associated with importing reduce the income earned as profits.

Table 3: Trade-Induced Gains in Real Income

| | Trade relative to autarky | | 5% reduction in τ_{21} | |
	Benchmark model	All plants importing	Benchmark model	All plants importing
Total income	+2.68%	+1.67%	+0.93%	+0.68%
Labor income	+9.64%	+1.67%	+1.89%	+0.68%
Profits	−36.76%	+1.67%	−8.49%	+0.68%

To asses the role of heterogeneity in importing in generating gains from trade, I also solve a model in which all plants import (or $b = 0$ in the import cost function), that is calibrated to match the aggregate share of imports in total input expenditures, and the elasticity of this import expenditure share with respect to a change in τ_{21} in the equilibrium of the model with heterogeneity. Then, each model economy generates the same amount of trade when they are open, and the same growth in trade in response to small changes in openness. In the spirit of Arkolakis, Costinot, and Rodriguez-Clare (2012), this experiment allows one to ask whether considering heterogeneity in import behavior generates *additional* gains from trade over those that exist in a model with no heterogeneity in importing. The values for these two statistics are 35.8 percent for the import share, and 6.44 for the trade elasticity. Maintaining these values in the model with all plants importing requires setting $\theta = 13.43$ and $\tau_{21} = 1.71$.

The welfare gains from trade in the model with all plants importing are in the second column of Table 3. Moving from autarky to trade generates a welfare gain of 1.67 percent. Since profits are a constant share of income in this model with all plants importing and no fixed costs, both labor income and profits rise by the same amount. Comparing the two

models, the model with heterogeneity in importing generates welfare gains that are about 60 percent larger than the model with all plants importing. Therefore, taking into account heterogeneity in importing significantly raises the welfare benefits of trade.

The right half of Table 3 shows the two models' results when variable trade costs are reduced by a small amount. Both models generate the same amount of growth in the import share (30 percent). Again, the model with heterogeneity in import shares generates an increase in welfare that is higher – by about 37 percent – than the model with all plants importing.

3.3 Changes in plant-level TFP

The gains from trade are different in these two models because of the way the productivity gains of importing are distributed across plants. Intuitively, for a given share of imported goods, spreading those imports proportionally across all plants raises their productivity by a fixed percentage, thereby raising aggregate value added in the economy. The results of Table 3 show that distributing the same share of imports alternatively – in a way that raises productivity most at the largest plants – raises aggregate value added more.

To illustrate this connection, I compare the following measure of plant-level TFP to compare across the benchmark calibration and autarky:

$$tfp_j(z) = \frac{y_j(z)}{\left(\ell_j(z) + g(n_j(z))\right)^\alpha \left(X_j(z) / \left(T_j^{-1/\theta} w_j\right)\right)^\eta} \tag{19}$$

In each case (benchmark, autarky), $y_j(z), \ell_j(z), g(n_j(z)), X_j(z)$ are output, labor for production, labor for fixed costs, and intermediate expenditures of a plant with efficiency z, and w_j is the equilibrium wage in each case. I use the index $T_j^{-1/\theta} w_j$ as an intermediate expenditure deflator because doing so means that plants that do not import anything when the economy is open gain nothing in terms of measured productivity. That is, deflating expenditures this way means that either in autarky or for plants who import nothing when the economy is open to trade, $tfp_j(z) = z^{1-\alpha-\eta}$. Also, $T_j^{-1/\theta} w_j$ is the expression for the overall price index for intermediate goods in autarky, and is the price index for domestically purchased inputs when the economy is open.

Figure 4 shows how TFP measured as in (19) changes from autarky to free trade, across the distribution of plants, both in the model with heterogeneity in import shares and in the model with all plants importing.

Average TFP growth in the benchmark model relative to autarky is the difference between diamond-marked line labelled "Benchmark" and the dashed line labelled "Autarky,"
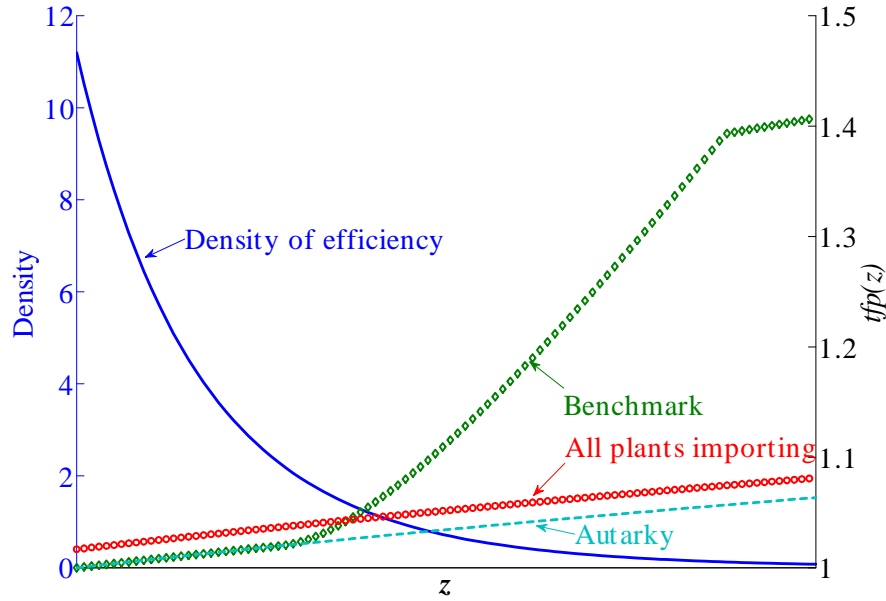
22

Figure 4: TFP across plants: autarky and equilibrium with trade, in benchmark and all-plants-importing models

integrated against the density of efficiencies. The difference between average TFP growth with and without heterogeneity is the difference between the diamond line and the circle-marked line labelled "All plants importing," integrated against the density. The magnitude of the difference between the diamond line and the circle line in the right hand side of the figure is large, but this is exactly where the density puts little weight, so this difference averages out to be only slightly positive (about 0.18%). However, since plants with high z account for a higher share of output, they contribute more to aggregate output than suggested by such an unweighted average. Table 4 reports two measures of average TFP growth relative to autarky in the benchmark model, along with an aggregate measure of TFP, where the plant-level terms in (19) are replaced with economy-wide aggregates.

Table 4: Effects of Trade on Average and Aggregate Productivity

	Trade relative to autarky: Benchmark model	
	Including fixed costs in labor	Not including fixed costs in labor
Aggregate TFP	2.94%	8.60%
Average TFP, all plants	1.85%	3.53%
Average TFP, importing plants	7.98%	15.22%

In the model with all plants importing, every number in table 4 would be 1.67 percent,

exactly the same as the welfare gain. In the first column, the average productivity gain across all plants is only 1.85 percent. However, aggregate TFP grows by much more, 2.94 percent, relative to autarky, than the 1.67 percent of the model with all plants importing. The last number in the first column shows the average TFP gain among plants that import when the economy is open to trade is about 8 percent; this number is much higher than either of the previous two, and indicates the importance of incorporating the presence of nonimporting plants in calculating aggregate gains from trade. Finally, the second column of the table reports measures that ignore the labor used in fixed costs when calculating TFP. Clearly, since opening to trade requires using resources for fixed costs that are being ignored in the calculation of the second column, these measures of TFP gains are significantly higher.

3.3.1   A Decomposition of TFP

In my model, the growth in aggregate TFP due to trade is due to both within-plant TFP growth and reallocation. More productive plants receive more resources, so account for a larger fraction of output, raising aggregate TFP. I quantify these channels by decomposing aggregate TFP. Aggregate TFP can be written as a weighted average of plant-level TFP across a sample of plants, indexed by i,

$$TFP = \sum s_i \times tfp_i$$

where s_i is plant i's share of aggregate output, and tfp_i is plant i's TFP. A change in aggregate TFP can be written:

$$TFP' - TFP = \underbrace{\sum_i \left(tfp_i' - tfp_i\right)s_i}_{\text{(WITHIN, 19\%)}} + \underbrace{\sum_i \left(s_i' - s_i\right)tfp_i}_{\text{(BETWEEN, 12\%)}} + \underbrace{\sum_i \left(s_i' - s_i\right)\left(tfp_i' - tfp_i\right)}_{\text{(CROSS, 69\%)}}$$

Here, primed variables denote the equilibrium with trade, and non-primed variables denote autarky. The first term is the contribution of within-plant TFP growth, holding fixed each plant's output share. The second term is the contribution of reallocation of output shares, holding fixed each plant's initial TFP. Finally, the third term is the covariance of plant-level TFP growth and changes in output shares. The numbers in parentheses under each term give the contribution to the aggregate productivity gain from trade (relative to autarky) of each component. By far, the majority of the gain from trade is attributed to the cross term, highlighting the importance of productivity gains at plants that grow when open to trade. Reallocation per se (that is, holding fixed each plant's productivity), plays a very small role. Therefore, my model gives a very different picture on the contributions to aggregate TFP

growth than would a model that abstracts from within-plant productivity gains.

4   Conclusion

The model presented here captures the heterogeneity in the use of imported intermediate inputs prevalent in studies of plant- and firm-level data, and is consistent with evidence on plant-level productivity gains from importing. The model has relatively few parameters that are easily related to observable moments of the cross-sectional distributions of imports and size in plant-level data. Trade liberalization generates large within-plant productivity gains that are distributed unevenly across plants: larger plants who import more gain more in productivity. This heterogeneity results in sizeable gains from trade that would not exist in a model in which all plants use identical input bundles.

A literal interpretation of the production technology in the model is that imports are perfect substitutes for domestic inputs, but may be available at a lower cost, so that importing a larger share lowers the average cost of production. More broadly, imported inputs could also yield productivity gains because imports are of higher quality than comparable domestic inputs, or because imported goods are imperfect substitutes for domestic goods. The quality explanation, for example discussed in Grossman and Helpman (1991), is studied in plant-level data for Mexico by Kugler and Verhoogen (2009). Imperfect substitutability would generate gains from input variety as in Ethier (1982) and Romer (1990).[10] Halpern, Koren, and Szeidl (2009) use data on the number of goods Hungarian firms import to measure the relative magnitudes of the quality and substitutability channels. For the purposes of this paper, these explanations are isomorphic to the one proposed in my model, in that data on total domestic and imported expenditures at the plant level cannot distinguish between them. Blaum, Lelarge, and Peters (2013) show that more detailed data imply that producers differ systematically in the shares that they spend on individual products, a feature that is missing from my model as well as from most of the existing literature. Even then, this paper has shown that simply accounting for heterogeneous responses of plants in terms of their import share significantly affects the magnitude of the gains from trade.

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[10]This variety mechanism is also the one operating in Kasahara and Rodrigue (2008), Goldberg, Khandelwal, Pavcnik, and Topalova (2010), and Gopinath and Neiman (2011). In a model that combines the decisions to import and export, Kasahara and Lapham (2007) assume plants gain from importing through the variety effect, but the number of imports each importing plant uses is fixed.

5 Appendix

5.1 Choice of n

A plant with productivity z in country j solves the problem:

$$\pi_j(z) = \max_{n \in [0,1]} \tilde{\pi}_j(z,n) - w_j b(f^n - 1)$$

The Lagrangian of this problem is $L = \tilde{\pi}_j(z,n) - w_j b(f^n - 1) + \lambda_0(n-0) + \lambda_1(1-n)$, where $\lambda_0, \lambda_1 \geq 0$, and the first order necessary condition is:

$$\frac{\partial \tilde{\pi}_j(z,n)}{\partial n} - w_j b f^n \log f = \lambda_1 - \lambda_0 \tag{20}$$

where the derivative of variable profit is given by $\frac{\partial \tilde{\pi}_j(z,n)}{\partial n} = (1-\alpha-\eta) z v_j \gamma_j^n \log \gamma_j$. From the complementary slackness conditions $\lambda_0 n = 0$ and $\lambda_1(1-n) = 0$, it is clear that only one of λ_0 or λ_1 can be positive.

For $\lambda_0 > 0$ and $\lambda_1 = 0$, $\frac{\partial \tilde{\pi}_j(z,n)}{\partial n} < w_j b f^n \log f$, so:

$$(1-\alpha-\eta) z v_j \gamma_j^n \log \gamma_j < w_j b f^n \log f$$

while when $\lambda_1 > 0$ and $\lambda_0 = 0$,

$$(1-\alpha-\eta) z v_j \gamma_j^n \log \gamma_j > w_j b f^n \log f$$

Define two cutoff z levels:

$$z_j^0 = \frac{w_j b \log f}{(1-\alpha-\eta) v_j \log \gamma_j}$$

$$z_j^1 = \frac{f}{\gamma_j} \frac{w_j b \log f}{(1-\alpha-\eta) v_j \log \gamma_j}$$

These come from the first order condition at equality for $n = 0$ and $n = 1$. Since $z^1 = z^0 \frac{f}{\gamma_j}$, $z^1 > z^0$ as long as $f > \gamma_j$, which is the condition assumed in the text.

Now, for $z < z^0$, the left hand side of the first order condition (20) is:

$$(1-\alpha-\eta) z v_j \gamma_j^n \log \gamma_j - w_j b f^n \log f$$
$$= \frac{w_j b \log f}{z^0} z \gamma_j^n - w_j b f^n \log f$$
$$= w_j b \log f \left(\frac{z}{z^0} \gamma_j^n - f^n\right)$$
$$< 0 \text{ for all } n$$

This implies $\lambda_0 > 0$ (and hence $\lambda_1 = 0$), so the optimal $n(z) = 0$.

Similarly, for $z > z^1$, the left hand side of (20) is positive for all n, implying $\lambda_1 > 0$ (and hence $\lambda_0 = 0$), so the optimal $n(z) = 1$.

For $z \in (z^0, z^1)$, the solution to the first order condition at equality is an interior solution, given by:

$$(1 - \alpha - \eta) z v_j \gamma_j^n \log \gamma_j = w_j b f^n \log f$$

Taking logs of both sides and rearranging,

$$n_j(z) = \frac{1}{\log f - \log \gamma_j} \left(\log z + \log \left(\frac{(1 - \alpha - \eta) v_j \log \gamma_j}{w_j b \log f} \right) \right)$$

which leads to the solution given in (10).

Now, to check the second order condition at this solution, the second derivative of the profit function is:

$$\frac{\partial^2 \tilde{\pi}_j(z, n)}{\partial n^2} - w_j \frac{\partial^2 b(f^n - 1)}{\partial n^2}$$
$$= \frac{\partial \tilde{\pi}_j(z, n)}{\partial n} \log \gamma_j - w_j b f^n (\log f)^2$$

For the range where n is interior, $\frac{\partial \tilde{\pi}_j(z,n)}{\partial n} = w_j b f^n \log f$, so the second derivative of profit evaluated at the solution is:

$$\frac{\partial \tilde{\pi}(z, n)}{\partial n} \log \gamma_j - w_j b f^n (\log f)^2$$
$$= b f^n \log f \left(\log \gamma_j - \log f \right)$$
$$< 0$$

which is true again by the assumption that $f > \gamma_j$.

5.2 Aggregation

The terms in the aggregated market clearing conditions (14) and (15) are, first:

$$
\begin{aligned}
\mu_{Yj} &= v_j \int z \gamma_j^{n_j(z)} h_j(z)\, dz \\
&= v_j \zeta \underline{z}_j^{\zeta} \left[\int_{\underline{z}_j}^{z_j^0} z^{-\zeta} dz + \int_{z_j^0}^{z_j^1} \gamma_j^{\psi_j \log z + \phi_j} z^{-\zeta} dz + \int_{z_j^1}^{\infty} \gamma_j z^{-\zeta} dz \right] \\
&= v_j \zeta \underline{z}_j^{\zeta} \left[\int_{\underline{z}_j}^{z_j^0} z^{-\zeta} dz + \gamma_j^{\phi_j} \int_{z_j^0}^{z_j^1} z^{\psi_j \log \gamma_j - \zeta} dz + \gamma_j \int_{z_j^1}^{\infty} z^{-\zeta} dz \right] \\
&= v_j \zeta \underline{z}_j^{\zeta} \left(\frac{(\underline{z}_j)^{1-\zeta}}{\zeta - 1} + \left(\gamma_j (z_j^1)^{1-\zeta} - (z_j^0)^{1-\zeta} \right) \left(\frac{1}{\zeta - 1} + \frac{1}{1 + \psi_j \log \gamma_j - \zeta} \right) \right)
\end{aligned}
$$

Second,

$$
\begin{aligned}
\mu_{Mj} &= v_j \int z n_j(z) \gamma_j^{n_j(z)} h_j(z)\, dz \\
&= v_j \zeta \underline{z}_j^{\zeta} \left[\int_{z_j^0}^{z_j^1} (\psi_j \log z + \phi_j) \gamma_j^{\psi_j \log z + \phi_j} z^{-\zeta} dz + \int_{z_j^1}^{\infty} \gamma_j z^{-\zeta} dz \right] \\
&= v_j \zeta \underline{z}_j^{\zeta} \left[\gamma_j^{\phi_j} \int_{z_j^0}^{z_j^1} (\psi_j \log z + \phi_j) z^{\psi_j \log \gamma_j - \zeta} dz + \gamma_j \int_{z_j^1}^{\infty} z^{-\zeta} dz \right]
\end{aligned}
$$

which is, integrating the first integral by parts,

$$
\mu_{Mj} = v_j \zeta \underline{z}_j^{\zeta} \left(\gamma_j (z_j^1)^{1-\zeta} \left(\frac{1}{1 + \psi_j \log \gamma_j - \zeta} + \frac{1}{\zeta - 1} \right) - \frac{\psi_j \left((z_j^1)^{1-\zeta} \gamma_j - (z_j^0)^{1-\zeta} \right)}{(1 + \psi_j \log \gamma_j - \zeta)^2} \right)
$$

Finally,

$$
\begin{aligned}
\mu_{Hj} &= b_j \left[\int \left(f^{n_j(z)} - 1 \right) h_j(z)\, dz \right] \\
&= b_j \zeta \underline{z}_j^{\zeta} \left[\int_{z_j^0}^{z_j^1} \left(f^{\psi_j \log z + \phi_j} - 1 \right) z^{-\zeta - 1} dz + \int_{z_j^1}^{\infty} (f - 1) z^{-\zeta - 1} dz \right] \\
&= b_j \zeta \underline{z}_j^{\zeta} \left[f^{\phi_j} \int_{z_j^0}^{z_j^1} z^{\psi_j \log f - \zeta - 1} dz - \int_{z_j^0}^{z_j^1} z^{-\zeta - 1} dz + (f - 1) \int_{z_j^1}^{\infty} z^{-\zeta - 1} dz \right] \\
&= b_j \zeta \underline{z}_j^{\zeta} \left[f^{\phi_j} \frac{1}{\zeta - \psi_j \log f} \left((z_j^0)^{\psi_j \log f - \zeta} - (z_j^1)^{\psi_j \log f - \zeta} \right) - \frac{1}{\zeta} \left((z_j^0)^{-\zeta} - f (z_j^1)^{-\zeta} \right) \right]
\end{aligned}
$$

5.3 Average size of importing plants relative to nonimporting plants

The average size of importing plants is given by

$$
\begin{aligned}
\bar{X}_m &= \frac{1}{1 - G_j\left(z_j^0\right)} \int_{z_j^0}^{\infty} \eta z v_j \gamma_j^{n_j(z)} g_j\left(z\right) dz \\
&= \frac{1}{\underline{z}_j^\zeta \left(z_j^0\right)^{-\zeta}} \eta v_j \left(\int_{z_j^0}^{z_j^1} z \gamma_j^{\psi_j \log z + \phi_j} \zeta \underline{z}_j^\zeta z^{-\zeta-1} dz + \gamma_j \int_{z_j^1}^{\infty} z \zeta \underline{z}_j^\zeta z^{-\zeta-1} dz \right) \\
&= \frac{1}{\underline{z}_j^\zeta \left(z_j^0\right)^{-\zeta}} \eta v_j \left(\frac{\gamma_j^{\phi_j} \zeta \underline{z}_j^\zeta}{1 + \psi_j \log \gamma_j - \zeta} \left(\left(z_j^1\right)^{1+\psi_j \log \gamma_j - \zeta} - \left(z_j^0\right)^{1+\psi_j \log \gamma_j - \zeta} \right) + \frac{\gamma_j \zeta \underline{z}_j^\zeta}{\zeta - 1} \left(z_j^1\right)^{1-\zeta} \right)
\end{aligned}
$$

while the average size of nonimporting plants is

$$
\begin{aligned}
\bar{X}_d &= \frac{1}{G_j\left(z_j^0\right)} \int_{\underline{z}_j}^{z_j^0} \eta z v_j g_j\left(z\right) dz \\
&= \frac{1}{1 - \underline{z}_j^\zeta \left(z_j^0\right)^{-\zeta}} \eta v_j \zeta \underline{z}_j^\zeta \frac{1}{1 - \zeta} \left(\left(z_j^0\right)^{1-\zeta} - \underline{z}_j^{1-\zeta} \right)
\end{aligned}
$$

The ratio of these two is

$$
\frac{\bar{X}_m}{\bar{X}_d} = \frac{\frac{1}{\underline{z}_j^\zeta\left(z_j^0\right)^{-\zeta}} \eta v_j \left(\frac{\gamma_j^{\phi_j} \zeta \underline{z}_j^\zeta}{1+\psi_j \log \gamma_j - \zeta} \left(\left(z_j^1\right)^{1+\psi_j \log \gamma_j - \zeta} - \left(z_j^0\right)^{1+\psi_j \log \gamma_j - \zeta} \right) + \frac{\gamma_j \zeta \underline{z}_j^\zeta}{\zeta - 1} \left(z_j^1\right)^{1-\zeta} \right)}{\frac{1}{1 - \underline{z}_j^\zeta\left(z_j^0\right)^{-\zeta}} \eta v_j \zeta \underline{z}_j^\zeta \frac{1}{1-\zeta} \left(\left(z_j^0\right)^{1-\zeta} - \underline{z}_j^{1-\zeta} \right)}
$$

which can be simplified to yield:

$$
\begin{aligned}
\frac{\bar{X}_m}{\bar{X}_d} &= \frac{1 - F_j^{im}}{F_j^{im}} \frac{\zeta - 1}{\left(F_j^{im}\right)^{(1-\zeta)/\zeta} - 1} \\
&\quad \times \left(\frac{1}{1 + \psi_j \log \gamma_j - \zeta} \left(\left(e^{1/\psi_j}\right)^{1+\psi_j \log \gamma_j - \zeta} - 1 \right) + \frac{\gamma_j}{\zeta - 1} \left(e^{1/\psi_j}\right)^{1-\zeta} \right) \\
&= \frac{1 - F_j^{im}}{F_j^{im}} \frac{1}{\left(F_j^{im}\right)^{(1-\zeta)/\zeta} - 1} \left(\frac{\zeta - 1}{\zeta} \frac{1}{\varsigma_{2j} - 1} \left(e^{(\varsigma_{2j}-1)\varsigma_{1j}} - 1\right) + \lambda_{jj}^{\frac{-\eta}{\theta(1-\alpha-\eta)}} e^{\varsigma_{1j}(1-\zeta)/\zeta} \right)
\end{aligned}
$$

where the parameter combinations already pinned down from other moments are:

$$
\begin{aligned}
\varsigma_{1j} &= \frac{\zeta}{\psi_j} \\
\varsigma_{2j} &= \frac{1 + \psi_j \log \gamma_j}{\zeta}
\end{aligned}
$$

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