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Abstract
We document that economies of scale in transportation and delivery lags are important features of international trade. These costs lead firms to import infrequently and hold substantially larger inventories of imported goods. We study a model economy in which international trade is subject to these frictions. When we calibrate our theory to the inventory levels and lumpiness of imports observed in the data, we find a large (20 percent) tariff equivalent of these frictions, mostly due to inventory carrying costs. These frictions have important consequences not only for the level of trade, but also for the dynamic response of imports and prices in the aftermath of large shocks. We focus on large devaluation episodes in six developing economies. The model predicts, consistent with the data, that desired inventory adjustment in response to a terms-of-trade and interest rate shock generates a short-term trade implosion, an immediate, temporary drop in the value and number of distinct varieties imported, as well as a slow increase in the retail price of imported goods.
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1. Introduction

The costs of international trade are large, especially in developing countries.[1] Given its simplicity, iceberg depreciation has been the usual approach to modeling these costs, but understanding trade flows requires a deeper understanding of the nature of frictions involved in international trade. The particular microstructure of trade frictions has implications for whether and which trade costs are policy-mutable, how trade patterns and trade costs change over time, and what the gains to trade are (e.g., Kim Ruhl, 2005, George Alessandria and Horag Choi, 2007b, Tomas Chaney, 2008). This paper documents two important frictions faced by firms participating in international trade: delivery lags and economies of scale in the transaction technology. We study an economy in which importers economize on these costs by storing goods as inventories and use the theory to evaluate the importance of these frictions. We show that shipping lags and economies of scale play an important role in the aggregate, both for the level of trade as well as for the dynamic response to shocks to the terms of trade and interest rates.

David Hummels (2001) forcefully documents nontrivial time lags between the order and delivery of goods in international trade. For instance, delivery times from Europe to the US Midwest are 2 to 3 weeks, whereas those to the Middle East are as long as 6 weeks. Man-made bureaucratic barriers slow the flow of goods across borders as well. A recent survey by the World Bank[2] finds that it takes an average of 12 days (OECD) to 37 days (Europe and Central Asia) for importers to assemble import licences, customs declaration forms, and other certificates required to engage in international transactions.[3]

Many of these bureaucratic procedures are transaction costs that are not proportional to a shipment's size, and thus important economies of scale characterize the technology of international trade. According to the World Bank report mentioned above, part of the cost of importing a

[1] James E. Anderson and Eric van Wincoop (2004) provide an excellent review of the evidence.

[2] Trading Across Borders. Available at http://www.doingbusiness.org/ExploreTopics/TradingAcrossBorders/

[3] In related work, delivery lags and the demand for timeliness have been shown to have important implications for gravity equation trade flows (Simeon Djankov, Caroline Freund and Cong S. Pham, 2006), location/sourcing decisions (Carolyn Evans and James Harrigan, 2005), and provide a structural interpretation of distributed lags in import demand equations (Tryphon E. Kollintzas and Steven L. Husted, 1984). Delivery lags have also been studied in business cycle models by David K. Backus, Patrick J. Kehoe and Finn E. Kydland (1994) and Elisabetta Mazzenga and Morten O. Ravn (2004).

container into Argentina includes the cost of document preparation ($750), customs clearing and technical control ($150), as well as the cost of ports and terminal handling ($600). We document in this paper that these, and other similar costs of international trade, amount to 3 to 11 percent of a shipment's value. Given that most goods transacted across borders are storable, the nature of these costs make it optimal for importers to engage in international transactions infrequently (in order to take advantage of the economies of scale) and to hold substantial inventories of imported goods.

Indeed, we provide direct evidence that participants in international trade face more severe inventory management problems. First, using a large panel of Chilean manufacturing plants, we find that importing firms have inventory ratios that are roughly twice those of firms that only purchase materials domestically. Second, we show that inventory behavior is different for imported and domestic materials even within the same firm. Using detailed data on the purchasing history of a US steel manufacturer from George Hall and John Rust (2000, 2002, 2003), we document that the typical international order tends to be about 50 percent larger and half as frequent as the typical domestic order.

We finally document that trade flows, at the microeconomic level, are lumpy and infrequent. Using monthly data on the universe of US exports for goods in narrowly defined categories (10-digit Harmonized System code), we show that annual trade is highly concentrated in a few months. The bulk of trade (85 percent) is accounted for by only three months of the year; the top month of the year accounts for 50 percent of that year's trade on average. No trade is recorded in half of the months. The infrequency and high concentration of these trade flows in a few months of the year reflect the role of economies of scale in international trade.

To capture these features of international trade, we write down the inventory management problem of an importer facing shipping delays, economies of scale in transacting, and uncertainty. Delivery lags and increasing returns mostly manifest themselves indirectly, through the inventory carrying expenses incurred by exporters. Using our model, we find a tariff equivalent of these frictions of 20 percent, nearly six times larger than the physical costs of trade. We thus conclude, as David Hummels (1999) does, that direct measures of freight rates severely understate the cost of trading internationally. The relatively high tariff equivalent of these frictions explains why directly observed trade costs are so low relative to the much larger trade costs inferred from trade flows (see Anderson and van Wincoop, 2004).

We also find that inventories contribute to the dynamics of imports and imported goods' prices after large shocks to the terms of trade and interest rates that characterize large devaluation episodes. We focus on large, unanticipated terms of trade and interest rate shocks associated with the large devaluations experienced in recent years by developing economies.[4] These are large, easily identifiable shocks that are economically important and exhibit a number of common trade-related patterns. Thus, they are ideal candidates for studying the role of the frictions we emphasize.

Figure 1 uses Argentine data to summarize three salient features of trade and price dynamics of devaluation episodes that we address. First, as documented by Ariel Burstein, Martin Eichenbaum, and Sergio Rebelo (2005), devaluations are associated with a gradual and smaller increase in the retail price of imported goods, despite the larger and more immediate increase in the at-the-dock (wholesale) price of imports. Second, imports collapse and the decline is especially large relative to the change in relative prices in the short-run.[5] Third, the number of goods that are imported contracts and recovers only gradually.

We argue that an important mechanism in understanding these three features of the data stems from inventory management considerations.[6] Our theory predicts that in response to an unanticipated devaluation associated with an increase in the wholesale price of imports and interest rates, i) importers reduce retail markups, thereby incompletely passing through the wholesale price increase to consumers, ii) imports collapse, and iii) this collapse is in large part due to a drop in the extensive margin: the number of varieties imported. These three predictions are all driven by the fact that the devaluation renders the importer's holdings of inventories higher than optimally desired. Importers

[4] We model devaluations as an exogenous increase in the relative (wholesale) price of imported goods, an increase in the interest rate, and a drop in consumption, but we are therefore agnostic about the causes of devaluations. The drop in consumption has a smaller, secondary role.

[5] In these developing countries, the relatively large, short-run trade response is the opposite of the small, short-run J-curve type trade response (Steven Magee, 1973, Helen B. Junz and Rudolf R. Rhomberg, 1973, Ellen Meade, 1988) observed in more industrialized countries.

[6] A wide literature exists on emerging market business cycles, and we view our mechanism as one of many potentially complementary explanations (see Pablo Neumeyer and Fabrizio Perri, 2005, Mark Aguiar and Gita Gopinath, 2007).

reduce their inventories by not importing for a while as well as by reducing retail markups in order to sell existing inventories more rapidly.

We also present microeconomic evidence on the importance of inventories during large devaluations. We show that goods that have been recently transacted, and thus have higher inventories, respond with larger drops in trade during devaluations. Moreover, inventory levels and carrying costs also appear to affect pass-through dynamics at the retail level.

The trade frictions we emphasize provide a new channel for the observed slow adjustment of retail prices to changes in international relative prices, a pervasive empirical regularity.[7] We complement existing explanations that emphasize price adjustment frictions (which break the link between desired and actual markups), or local costs[8] (which break the link between import and retail prices), by emphasizing that quantity adjustment frictions break the link between a good's replacement cost and its marginal valuation.[9] Indeed, our mechanism is closely related to the local cost explanation; we think of inventory management frictions as a microeconomic foundation for an important part of retail distribution costs. In the US, inventory costs on average account for 6 percent of sales, more than half of the 10 percent accounted for by labor. In the short-run, inventory turnover is even more important for pricing, however, since retailers have two months of inventory on hand and inputs account for 70 percent of overall costs.[10] Unlike the above explanations, our theory emphasizing micro trade costs has joint implications for pricing and quantities at the micro-level that depart from constant, time-invariant elasticities.[11]

Our focus on the extensive margin and fixed cost of trade (our approach to modelling economies of scale in the transaction technology) is related to work by Richard Baldwin (1988), Mark J. Roberts and James R. Tybout (1997), Marc Melitz (2003), and Sanghamitra Das, Mark J. Roberts, and

[7] Pinelopi Goldberg and Michael Knetter (1997) provide a thorough summary of exchange rate pass-through.

[8] See for instance Giancarlo Corsetti and Luca Dedola (2005) and José M. Campa and Linda Goldberg, (2006).

[9] Victor Aguirregabiria (1999) and Adam Copeland, Wendy Dunn and George Hall (2005) study the relationship between prices and costs in a closed economy.

[10] US retailers hold two months of inputs on hand (see Census of Retail Trade and Annual Survey of Retail Trade). Inventory carrying costs are 3 percent per month, so that total inventory costs are 6 percent of sales. US costs likely understate costs in other countries. For instance, inventory turns in the retail sector are about 40 percent slower in Canada, and overall logistic costs in Korea are estimated to be about 50 percent higher than US logistic costs.

[11] In related work, Pinelopi Goldberg and Rebecca Hellerstein (2007) use a structural model of the retail and wholesale beer industry to decompose incomplete exchange rate pass-through into non-traded costs, price adjustment frictions, and markup adjustments.

James R. Tybout (2007). These papers primarily focus on the large, fixed costs that firms incur in starting or continuing to export. These fixed costs are important in explaining export participation by plants as well as the dynamics of trade over the business cycle (Fabio Ghironi and Marc Melitz, 2005, and George Alessandria and Horag Choi, 2007a) or following trade reforms (Ruhl, 2005). A key finding in this literature is that, with fixed costs of exporting, in the short-run, trade responds less to shocks than in the long-run.[12] In contrast, the type of trade costs we study, fixed ordering costs and delivery lags, combined with the storability of goods, leads to the opposite result: short-run trade responses are much larger than long-run responses.

The paper is organized as follows. The next section summarizes some measures of lags and fixed costs in international trade and provides evidence that these frictions contribute to trade being lumpy and importers holding relatively high inventories. In Section 3, we develop a partial equilibrium model of an importer with fixed costs and lags. In Section 4, we calibrate the model and show that the frictions explain differences in the behavior of domestic buyers and importers. In Section 5, we summarize the key features of trade and price dynamics in large devaluation episodes and study the response of our model economy to a similar shock. Section 6 concludes.

2. Data

This section uses microdata to document several related facts of importing behavior. We start by documenting transaction level frictions that lead to an inventory management problem: delivery lags and economies of scale in trade costs. We then document the features of the data that the inventory management model will be designed to explain: large inventory/sales ratio and lumpy transactions for importers. These features of the data will be used to discipline the quantitative implications of the model.[13]

[12] Richard Baldwin and Paul Krugman (1989) show that these fixed costs contribute to the gradual current account reversal following the large depreciation of the dollar in the mid-1980s.

[13] We focus primarily on data for developing countries in documenting these facts, since our sources for the direct costs (Djankov, Freund, and Pham, 2006 and Hummels, 1999) emphasize that the costs they measure are larger for developing countries. We believe these frictions and inventory considerations are more broadly applicable, however.

A. Direct Evidence on Frictions

An important characteristic of international trade is the presence of sizable economies of scale and shipping lags in the transportation technology. To measure the magnitude of these frictions we use data from the World Bank's Doing Business database (World Bank, 2007)[14] on the costs of document preparation, customs clearing/technical control, and port/terminal handling faced by both the exporting and importing country. The database reports both the number of days involved in fulfilling each of these steps (we refer to these as time lags) as well as a monetary amount associated with them. Table 1 summarizes the costs and lags faced by different countries. The first column shows that procedural time lags are considerable. Importing time lags range from 11 (Korea) to 33 (Russia) days, but roughly three weeks is the norm in the other countries. These lags exclude international shipping times and inland transportation on both sides (typically two days in the US and two days in the destination country). The second and third columns show the monetary costs of these transactions. These costs are in US dollars for 2006. Importing costs are roughly $500 for Mexico and Korea, $1,000 for Brazil, Russia, and Thailand, and $1,500 for Argentina, while US export costs are an additional $625.[15] The median shipments in 2004 from the US export data are in the range of $10,900 (Mexico) to $21,000 (Russia), while average shipments are much larger, ranging between $37,500 (Mexico) to $89,300 (Korea). Based on these data, importing and exporting costs as a fraction of median shipments range from 0.07 to 0.17, and 0.01 to 0.06 as a fraction of mean shipments.

The nature of these costs suggests to us that important economies of scale characterize the nature of the transportation technology. Although the database does not report how these monetary costs of importing vary with the shipment's size (all numbers assume a dry-cargo, 20-foot, full container load), one would expect that the cost of the paperwork/customs clearance/inspection/handling of a half-full container are more than half of the cost of similar procedures for a full container. Indeed,

[14] The numbers reported are based on a standardized container of cargo of nonhazardous, nonmilitary textiles, apparel, or coffee/tea/spice between capital cities. We exclude inland transportation on both sides, since these costs may not be specific to international trade.

[15] Russian import costs omit port/terminal handling charges. US export costs are not broken down by individual country.

as we show below, micro-level data shows considerable lumpiness in trade flows, suggesting that economies of scale indeed make it optimal for importers to lump transactions in order to economize on these costs. The costs reported above omit freight rates, which are also non-negligible, and involve important economies of scale due to the prevalence of containerized shipping technology.

B. Importer Inventory Management

We argue that the economies of scale and time lags documented above lead to larger inventory holdings and lumpier adjustment of imported goods relative to domestic goods. We document this using two micro data sets: one multi-plant data set from a developing country (Chile) that allows us to see how inventory behavior varies with the importance of imported goods and a more detailed data set from a single firm (a US steel importer) that shows that inventory behavior for imports and domestic purchases differs even within the same firm.

Chilean Plant-level Evidence

We study inventory and importing behavior of a balanced panel[16] of 1798 manufacturing plants over 12 years (1990 to 2001). The data are from the Chilean Industrial Survey conducted by the Chilean National Statistics Institute and have been used elsewhere (see Chang-Tai Hsieh and Jonathan A. Parker, 2007). The plant-level data are well suited for our purposes, since Chile is at a comparable level of economic development to the countries that experienced devaluations, and so its plants are likely to be similar to plants in these countries.

For each plant j, we have data on inventories broken down by materials, I_{jt}^m, and goods in process, I_{jt}^f, as well as annual material purchases, M_{jt}, sales, Y_{jt}, and materials imports, M_{jt}^{im}. We define inventories as the average of beginning- and end-of-period inventories, or $\overline{I}_{jt}^f = (I_{jt+1}^f + I_{jt}^f)/2$ and $\overline{I}_{jt}^m = (I_{jt+1}^m + I_{jt}^m)/2$. Import content is measured as the share of materials imported, $s_{jt}^{im} = M_{jt}^{im}/M_{jt}$. Each plant's inventory holdings are normalized by their annual use. For materials, inventory holdings are relative to annual purchases $i_{jt}^m = \overline{I}_{jt}^m/M_t$, while for finished goods inventories these are a share of annual sales $i_{jt}^f = \overline{I}_{jt}^f/Y_t$. Our measure of finished inventories reflects the

[16] The balanced panel eliminates the effect of entry and exit on inventories. Nonetheless, results are similar for the unbalanced panel.

materials content of final goods. The total investment in inventories equals $i_{jt} = i^{m}_{jt} + i^{f}_{jt}$.

On average, manufacturing plants hold approximately 23.5 percent of their annual purchases in inventories and import 11.2 percent of their inputs. However, only 31.2 percent of plant-year observations in the sample actually import anything. Among nonimporters, the typical plant holds 20.6 percent of its annual purchases in inventories, while the typical importer holds 29.8 percent and imports account for 35.8 percent of the value of annual materials inputs. When we split inventory holdings by stage of production, we see that importers hold both more materials (20.6 vs. 15.5 percent) and more finished goods (7.8 vs. 4.9 percent) than nonimporters.[17]

From these summary statistics, it is clear that importers hold more inventories than nonimporters. However, we would like to know to what extent importers hold more inventories of their imported goods. To get at this, we need to control for the fact that importers do not import all inputs. From the following linear regression of inventory holdings on import content,

$$(1) \quad i_{jt} = c + \alpha * s^{im}_{jt} + e_{jt}$$

we find a strong positive relationship between import content and inventory holdings. In a range of specifications reported in Table 2, moving from complete domestic sourcing (c) to complete international sourcing ($c + \alpha$) is associated with an increase in inventory holdings of two-thirds on average across the different specifications. For example, in the unweighted linear regression that controls for size (employment), an establishment that only buys domestically holds 18.0 percent of its annual input purchases in inventories, while a complete importer holds 36.4 percent. Converting these to monthly numbers, we can infer that plants tend to have 2.1 months of domestic inputs on hand and 4.3 months of imported goods on hand. The 4.3 months of imported goods will be the target inventory level for our quantitative model.

[17]The numbers we report here are simple averages; using medians or sales-weighted averages yields similar patterns.

Import Transactions at a US Steel Wholesaler

We now focus on a single wholesaler that purchases both domestically and internationally. The data are from a US steel wholesaler from 1997 to 2006 and are unique in that they are transaction-level data.[18] We confirm that shipments are larger and less frequent for international purchases than domestic purchases. Over this period, this firm purchased 3,573 different types of goods divided between 12,472 domestic purchases and 5,632 international purchases.[19] We find that for the typical product, international orders tend to be about 50 percent larger and occur nearly half as frequently as domestic orders.

For each good j delivered on date t either from the US or overseas, $k \in \{D, F\}$, we have data on the value, v_{jt}^k, quantity, q_{jt}^k (either units or weight), and price, p_{jt}^k, of the transaction. Panel B of Table 3 presents the results of separate regressions of quantity, price, and amount on good and year fixed effects and a dummy for the foreign order

$$\ln q_{jt}^k = c_t + c_j + c_k.$$

Clearly, imported orders are larger in value and quantity and are cheaper. In Panel C, we report the results of a regression of the amount imported where we also control for the transaction price

$$\ln q_{jt}^k = c_t + c_j + c_k + \alpha \ln p_{jt}^k.$$

We find an elasticity of demand of $\hat{\alpha} = -2.1$ and an order size premium of 48 percent (in logs).

Panel D reports the mean and median interval between orders of each good. To compute these intervals, let D_j^k denote the number of days between the date of the first and last order of good j and let N_j^k denote the number of transactions in this interval.[20] Let $d_j^k = D_j^k / \left(N_j^k - 1\right)$ denote the mean duration between orders of good j from source country k. From panel D, we see that domestic goods are purchased every 100 days, while foreign goods are purchased every 204.5 days.

[18] Hall and Rust (2000) summarize the data. We thank George Hall and John Rust for providing these data.

[19] We only know whether deliveries are domestic or foreign.

[20] This measure understates the typical interval since goods with long durations will be censored.

C. Lumpiness of International Transactions

To what extent do the lumpy international transactions of a particular US steel importer reflect importing behavior generally?

We document findings of lumpy transactions for a broad range of disaggregated imported goods (over 10,000 goods defined by their 10-digit Harmonized System codes and exiting district) using monthly data on US exports. The data are comprehensive of US merchandise exports from January 1990 to April 2005 and include monthly totals of exported quantity, value, and number of individual transactions by destination country and exiting customs district. We focus on exports to six importing countries: Argentina, Brazil, South Korea, Mexico, Russia, and Thailand. Each of these six countries experienced a large devaluation making them of particular interest to our quantitative exercise.

Table 4 presents lumpiness statistics for the (trade-weighted) median good of each of the six countries.[21] Ideally, we would like to capture the extent of lumpiness in the purchases of a single importer and a single product. However, as the first row shows, the median good is transacted multiple times in months when it is traded. This is particularly true for Mexico, where the median good is traded 32.3 times a month.[22] We view these data as likely aggregating the shipments of multiple importers or multiple products; therefore, they are likely to understate the lumpiness of any individual importer's purchases of a single product. The lumpiness of a single importer's purchases is most closely approximated by Argentina (2.2 transactions per month) and Russia (2.7).

The first evidence of lumpiness is that goods are traded infrequently over the course of a year. The second row shows, for each country, the fraction of months that the median good in the sample is exported. This fraction ranges from 0.13 (Russia) to 0.81 (Mexico) but may overstate lumpiness, since some goods move in and out of the sample. The third row gives the fraction of months the median good is exported in years when it is exported to the country at least once. With the exception of Mexico, whose median good is traded quite frequently (0.90 fraction of months), the

[21] Trade-weighted means have comparable lumpiness measures, but the mean number of transactions per month greatly exceeds the median.

[22] Mexico is also unique in that much of their trade is transported by ground rather than by sea or air.

other countries import their median good roughly half the months (0.43-0.70).

Mere frequency of trade also understates the degree of lumpiness, however, because most of the value of trade is concentrated in still fewer months. One way of summarizing this concentration is by using the Herfindahl-Hirschman (HH) index. The HH index is defined as follows:

$$HH = \sum_{i=1}^{12} s_i^2$$

where s_i is the share of annual trade accounted for by month i. The index ranges from $1/12$ (equal trade in each month) to one (all trade concentrated in a single month). If annual trade were distributed equally across n months in a year, then the HH would equal $1/n$. The HH indexes for all countries but Mexico range from 0.28 to 0.45. If all trade were equally distributed across months, these numbers would translate into roughly two to four shipments per year.

The last three rows constitute another measure of concentration: the fraction of annual trade accounted for by the months with the highest trade in a given year for the median good. The numbers show that the top month accounts for a sizable fraction (ranging from 0.38-0.53, excluding Mexico), while the top three months account for the vast majority of trade (0.70-0.85), and the top five months account for nearly all of annual trade (0.85-0.95).

In summary, annual trade of disaggregated goods is heavily concentrated in very few months. This lumpiness or concentration is pervasive across different types of imported goods and does not appear to be driven by seasonalities.[23] Finally, this evidence from aggregated trade flows is likely to understate the lumpiness of transactions to individual importers, since the monthly data contain multiple transactions that likely reflect multiple purchasers. The HH values of 0.40 (Argentina) and 0.45 (Russia) will be quantitative targets for the model, since these are more representative of concentration for individual importers.

[23] See our unpublished online appendix for detailed documentation of these claims.

3. Model

Here we consider the partial equilibrium[24] problem of a monopolistically competitive importer that faces fixed costs of importing a storable foreign good, a one-period lag between the ordering and delivery of goods, and uncertain demand. The fixed cost gives rise to economies of scale in the transportation technology of the type we have documented earlier. We start by characterizing the importer's optimal decision rules in an environment in which the only source of uncertainty is demand shocks for its product.[25] We then assume a continuum of importers that are otherwise identical except for their different histories of demand shocks, and we aggregate their decision rules in order to characterize the ergodic distribution of importer-level inventory holdings. Finally, we characterize the transition dynamics in response to an unanticipated change in the relative price of imported to domestically produced goods, considering both permanent and temporary changes.

Formally, we consider a small open economy inhabited by a large number of identical, infinitely lived importers, indexed by j. In each period t, each importer experiences one of infinitely many events, η_t. Let $\eta^t = (\eta_0, ..., \eta_t)$ denote the history of events up to period t.

Let $p_j(\eta^t)$ denote the price charged by importer j in state η^t and let $\nu_j(\eta^t)$ denote the importer-specific demand disturbance. $\nu_j(\eta^t)$ is assumed iid across firms and time. We assume a static, constant-elasticity-of-substitution demand specification for the importer's product:[26]

$$y_j(\eta^t) = e^{\nu_j(\eta^t)} p_j(\eta^t)^{-\theta}.$$

Let $\omega_j = \omega$ be the wholesale per-unit cost of imported goods, assumed constant across all

[24] Understanding the source of the large devaluation and terms of trade movement is beyond the scope of this paper. Our focus is solely on the propagation of this relative price change. General equilibrium models that attribute these relative price movements to productivity, demand, or interest rate shocks have limited success in generating large real exchange rate movements, and hence we remain silent about the source of the shock. Similar to Enrique Mendoza (1995), we treat the terms of trade as exogenous.

[25] There are many ways to introduce heterogeneity into the model that will help to capture the large and infrequent orders we observe in the data. Our approach is to have idiosyncratic demand shocks. An alternative approach would be to have idiosyncratic shocks to the cost of ordering (as in Aubhik Khan and Julia Thomas, 2007a) or idiosyncratic shocks to productivity (as in Alessandria and Choi, 2007a) or uncertainty in the delivery process.

[26] In the background, we have in mind a consumer who has preferences over foreign and home goods: $c = \left(h^{\frac{\theta-1}{\theta}} + \alpha \int_0^1 \nu_j^{\frac{1}{\theta}} m_j^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$ where m_j is consumption of imported good j, h is consumption of the domestic good, and α, the weight on imported goods, is assumed to be close to 0. Normalizing the price of home goods to 1 would yield our demand functions.

importers. We will interpret changes in ω as changes in the relative price of (at-the-dock) imported goods to that of domestic goods. In addition, we assume that the importer faces an additional, fixed cost of importing every period in which it imports, f.

Given that the imported good is storable, the firm will find it optimal to import infrequently and carry non-zero holdings of inventories from one period to another. Let $s_j(\eta^t)$ be the stock of inventory the importer starts with at the beginning of the period at history η^t. Given this stock of inventory, the firm has two options: pay the adjustment cost f and import $i_j(\eta^t) > 0$ new units of inventory; or avoid the fixed cost and not import, i.e., set $i_j(\eta^t) = 0$. Implicit in this formulation is the assumption that inventory investment is irreversible, i.e., re-exports of previously imported goods, $i_j(\eta^t) < 0$, are ruled out.[27]

We also assume a one-period lag between orders of imports and delivery. That is, sales of the importer, $q_j(\eta^t)$, are constrained to not exceed the firm's beginning-of-period stock of inventory:

$$q_j(\eta^t) = \min[e^{\nu_j(\eta^t)} p_j(\eta^t)^{-\theta}, s_j(\eta^t)].$$

The amount the importer orders today, $i_j(\eta^t)$, cannot be used for sales until next period. In particular, the law of motion for the importer's beginning-of-period inventories is:

$$s_j(\eta^{t+1}) = (1-\delta)\left[s_j(\eta^t) - q_j(\eta^t) + i_j(\eta^t)\right],$$

where δ is the depreciation rate. We assume that inventory in transit, $i_j(\eta^t)$, depreciates at the same rate as inventory in the importer's warehouse, $s_j(\eta^t) - q_j(\eta^t)$.

The firm's problem can be concisely summarized by the following system of two functional Bellman equations. Let $V^a(s, \nu)$ denote the firm's value of adjusting its stock of inventory and $V^n(s, \nu)$ denote the value of inaction, as a function of its beginning-of-period stock of inventory and its demand shock. Let $V(s, \nu) = \max[V^a(s, \nu), V^n(s, \nu)]$ denote the firm's value. Then the firm's problem

[27] A justification for this assumption is that one-time re-exports may be prohibitively expensive. In addition to any fixed transaction costs, firms are likely to face large costs involved with exporting as emphasized by Roberts and Tybout (1997). Introducing a fixed cost of returning the good along with an iceberg shipping costs would lead to an upper threshold substantially above the typical ordering point.

is:

$$
\begin{aligned}
(2) \qquad V^a(s,\nu) &= \max_{p,i>0} q(p,s,v)p - \omega i - f + \beta EV(s',\nu') \\
V^n(s,\nu) &= \max_{p} q(p,s,v)p + \beta EV(s',\nu')
\end{aligned}
$$

where

$$
\begin{aligned}
q(p,s,v) &= \min(e^v p^{-\theta}, s) \\
s' &= \begin{cases} (1-\delta)\left[s - q(p,s,v) + i\right] & \text{if import,} \\ (1-\delta)\left[s - q(p,s,v)\right] & \text{if don't import.} \end{cases}
\end{aligned}
$$

The expectations on the right-hand sides of the Bellman equations are taken with respect to the distribution of demand shocks ν. We assume $\nu \sim N(0,\sigma^2)$.

A. Optimal Policy Rules

We next characterize the optimal decision rules for the firm's problem.[28] In particular, we characterize: $\{p^a(s,\nu), p^n(s,\nu)\}$, the prices the firm charges conditional on adjusting its inventory holdings; $i(s,\nu)$, the firm's purchases of inventory conditional on adjusting; and $\phi(s,\nu)$, the firm's binary adjustment decision.

Figure 2 depicts the inaction and adjustment regions in the (s,v) space, together with the optimal level of inventory holdings, s', conditional on firm adjusting. Inventory numbers are normalized relative to mean sales in this economy. The figure shows that all firms that decide to import will start next period with inventories that are approximately 6 periods' worth of average sales, regardless of their current state. Notice that the optimal import level satisfies

$$
(3) \qquad \omega = \beta(1-\delta)EV_s(s',v'),
$$

[28] We solve this problem numerically, using spline polynomial approximations to approximate the two value functions, and Gaussian quadrature to compute the integrals on the right-hand side of the Bellman equations. Details are available from the authors on request.

We also provide analytical results for a simplified version of the model in the unpublished online appendix. This version has no uncertainty or fixed costs but formalizes many of the important results.

and, given the iid nature of demand shocks, s' is independent of the current state of the firm. The figure also shows that the adjustment threshold, i.e., the cutoff inventory level that makes a firm indifferent between adjusting and not adjusting, increases in the firm's demand level, v. Firms with high demand deplete more of their current inventory holdings and import more readily.

We next turn to Figure 3, which plots the optimal pricing rule of the firm and how it varies with the level of inventories.[29] Given isoelastic demand, the monopolist price is a constant markup over marginal cost. Marginal cost is not, in general, the replacement cost ω, however, but the firm's marginal valuation of an additional unit of inventories $V_s(s,v)$. The price is therefore:

$$p = \frac{\theta}{\theta - 1} V_s(s,v).$$

Given a demand shock ν, $V_s(s,v)$ varies with inventories s. When inventories are sufficiently low relative to demand ν, the firm stocks out. The marginal value of inventories, $V_s(s,v)$, exceeds the replacement cost ω, but given the shipping delay, the firm cannot adjust its inventories contemporaneously. In the case of stockout, the firm charges a price high enough so that the consumer demands its entire available stock, so the price is implicitly defined by:

$$vp^{-\theta} = s.$$

When current inventory holdings do not constrain current sales, the firm carries inventories forward to the next period, and therefore $V_s(s,v) = \beta(1-\delta) EV_s(s',v')$. For low values of inventory, the firm will adjust its inventories, and so $\omega = \beta(1-\delta) EV_s(s',v')$ according to (3). In this case, the value of having additional inventories $V_s(s,v)$ is indeed ω, since higher inventories mean the firm will purchase fewer imports in its order. Thus, firms that are adjusting but not stocking out charge a constant markup over the replacement cost, $p = \theta/(\theta-1)\omega$.

At the adjustment threshold, there is a kink in the value function, and $V_s(s,v)$ jumps upward discretely. When the firm is not adjusting, the value of the marginal good in inventory remains

[29] Aguirregabiria (1999) and Hall and Rust (2000) also study the optimal markup decisions in economies with inventory adjustment frictions but without lags.

above the replacement cost ω, since more inventories allow the firm to delay paying the fixed cost in the future and to avoid a stockout. The marginal value falls with s, however, as the likelihood of paying the fixed cost and stocking out is reduced and expected total carrying costs increase. Thus, the presence of the fixed cost causes the price to be above $\theta/(\theta-1)\,\omega$ but decreasing in s in this region.

Finally, a third region is one in which the irreversibility constraint binds as the current stock of inventories exceeds the level of inventories at which (3) is satisfied. In this region, the marginal valuation of inventories is less than the replacement cost ω and firms lower their price below $\theta/(\theta-1)\,\omega$ in order to rid themselves of excess inventories and avoid future carrying costs.

Returning to Figure 3, the effects of our trade frictions on pricing are clear. We have labeled the low inventory region in which the firm adjusts. At very low inventory levels, prices are high due to stockouts arising from shipping lags. The higher prices in the region where the firm does not adjust are an outcome of the fixed costs. Finally, in the region of excess inventories, prices fall below $\theta/(\theta-1)\,\omega$, a result of the constraint that imports may not be sold back.

To conclude, our economy is characterized by the familiar (S,s) adjustment rules for inventories in which firms import every time their inventory stock decreases below a threshold. Moreover, firm prices in general vary with the firm's current stock of inventories. While markups are constant relative to marginal cost, markups relative to the replacement cost ω vary with inventories (and ν).

4. Quantifying Frictions

We now examine the quantitative implications of our inventory management model of importing. We begin by calibrating the model. We then use the model to show that the key frictions we study are important impediments to international trade, with a tariff equivalent nearly 5.5 times the size of our estimated fixed cost. The high tariff equivalent relative to observed fixed costs rationalizes a key puzzle in international trade that direct measures of trade costs are low while indirect measures, based on trade flows, are high (Anderson and van Wincoop, 2004). In our model, trade costs appear small because firms place large, infrequent orders to economize on the fixed component of these costs, choosing instead to incur higher inventory carrying costs. We then examine whether reasonable differences in these frictions between international and domestic shipments can rationalize the observed differences in lumpiness and inventories of importers and nonimporters. Finally, we decompose the contribution of fixed costs, lags, and other aspects of our model for inventory holdings and lumpiness.

A. Benchmark Calibration

We choose parameters to match the frequency of trade, measured by lumpiness from the US export data and the inventory holdings of importing plants from the Chilean survey. We interpret the length of the period as one month, consistent with the evidence that lags between orders and delivery in international trade are 1-2 months. We set the discount factor β to $0.94^{\frac{1}{12}}$ to correspond to a 6 percent annual real interest rate.

To set the depreciation rate δ, we draw on a large literature that documents inventory carrying costs for the US. Annual non-interest inventory carrying costs range[30] from 19 to 43 percent of a firm's inventories, which imply monthly carrying costs ranging from 1.5 to 3.5 percent.[31] We thus choose $\delta = 0.025$, in the mid-range of these estimates. Given that J. Luis Gausch and Joseph Kogan (2001) find that inventory costs in developing countries are about three times higher than in the US, we also consider an alternate, high depreciation rate parameterization.

The elasticity of demand for a firm's products, θ, is set equal to 1.5, a typical choice used in the international business cycle literature, which, in turn, reflects the low elasticities of substitution between imported and domestic goods estimated using time-series data.[32]

Two other parameters, f, the fixed cost of importing, and σ^2, the volatility of demand shocks, are jointly chosen in order for the model to accord with two features of the microdata. The first target is the lumpiness of trade flows documented in the microdata. Recall that the trade-weighted median HH indexes are equal to 0.40 in Argentina and 0.45 in Russia, the two countries in our sample with the least number of individual transactions per HS-10 digit product category and for

[30] These costs include taxes, warehousing, physical handling, obsolescence, pilfering, insurance, and clerical controls.
[31] See, e.g., Helen Richardson (1995).
[32] Given that in our model the substitution elasticity is also tightly linked to the firms' markups, which are counterfactually high, we ran simulations that break this link between the Armington elasticity for imports and firm markups. Our results were essentially unchanged in an economy with lower markups. Details are available in the appendix.

which lumpiness at this level of disaggregation most closely corresponds to lumpiness at the firm level. We thus ask our model to match a concentration ratio of 0.44. Second, consistent with the Chilean plant data, we target an annual inventory-to-purchases ratio of 36 percent.[33]

The upper panel of Table 5 reports the moments we ask the model to match. The lower panel of Table 5 reports the choice of parameter values that we use. Notice, in the lower panel, that we require demand shocks with a standard deviation of $\sigma = 1.15$ in order for importers to be willing to hold the inventory values we observe in the Chilean data. This number should not be interpreted literally, since given our calibration strategy and parsimonious setup, it reflects additional sources of uncertainty (productivity shocks as well as shocks to the cost or lags in delivering goods) that lead importers to hold the levels of inventory observed in the data.[34]

The fixed cost of importing amounts to approximately 3.6 percent of the average value of an import shipment, solidly in the range of our measures of the fixed costs from the trade data. In terms of revenue, the fixed cost, which is paid only when importing, is equal to 9.5 percent of the median firm's per-period revenues. As in other economies with fixed costs, small fixed costs are necessary in order to generate substantial lumpiness in our economy, a result driven by the low carrying cost of inventories assumed here.

B. Tariff Equivalent

Since importers choose to hold inventories to avoid incurring fixed costs, the cost of these frictions, as a share of the value of imports, will exceed our estimated fixed cost. Moreover, the delivery lags are costly to importers since they cannot respond immediately to shocks and will also lead to great inventory holdings. To estimate the cost of the two frictions to importers, we calculate the compensating price, or tariff equivalent, that an importer would be willing to pay to avoid these

[33] Our model abstracts from finished-good inventories so we include both materials and finished-goods inventories in our definition of inventories in the data. Given the fixed costs of importing and no other frictions or differences in depreciation rates, importers are presumably indifferent between holding the imported intermediate goods as material inventories or finished-good inventories.

[34] For example, Ariel Burstein and Christian Hellwig (2007) find that a standard deviation of demand shocks equal to 0.21-0.30 is necessary to account for the joint comovement of prices and quantities in grocery stores, a number much smaller than our estimate of demand volatility. This suggests that other sources of uncertainty are necessary in order to account for the large inventory holdings observed in the Chilean data and is consistent with the findings of Aubhik Khan and Julia Thomas (2007b) that stockout-avoidance motives for inventory holdings are difficult to reconcile with the large inventory holdings observed in the data.

frictions. Let

$$V^f(\tau) = \max_{p_t} E_0 \sum_{t=0}^{\infty} (p_t - (1+\tau)\,\omega)\, e^{v_t} p_t^{-\theta}$$

denote the expected value of an importer that faces an ad-valorem tariff τ on imports but no other trade frictions. The value of τ that delivers that same expected value as in the economy with no tariffs, but with the shipping lags and fixed transactions costs is implicitly defined as

$$V^f(\tau) = EV(0, \nu),$$

where the right-hand side is the expected value of an importer in our economy that starts out with no inventories.[35]

The tariff equivalent of these frictions is reported in Table 5. In our benchmark model, these frictions are quite costly, equivalent to a tariff rate of 20 percent or roughly 5.5 times as large as the measured fixed cost. That the tariff equivalent of these frictions is so high may appear surprising. A simple way of understanding this relatively high tariff equivalent is to recognize that the typical importer holds about 36 percent of its annual purchase, and in each month, these inventories incur carrying costs of about 3 percent (2.5 percent depreciation plus 0.5 percent interest) or 1.08 percent of annual purchases per month. Adding these costs over the year, the inventory carrying cost amounts to nearly 13 percent of annual purchases. On top of that the importer incurs fixed costs equivalent to 3.6 percent of annual purchases and incurs inventory costs related to the lag of another 3 percent, for a total of about 19.6 percent. For comparison, Hummels (2001) directly estimates freight rates in the range of 7 to 17 percent (not separated between fixed and proportional cost). Thus, the frictions we emphasize are relatively costly compared to estimates of freight rates.

[35]Implicitly, we do not allow firms to sell in the first period here, which could overstate the results in Table 5, but this is quantitatively minor. With $\beta = .995$, not selling at all in the first period only loses 0.005 of the lifetime value (e.g., in Table 5, the 0.20 would change to 0.195).

C. Domestic retailers

We next ask: Can our model account for the different inventory and ordering behavior of importers and nonimporters?[36] To answer this question, we recalibrate the model assuming a one-half month lag between orders and delivery (consistent with the evidence that international shipments are more time-consuming), and calibrate the fixed cost, f, to match a twice higher frequency of orders (consistent with the evidence from the steel wholesaler that imported goods arrive half as frequently as domestic goods). All other parameters are set to their values in the Benchmark setup.[37] The results are reported in the column titled *Domestic*.

In this economy, firms have an average inventory-sales ratio of 0.21, in line with the evidence for domestic firms from the Chilean data. Moreover (not reported in the table), firms now order on average 60 percent of the value of imports of firms in the Benchmark economy, in line with the 50 percent import premium we documented for our steel wholesaler. Overall, we conclude that a reasonable parametrization of the frictions faced by firms involved only in domestic transactions accounts for the differences in inventory holdings, as well as the frequency and size of shipments in the data. This suggests that the time lags from international transactions are roughly twice those of domestic shipments, while transacting internationally nearly quadruples the cost of an order.

Even though the cost of ordering internationally is nearly 4 times the cost of ordering domestically, because order sizes are quite different the measured trade cost, as a share of the mean shipment, between importers and nonimporters is only double. In absolute terms, the difference in cost per shipment is only 1.9 percent, yet the tariff equivalent of this gap is nearly 11 percentage points. Thus, measured trade costs once again substantially understate the cost of these barriers for trade flows.

[36] We thank an anonymous referee for suggesting these calculations.

[37] We solve this problem by assuming a one-period lag between orders and delivery and a period length of two weeks. We adjust the discount factor and rate of depreciation accordingly to maintain the same monthly values as in the Benchmark economy. The standard deviation of taste shocks is $1.15/\sqrt{2}$ at the bi-weekly frequency and thus 1.15 at the monthly frequency as taste shocks are assumed iid. We report statistics computed using monthly data.

D. Sensitivity

Our model incorporates numerous forces that lead importers to hold inventories and import infrequently. We evaluate the contribution of each of these forces by shutting them down sequentially and computing the average holdings of inventories and lumpiness statistics in the invariant distribution. The results of the model in which we eliminated the fixed cost are reported in the column *No Fixed Cost,* and the results with the fixed cost but no shipping lags are reported in the column *No Lag.* Finally, we examine the effect of higher inventory carrying costs.[38]

No Fixed Costs

What is the role played by the fixed cost of importing? To answer this question, we assume away the fixed costs ($f = 0$). We then compute the stationary distribution of inventories in an economy in which all other parameters are equal to those in the Benchmark economy. The fourth column of Table 5 shows that, in this economy, the HH index declines from 0.44 to 0.14, much closer to the one-twelfth that would prevail if trade flows were equally distributed across all months of the year. The fixed cost thus accounts for most of the lumpiness in trade in our Benchmark setup. Without the fixed transaction cost, the motive for holding inventories weakens with the inventory holdings falling nearly 20 percent to 0.29 of annual sales. The tariff equivalent of the remaining friction (lags) is 13 percent, roughly two-thirds of the 20 percent in the Benchmark economy. For comparison, using an alternative empirical model, Hummels (2001) estimates that a 30-day shipping lag has a 12 to 24 percent ad-valorem tariff equivalent.

No Shipping Lags

We next assume away the lags in shipping, but keep the fixed cost. We modify the firm's problem to allow it to sell, at any given date, out of inventories it orders in that period:

$$q(p, s, v) = \min(e^v p^{-\theta}, s + i).$$

[38]We study the role of the elasticity of demand and markups for estimates of the trade costs in the unpublished online appendix. High markups yield smaller fixed costs and tariff equivalents, but these reduce trade by even more.

Once again, we use the same parameters as in the Benchmark model to compute an ergodic distribution. The fifth column of Table 5 shows that with no lags in shipping, inventory holdings drop to one-third of their level in the Benchmark economy (0.12 vs. 0.36). Without lags in shipping, firms can respond contemporaneously to unexpected increases in demand; therefore, the motive to hold a buffer stock to insure against the possibility of a stockout is absent. The lumpiness of trade decreases as well ($HH = 0.32$ vs. 0.44). Finally, fixed costs alone are equivalent to an 8 percent ad-valorem tariff rate, or 40 percent of the tariff equivalent in the Benchmark setup.

Higher inventory carrying costs

We have shown that inventory costs are critical in measuring the tariff equivalent of the frictions. Here, we consider the role of an increase in the inventory carrying cost. Recall that the optimality conditions that govern the price and inventory decisions are:

$$
\begin{aligned}
p &= \frac{\theta}{\theta - 1}\beta(1-\delta)EV_s(s', v'), \\
\omega &= \beta(1-\delta)EV_s(s', v').
\end{aligned}
$$

Letting $r = \frac{1}{\beta} - 1$, the cost of carrying inventories depends on the rate of depreciation, δ, and the interest rate, r, $c = \frac{1-\delta}{1+r}$. We perform a comparative statics exercise with respect to δ alone, but clearly the effect of an increase in the interest rate is qualitatively identical to that of an increase in δ.

We increase the rate of depreciation to $\delta = 0.05$ and leave all other parameters at their values in the Benchmark model. Table 5 shows that higher depreciation reduces the amount of inventories held by importers (by almost one-third: 0.25 vs. 0.36) as well as the lumpiness of trade ($HH = 0.33$ from 0.44). Importers now order more frequently, incurring more costs of trade, as evident in that fixed costs now equal 4.7 percent of each shipment, but these trade costs allow firms to economize on their inventory carrying costs. With higher depreciation, the frictions we study are more costly; their tariff equivalent is equal to 32 percent, or nearly 7 times the fixed cost, and about 60 percent higher than in our benchmark case.

5. Dynamics of Devaluations

Before examining the dynamic implications of our model, we briefly show that the salient features of the terms of trade and trade flows observed in Argentina's devaluation are also present in the devaluations in Brazil (January 1999), Korea (October 1997), Mexico (December 1994), Russia (August 1998), and Thailand (July 1997).

A. Salient Features of Large Devaluations

Table 6 reports stylized features of import dynamics across these six devaluation episodes. The first column of Panel A reports the maximum increase in the terms of trade, measured as the ratio of the import price to the domestic PPI, in logs. The peak change ranges from 34 percent in Korea to over 100 percent in Russia, with the peak generally within the first few months of the initial devaluation. In all countries, the terms of trade remain elevated after 15 months. The second column reports the maximum drop in imports from the US during the 15 months after the devaluation, relative to the pre-devaluation month, again in logs. All countries experience a large and fairly rapid decline in both import measures immediately following the devaluation.[39] The maximal drop in trade ranges from 34 percent in Mexico to 151 percent in Russia.

The next columns report the share of the drop in trade accounted for by the extensive margin. The first measure is the number of distinct HS-10 varieties imported from the US. The second, more disaggregated measure is a count of the number of transactions (customs claims filed). We report the (log) change in these measures relative to the month prior to the devaluation, relative to the (log) change in imports from the US. In all countries, both measures of the extensive margin follow a pattern similar to real imports, with the peak decline ranging from 39 to over 100 percent of the overall decline in trade volume. We also report these measures of changes in the extensive margin by weighting goods by their importance in trade over the whole sample (method 2) and in the pre-devaluation period (method 3). These measures are consistent with the simple counts; high-volume goods also experience large declines in the extensive margin.[40]

[39] Thailand's trade and price dynamics are a bit more gradual. This is in part due to the two major devaluation episodes in a six-month period.

[40] To remove the changes in imports from NAFTA from the Mexican data, we weight Mexican goods by their pre-

The lower panel reports similar measures in a three-month window around the month with the worst trade drop. In all cases, the transaction-based measures attribute a more important role to the extensive margin. On average, focusing on the bottom panel, the data show that the extensive margin accounts for about two-thirds of the decline in peak trade flows. Thus, the extensive margin of trade plays an important role in the months following the devaluations.

A second feature of the data is that the collapse in trade flows is initially much more rapid than the increase in the relative price of imported goods would suggest. Figure 1 shows this clearly for Argentina, with the peak drop in trade occurring before the peak increase in relative prices. The high short-run response is opposite of the traditional view in the J-curve literature (see Magee, 1973, and Meade, 1988) that trade initially responds little, or not at all, to relative price movements following devaluations.[41]

Indeed, a relatively high short-run elasticity of imports is common to many countries' devaluation episodes, though not all. One way of seeing this is to directly measure the change in imports relative to the change in the terms of trade. We measure this elasticity as the log change in the ratio of real imports to real income, $\Delta \frac{m_{it}}{y_{it}} = \ln M_{it}/M_{i0} - \ln Y_{it}/Y_{i0}$, relative to the change in the relative price of imports to domestic output, $\Delta \tau_{it} = \Delta \frac{p_{m,it}}{p_{y,it}} = \ln \left(\frac{P_{m,it}}{P_{y,it}} / \frac{P_{m,i0}}{P_{y,i0}} \right)$, since the quarter of the devaluation (see the appendix for details on the data),

$$\widehat{\gamma}_{it} = -\frac{\Delta \left(m_{it}/y_{it} \right)}{\Delta \tau_{it}}.$$

Figure 4 plots the median elasticity for our six countries and a group of four countries (Argentina, Brazil, Mexico, and Russia) for which the change in the relative price of imports was relatively larger initially.[42] We tend to see the higher short-run elasticity when the increase in relative price

NAFTA (pre 1994) trade flows in all experiments. As evident from comparing methods 2 and 3, weighting either based on trade in the pre-devaluation period or the whole sample has a very minor impact on our measures of the extensive margin for the other five countries.

[41] The J-curve literature studies net export dynamics following exchange rate devaluations. This literature finds that for industrialized countries, net exports initially decline prior to increasing toward a surplus gradually. In contrast, in our six emerging market devaluations, net exports increase initially and move to a surplus within one-quarter of the devaluation.

[42] There is some variation across countries in the comovement between trade and prices. Based on total imports, the elasticity for Argentina, Brazil, Mexico, and Russia peak in the first quarter while Korea and Thailand peak in the

has been most sudden, as our theory suggests. Thus, the relationship is much stronger when we exclude Thailand and Korea. In Thailand and Korea, respectively, the terms of trade had only risen 30 percent and 17 percent of the total after the first two months, in contrast to Argentina, Brazil, Mexico and Russia, where the terms of trade had risen 65, 100, 81 and 88 percent, respectively. For this subset of countries the quantity response is 2/3 larger in the first quarter than the fifth quarter. Perhaps another issue affecting trade dynamics in Korea and Thailand, is that these devaluations did not really occur in isolation; they lead the rest of the Asian crisis, which surely had an impact on demand/trade costs/financing/etc. Taken as a whole, the data on emerging market devaluations suggest that trade actually responds quite quickly to changes in relative prices.[43]

Finally, in addition to the salient features documented in Figure 4 and Table 6, Burstein, Eichenbaum and Rebelo (2005) persuasively show that each nominal exchange rate devaluation in these countries is also associated with a rapid and almost one-for-one increase in the country's local currency import price index, but a slower rise in the domestic price of importables.

We next ask whether our calibrated model can account for these features of the data.

B. Model Experiments

The countries in our sample experience an average increase in the relative price of imported goods of about 50 percent that only gradually reverts over time. We thus start by modeling a devaluation as an unanticipated,[44] permanent increase in ω : $\Delta \log \omega = 0.5$. The devaluations are associated with sharp increases in interest rates as well: the EMBI+ spread that captures the average spread of sovereign external debt securities rose by as much as 7000 basis points in Argentina, 2400 basis points in Brazil, 1600 basis points in Mexico, 1400 basis points in Russia, and 950 points in Thailand. We thus also associate a crisis with a permanent drop in the discount factor to $\beta = 0.7^{\frac{1}{12}}$, which corresponds to a 24 percent rise in annual real interest rates.[45] Finally, the devaluations are

sixth quarter. Looking just at US exports to these destinations, the peak elasticity is in the first quarter in Argentina and Brazil, second quarter in Mexico and Russia, fourth quarter in Korea, and seventh quarter in Thailand.

[43] The relationship in Figure 4 is even stronger when estimating elasticities using just U.S. exports, as we show in our unpublished web appendix.

[44] While interest rates tend to rise prior to crises, the increases tend to be small relative to the subsequent depreciation, suggesting from uncovered interest parity that a large part of the devaluation is unanticipated.

[45] Our approach follows the tradition in the small open-economy literature of taking changes in relative prices and interest rates as exogenous. We then work out the implications of these changes in relative prices holding all else

associated with sharp recessions. We capture these by assuming an additional 15 percent exogenous drop in demand to capture the aggregate consumption drops in episodes of devaluation. We model this by assuming now $\nu \sim N(\Delta\mu_v, \sigma^2)$, where $\Delta\mu_v = -0.15$. Finally, we also assume, in line with the evidence from Burstein, Eichenabum and Rebelo (2005), that the marginal cost of supplying imported goods to the market does not increase one-for-one with the change in the import price index, ω. One interpretation is that importers produce final output using labor l and imported materials m according to

$$y = l^a m^{1-\alpha},$$

and, consistent with the evidence, wages do not change after the devaluation. Consistent with the Chilean data, we set the share of labor, α, to 25 percent.

Figure 5 illustrates the ergodic distribution of firm inventory holdings, as well as the adjustment hazards, in the pre- and post-devaluation steady states. Inventory holdings in both cases are normalized by mean sales of the importer in the pre-crisis steady state. Consider first the upper panel, which illustrates the pre-crisis steady state. Firms that have paid the fixed cost in the previous period have the same level of inventories, roughly 6 periods of mean sales. They account for roughly one-fifth of all firms. The rest of the firms are those that have adjusted in previous periods; the further in the past they have adjusted and the larger the demand realizations, the smaller their inventory holdings are. As a firm's inventory holdings decrease, there is an increased probability that the firm will experience a demand disturbance sufficiently large that it will find it optimal to pay the fixed cost and import. The adjustment hazard is thus increasing for firms with lower levels of inventories. As a firm's inventory values reach close to two period's worth of mean sales, the firm finds it optimal to pay the fixed cost and import with probability one.

The qualitative shape of the ergodic density and adjustment hazards in the post-devaluation steady-state are virtually identical. Now, however, the higher relative wholesale price of imports makes it optimal for importers to increase the price they charge for their goods, sell less, and thus

equal.

hold fewer inventories. The decrease in inventory holdings is smaller than the frictionless drop in trade: $-\theta(1-\alpha)\Delta\log\omega - \Delta\mu_v$. This is because the fixed cost increases relative to profits after the devaluation and firms prefer to decrease inventory holdings by less in order to avoid paying the relatively higher fixed cost too often. Clearly, because the desired inventory holdings decrease, the adjustment hazard shifts to the left. As a result, firms with inventory holdings that would render adjustment optimal in the pre-crisis steady state are now less likely to pay the fixed costs and import.

We are interested in characterizing the transition to the new post-crisis steady state. Given the leftward shift of the hazard in Figure 5, one can expect that as a result of the change in the relative price of imported goods, firms that would have otherwise imported will now find it optimal to postpone adjustment. As a result, the fraction of goods imported would drop precipitously following the crisis as firms run down their now higher-than-desired levels of inventories acquired prior to the crisis. This drop in the extensive margin of trade will last until firms exhaust their higher-than-desired levels of inventories and the economy converges from the pre- to the post-devaluation steady state.

The optimal price functions that were illustrated in Figure 3 also shift (in logs) to the left by (approximately) $-\theta(1-\alpha)\Delta\log\omega$ and up by (approximately[46]) $(1-\alpha)\Delta\log\omega$ as a result of the change in the relative price of imports.

The left panel of Figure 6 illustrates the response of prices in our model economy. We compute an aggregate index for the retail price of imports by constructing the consumption-weighted average[47] of imported goods' retail prices. Note that no goods disappear entirely from the consumption basket, since the lower bound on inventory holdings in the pre- and post-devaluation steady state is above zero (Figure 5). That is, even though few firms import in any given period, they all sell domestically out of existing inventories.

On impact the retail price of imports rises more slowly than the wholesale price, ω: The pass-

[46] Retail prices increase somewhat more than marginal cost because of the increase in the fixed cost of importing (relative to profits).

[47] Results are qualitatively and quantitatively very similar if we construct instead an unweighted average of prices.

through immediately after the change in relative prices is only 50 percent of its long-run change ($\Delta p^{LR} \approx (1-\alpha)\,\Delta \log \omega$). As firms exhaust their inventory holdings, they find it optimal to raise prices, and the economy converges to the new steady state. The central insight here is that even without price adjustment costs or sources of strategic complementarities, firms will choose not to pass-through changes in international relative prices (equivalently, replacement costs) one-for-one to consumers. The optimal price is proportional to the marginal valuation of inventories, which, in times of crisis, may be substantially less than the replacement cost of inventories. That is, while markups relative to the marginal value of inventories are constant, markups relative to replacement cost fall.

The middle panel of Figure 6 illustrates the response of import volumes. The higher relative price of imports leads initially to a trade implosion: a drop in import values that is six times larger than the change in the relative price of goods (ω), much larger than the drop that a frictionless economy would generate. As the right panel of Figure 6 shows, this large initial drop in imports is to a large extent accounted for by a sharp drop in the extensive margin of trade; the fraction of importing firms drops precipitously. Thus, the extensive margin accounts for roughly 70 percent (-2.25/-3.2) of the drop in imports in the model economy immediately after the devaluation. As firms run down their higher-than-desired inventories, import volumes converge to the new steady state level approximately $\theta\,(1-\alpha)\,\Delta \log \omega$ below the pre-crisis level, and the fraction of importing firms returns to a level slightly greater than the pre-crisis level. This transition lasts for about 10 months.

Figure 6 (solid line) also reports results of an experiment in which the only effect of the devaluation is an increase in the relative price of imports, $\Delta \log \omega = 0.5$. We shut down all other shocks (the change in mean demand and the interest rate) and assume a local factor content of 0 $(\alpha = 0)$. This experiment isolates the role of an increase in the price of imports alone on the dynamics of retail price of imports and quantities after a devaluation. The figure shows that the drop in quantities and fraction of firms importing is approximately the same as in the Benchmark setup. On one hand, the marginal cost of imported goods increases by more than in the Benchmark setup, as the local factor content is zero. On the other hand, interest rates and, therefore, the cost of carrying inventories no longer increase and the incentive to shed inventories is reduced. The two effects approximately cancel out. Similarly, the response of prices is qualitatively similar to that of the Benchmark setup. The immediate pass-through of the higher cost of imports is now 80 percent of its long-run value. Thus, roughly half of the imperfect pass-through to a devaluation in the Benchmark economy is accounted for by the increase in the interest rate and, therefore, the carrying cost of inventories. The latter increases the incentive to keep retail prices low in order to avoid tying up funds in an excess of inventories.

C. Sensitivity

We next conduct a number of counterfactual experiments in order to gauge the sensitivity of our results. In particular, we show that our results are robust to variations of the assumptions about economic activity leading into the devaluation and the dynamic path for the relative price of imported goods after a devaluation.[48]

C Drops Prior to Devaluation

Devaluations generally occur in recessionary environments that are likely to lead firms to begin shedding inventories. We explore whether the dynamics of aggregate economic activity leading up to the devaluation affect the dynamics of quantities and prices in our model economy by assuming that the drop in aggregate consumption occurs several months prior to the devaluation. In particular, we assume that the mean demand μ_v (aggregate consumption) drops by 0.15 log-points three months prior to the devaluation (an increase in ω by 0.5 log-points and increase in annual interest rates to 0.30). Figure 7 reports the transition in response to this devaluation. The figure shows a small drop in the retail price of imports in the months following the drop in aggregate consumption but preceding the devaluation. Similarly, the fraction of importers and import values drop in response to this first shock as well. Both of these effects are accounted for by the incentive of importers to reduce inventory holdings to a new, lower level.

[48] In the appendix we show results are also robust to variations in the level of markups.

The drop in consumption, however, is too small relative to the much larger change in demand for imported goods arising from the change in the relative price of imports to substantially alter the dynamics of prices and quantities in our model. With an Armington elasticity of demand of 1.5, the 0.5 log-point change in the relative price of imports has a much larger effect on the demand for imported goods than the 0.15 drop in aggregate consumption. As a result, the dynamics of the economy in response to the devaluation is very similar to that in the case in which the drop in consumption and the devaluation are simultaneous. Although the initial drop in consumption does reduce desired and actual inventory holdings, it does so by much less in response to a drop in aggregate consumption alone.

Gradual Devaluation

We next characterize the response of prices and quantities to a gradual devaluation. In particular, the devaluation experiment we consider next is identical to that in the Benchmark economy studied earlier, but instead of assuming a permanent change in the relative price, we feed the model the actual path of the relative price of imports to PPI for Argentina. We report the results in Figure 8. In the first experiment, we assume that each change in the relative price for imports is unanticipated. That is, agents expect whatever level of ω in effect at date t to persist forever. In the second experiment, we assume that the entire path for the relative price, $\omega_t|_{t=0}^T$, is revealed to the firms at the moment of the devaluation. Although these are both extreme assumptions, and there are elements of both in the data, Figure 8 shows that the response of the economy to a gradual devaluation is not too dissimilar across the two. Both experiments show a strong contraction in trade flows and in the fraction of importing firms, as well as a slow and incomplete response of retail prices. The key difference is that when firms anticipate the entire path for $\omega_t|_{t=0}^T$, they find it optimal to initially invest in inventories in anticipation of the future higher replacement cost. As a result, imports slightly increase in the first month when the devaluation is announced and the higher inventory holdings in this experiment lead to a sharper drop in trade and a more gradual response of prices.

Notice also in Figure 8 that inventories are key to accounting for the dynamics of trade flows after a devaluation. Because the devaluation is gradual, a frictionless model or a model with fixed costs of importing (calibrated to match the lumpiness of trade) but no inventories will both predict a gradual decline in imports after the devaluation. In contrast, the model with inventories predicts a much larger and more rapid drop in trade flows, consistent with the evidence in the data. For example, Figure 1 shows that in Argentina, the drop in trade was highest in the first month of the devaluation and reached its trough in the second month, while the peak increase in the retail price of imports was five months after the shock.

D. Direct Evidence of the Inventory Mechanism

We now consider some direct microeconomic evidence on the role of inventories for price and quantity dynamics in large devaluation episodes. Specifically, our model predicts that the presence of excess inventories contributes to a larger short-run drop in trade volumes and a more gradual pass-through of nominal exchange rate movements to retail prices observed in large devaluation episodes. We next evaluate these predictions in the data.

Evidence for Quantities

Although we do not directly observe inventory holdings in the disaggregate US export data, our model predicts a tight relationship between inventories and the date when a good was last imported. *Ceteris paribus*, importers who have recently purchased inventories (and thus have a higher stock of these) will import less after a large increase in the replacement cost than importers who have not recently purchased inventories (since recent purchasers will, on average, hold higher inventories at the time of the devaluation). This prediction is illustrated in Figure 9, in which we report import values for firms that have not (solid-lines) and have (dashed-lines) ordered imports in the three months preceding the devaluation in our Benchmark experiment.

The three-month cutoff roughly divides firms into two equally-sized bins: firms that have not imported recently have 50 percent lower inventory holdings than those that have imported recently. The figure illustrates that import values are higher for those firms that have not recently imported, as these firms exhaust their inventory holdings more rapidly and return to the market sooner. Over the course of the first 12 months after the devaluation, the total import value (per firm) for these firms is 50 percent greater than that for the rest. We emphasize that we assume that firms are identical in these experiments in all dimensions other than the pre-crisis inventory levels. We, therefore, need to control for importer characteristics carefully in order to perform an analogous experiment in the data and ensure that our results are not driven by a differential increase in costs, or differences in price or income elasticities for the goods in our sample.

We evaluate the model predictions using monthly shipment records of disaggregate (HS-10 good) US imports by port of exit. Since we have data on shipments of identical HS-10 goods by port, we can control for much heterogeneity in goods characteristics by exploring within-good, across-port differences in trade flows after the devaluation.

Specifically, let i index goods (HS-10 product categories), j index ports, and t index years. We focus on annual frequency in order to filter out the noise in trade flows at this level of disaggregation and define years as 12-month windows around the month of devaluation. Let REC_{ijt} denote a dummy variable for whether or not there was an import of good i, from port j, in the three months prior to the beginning of year t. Let M_{ijt} denote the annual value imported in year t. Finally, let c_{it} denote good-year fixed effects, which control for differences in goods characteristics per our discussion above, as well as for differences in trade flows in various years. Finally, let $\boldsymbol{I}_t$ denote an indicator variable that takes a value of 1 in the year after the crisis. We estimate the following regression specification:

$$M_{ijt} = c_{it} + \rho M_{ij,t-1} + \alpha REC_{ijt} + \beta \left(\boldsymbol{I}_t \times REC_{ijt} \right) + u_{ijt}.$$

We allow annual import values to depend on their lagged values to capture other port-level dynamics that are not related to inventories. Here, α captures the effect of a recent shipment on trade over the entire sample, while β captures the differential effect in the year after devaluation.

Table 7 presents the results of the estimation for the six devaluation episodes. We have normalized all M_{ijt} by the average (across all goods) imports in the year prior to the crisis, so that coefficients can be interpreted in terms of a percentage of pre-crisis import values. First, notice that the estimates of α are positive, a finding reminiscent of the finding of downward-sloping age hazards in related contexts.[49] We interpret these coefficients as evidence of unobserved heterogeneity: goods that happen to have been imported recently are (by selection) goods that are imported more frequently and, therefore, likely to be imported again.

More to the point, the estimates of β are in bold and are negative, significant, and sizable for all countries, consistent with our theory. Using Argentina as an example, the coefficient of -1.51 indicates that a good that was recently imported will have a 151 percent lower import value in the crisis year than a good that has not been recently imported.[50] Thus, inventory considerations have important effects on trade decisions immediately following the devaluation.

Evidence for Prices

Our theory also implies that inventory management considerations may contribute to the gradual pass-through of nominal exchange rate movements to retail prices observed in large devaluation episodes. As with inventories, the available data are not ideal. Still, we present suggestive empirical evidence consistent with some implications of our model, namely, that inventory holdings and inventory carrying costs will affect how firms pass-through a change in the replacement cost of inputs.[51]

In the model, both inventory holdings and inventory carrying costs will independently decrease pass-through. That is, all else equal, firms with large inventory holdings will increase their price more gradually in response to a devaluation than those with low inventory levels. Similarly, all else equal, firms with higher carrying costs will increase prices more gradually. For instance, a firm selling high-fashion clothing, which tends to go out of style quickly, will tend to pass-through less of an increase in the replacement cost than a firm selling bricks, which are fairly storable and hence may have lower carrying costs.[52] We show these predictions in Figure 10. Panel A plots the transition

[49] E.g., in the literature on pricing, a typical finding is that prices are more likely to adjust immediately after a price change.

[50] We also tested a more general regression equation that allows for year-specific effects in different post-crisis years. The coefficients were lowest (most negative) in the first year directly after the devaluation, presumably the largest surprise change in desired inventories. The exception here was Thailand, which experienced a much more gradual change in the relative price of tradables.

[51] We thank an anonymous referee for suggesting we test the model in these dimensions.

[52] The model also predicts a larger short-run drop in quantities (and the extensive margin) for more durable goods. The data are also consistent with this relationship, but we emphasize the evidence from the recent shipment-based analysis because the disaggregation by port allows us to control for good-level heterogeneity.

paths for average prices of three sets of firms in our model that differ only in their initial inventory holdings at the time of the devaluation. Each transition path averages over different realizations of the idiosyncratic demand shocks. Panel B plots the dynamics of prices for three sets of goods in our model that start out with the same level of inventories but have different holding costs (δ). The retail price of less storable goods increases more slowly. The more storable good's ($\delta = 0.01$) retail price in the first month after the devaluation is 80 percent ($\approx \exp(-0.22)$) of its long-run value. In contrast, the retail price of the less storable good ($\delta = 0.05$) is 2/3 ($\approx \exp(-0.41)$) of its long-run value. In equilibrium, however, less storable goods will tend to also have lower inventories, so that the two effects will tend to work in opposing directions. The discussion above suggests that we must control for inventories and holding costs simultaneously as they have similar effects on prices but are negatively correlated.

The first way we evaluate these predictions empirically is to look at a set of goods for which firms hold no inventories. In this case, inventory holding costs are irrelevant as inventory holdings are essentially zero. The theory then has a sharp prediction that the prices of these goods should respond fully to the nominal exchange rate, or costs more generally. Using product level price data used in the construction of the Argentine CPI, we construct two baskets of products based on each product's inventory holdings.[53] The first basket includes imported products that have little or no inventory holdings. We call these nonstorables, and we have tried to be conservative in choosing items with little to no inventories. In this basket, there are 12 products (pineapples, bananas, airline tickets, cruises, and tourist packages). In the second basket, which we call storables, there are 52 other imported products in the CPI (automobiles, air conditioners, etc.).[54] Figure 11 plots the dynamics of prices for these two groups. Consistent with our theory, the price of nonstorable goods, those with little or no inventories, increases faster, and follows the dynamics of the nominal exchange rate more closely. In the long-run though, 15 months because of data constraints, both baskets have about the same price change, suggesting cost changes of the baskets are comparable. These results are suggestive, but clearly many of the nonstorable goods are actually services that

[53] We use the data from Burstein, Eichenbaum and Rebelo (2005), available at Ariel Burstein's website.

[54] Focusing on the set of imported goods allows us to control for cost changes as well.

do not precisely fit our model.

In our second analysis, we therefore exclude services and evaluate the model's pricing dynamics predictions on a wider set of 538 storable goods that are used in the construction of the Argentine CPI in the 20 months surrounding the Argentine crisis.[55] This involves controlling for and estimating the independent effects of inventory holdings and carrying costs.

For each good i, we have two proxies for inventory holdings: retail inventories-to-purchase ratios (INV_i) and our HH indexes of the lumpiness of orders (HH_i). The inventory-sales ratios are based on 13 US NAICS sectors averaged from 1992 to 1997, while the lumpiness is based on 4-digit HS classification in the five years prior to the crisis in Argentina. We include lumpiness as it is positively related both to the time interval between orders and level of inventory holdings, but the results are robust to its exclusion.

We proxy for inventory carrying costs using a measure of each good's depreciation rates (DEP_{it}) collected from a variety of official sources (see the appendix for a description of our methodology). Depreciation rates are related to the speed at which the products lose value and inversely related to the length of time that a product can either be used or stored. For instance, depreciation on a men's winter sportcoat is assigned a monthly depreciation rate of 2 percent based on an average useful life of 48 months, while an air conditioner is assigned a depreciation rate of 0.8 percent based on a life of 120 months. The depreciation measures capture both physical depreciation of the good through use as well as from obsolescence over time. Depreciation rates for our goods range from 25 percent to 0.2 percent.

We run the following regression on monthly data (where t indicates month since the devaluation and i indexes the good),

$$\frac{\Delta p_{i,t}}{\Delta p_{i,15}} = c_{jt} + \alpha_0 \ln \text{DEP}_i + \alpha_1 \ln \text{INV}_i + \alpha_2 \ln HH_i + \varepsilon_{it}.$$

On the left-hand side, we have a measure of good level pass-through, measured as the ratio of

[55] 538 of the 643 products in Argentine CPI over this period have monthly depreciation rates of less than 25 percent. This subset eliminates non-storables, which have low inventories and also suffer from seasonal variation, and focuses the analysis on goods sufficiently storable to be traded.

the cumulative price change in month t ($\Delta p_{i,t}$) to the cumulative 15-month price change ($\Delta p_{i,15}$). Normalizing by the long-run change allows us to proxy for the change in marginal cost and narrows our focus to short-run pass-through, which is most relevant for our model. The Argentine government also classifies goods by their tradedness[56] and so we control for this characteristic using the dummies c_{jt}. Tradedness is also likely to be related to changes in the underlying cost of the good.

Table 8 shows that products purchased infrequently (high HH) or with high inventories tend to have lower pass-through initially, i.e. over the first three months. Similarly, goods with high inventory costs, proxied by high depreciation rates, tend to have low pass-through initially. These effects are significant and of the right sign initially, over the first three to six months, and become less important with time as predicted by the theory.

We conclude with two final thoughts. First, in addition to explaining some of the variation in prices across goods, inventory considerations will also contribute to the gradual increase in average prices, measured by the constant term in each regression. Second, the results here may actually understate the role of inventory management concerns for price dynamics because depreciation is likely to be an imperfect measure of inventory cost that exerts an offsetting effect on prices. In particular, because consumers have a stock of consumer durables that yield a service flow, a reduction in current purchases of durables has a smaller effect on current utility than an equivalent cut in non-durable purchases, making both durable purchases and prices strongly procyclical.

6. Conclusions

We have documented that importers face delivery lags and economies of scale in transacting. These frictions lead to inventory-management problems that are more severe for importers than nonimporters. As a consequence, at the micro level, importers hold relatively high level of inventories and international transactions are relatively lumpy. We show that a parsimoniously parameterized $(S, s)-$type economy successfully accounts for these features of the data.

We find that the frictions we highlight have important aggregate consequences for both the level

[56] The classifications are 1) with exported inputs; 2) with imported inputs; 3) exportables; 4) imported; 5) mixed, and 6) not sensitive to trade.

of trade and the dynamics of trade following large devaluations. With respect to the level of trade, our model can account for the differences in both inventory holdings and lumpiness of transactions between buyers of domestic or imported inputs. We also find that while fixed costs appear quite small, about 3.6 percent of the mean international shipment, the tariff equivalent of the inventory costs is about 20 percent. The relatively high tariff equivalent of the frictions we emphasize helps to explain why observed trade costs are so low and inferred trade costs from trade flows are so high (see Anderson and van Wincoop, 2004). Firms incur higher inventory costs to economize on international trade costs.

We then show that the model incorporating the observed micro frictions predicts that in response to a large increase in the relative price of imported goods, as is typical in large devaluations, both the volume of imports and the number of distinct imported varieties drop sharply immediately following the shock. The model also predicts that importers find it optimal to reduce markups in response to the increase in the wholesale price of imports and thus partly rationalizes the slow increase in tradeable goods' prices following large devaluations. These predictions of the model are quite different than what one would get using standard forms of trade costs, namely iceberg costs or fixed costs of exporting. Our model's predictions are supported by the events in six current account reversals following large devaluation episodes in the last decade.

Finally, we produce microevidence that both the drops in trade and pass-through of prices during the devaluation are linked to inventory considerations. We believe that bringing further microevidence to bear on these questions is a fruitful avenue for future research.

The trade costs we study are particularly large for developing countries as are the inventory holdings. An avenue for further research would be to examine whether these frictions play a role in explaining differences in business cycles and net export dynamics between developed economies and emerging markets. Preliminary work (George Alessandria, Joseph Kaboski and Virgiliu Midrigan, 2009) suggests that inventory considerations have played an important role in the global collapse in trade from mid-2008 onward.[57]

[57] For example, in the case of autos, inventory-sales ratios rose 25 percent from September 2008 to January 2009, and although the drop in foreign light-vehicle sales was 9 percent, the drop in imported autos was 35 percent.

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Appendix on Measures of Depreciation Rates/Durability.

Each good is assigned a measure of depreciation rate based primarily on seven sources (described below). Four sources are geared toward relatively more durable goods and three sources are geared more toward food and personal care type products. For the group of more durable goods, we prioritized in the following way. If we had an exact match from our useful life classification from the Department of Housing of the state of Georgia, we used it. Next, we took an average of the US Government General Services Administration (GSA) and the claims adjuster series, except when the closest match of the GSA was nes (not elsewhere specified). Depreciation rates were thus constructed as the inverse of the useful life/durability data rate for these sources. For a group of five products (large and small motor vehicles, orthopedic inserts, kneepads and thermometers.) we used the Bureau of Economic Analysis (BEA) depreciation rates for durable assets. The BEA and GSA provide estimates of annual depreciation rates.

For the second group of relatively less durable goods, primarily food, we took an average of What's Cooking America (WCA), Timestrip online, and Produce estimates. Unless the description of the good asked for a fresh product, we used the shelf-life of a product in the freezer. For a small group of goods such as olives, frozen lamb, alcoholic beverages, fabric softener, and energy products (coal, diesel, and gasoline), we based our estimates from a variety of web sources (BBC, New Zealand lamb cooperative, etc). Finally, for a group of about 22 cleaning products, we estimated the durability based on our judgment and similar products. These goods were given durability of 12 (toothpicks, liquid disinfectant) or 24 months (broom, bucket, mops, nails) based on similar goods. In total, we were able to classify 643 goods by durability. Again, depreciation rates were constructed as the inverse of the durability data.

Our seven sources are:

- General Services Administration (GSA): http://www.fss.gsa.gov/fsstt/archives/dtos/dsec 12.htm
- Bureau of Economic Analysis: http://www.bea.gov/national/FA2004/Tablecandtext.pdf and for autos and computers http://www.bea.gov/national/pdf/Fixed_Assets_1925_97.pdf.
- Claims adjuster: http://www.claimspages.com/documents/docs/2001D.pdf
- Georgia Department of Housing: http://www.dca.state.ga.us
- Timestrip: http://www.timestriponline.com/shelflife/shelflife.htm
- What's Cooking America: http://whatscookingamerica.net/Information/FreezerChart.htm
- Produce shelf-life: http://www.completeproduce.com/html/shelflife.html

Notes on Figures, Tables and Data

1. Table 1: Importing costs: World Bank Doing Business Survey. Mean and median shipments: US Census Bureau (Census) US Exports of Merchandise - History DVD.
2. Table 2: Plant level data from the Chilean census (Hsieh and Parker, 2007). Materials inventory measures the ratio of the average stock of material inventory to material purchases, $i_{jt}^{m} = \frac{I_{jt+1}^{m}+I_{jt}^{m}}{2M_t}$. Finished inventory measures the ratio of the average stock of material in process or finished to the annual sales, $i_{jt}^{f} = \frac{I_{jt+1}^{f}+I_{jt}^{f}}{2Y_{jt}}$. Inventory denotes the sum of materials inventory and finished inventory, $i_{jt} = i_{jt}^{m} + i_{jt}^{f}$. Import content measures the ratio of imported raw materials to total raw materials, $s_{jt}^{im} = M_{jt}^{im}/M_{jt}$.
3. Table 3: The US steel wholesaler data are from Hall and Rust (2000). The data contain information on deliveries by date, good, value, quantity, and source (domestic or foreign).
4. Tables 4 and 6 to 8: US trade data used to measure characteristics of trade flows are from the Census' US Exports of Merchandise History DVD.
5. Table 8 and Figure 11: price data: Burstein, Eichenbaum and Rebelo (2005). Available at http://www.econ.ucla.edu/arielb/ AdditionalMaterialLargeDevJPE.html in pricedataJPE.xls.
6. Figure 1:

- Panel 1 of Figure 1: All data from Burstein, Eichenbaum and Rebelo (2005). Available at http://www.econ.ucla.edu /arielb/AdditionalMaterialLargeDevJPE.html in pricedataJPE.xls. CPI imports constructed using microdata in Burstein, Eichenbaum and Rebelo (2005) on CPI for disaggregated product categories and origin classification. NER denotes monthly average Argentine Peso/$ exchange rate.
- Panel 2: Argentina: WPI Imports from MECON, PPI from IFS (21363...ZF...)
- Panels 3 and 4: US Nominal Exports, transactions and HS 10 varieties by destination are from the Census' US Exports of Merchandise History DVD. Total imports are from the IFS nominal dollar value and are C.I.F. Total imports and US exports are deflated by the BLS's US Export Price Index.

7. Figure 4

- US export data constructed using Census US Exports of Merchandise History DVD exlcudes shipments of aircrafts (HS 8802). Deflated using US export price index. US export data and data from Argentina, Mexico, Russia, and Thailand seasonally adjusted using Census X-12 method.
- Argentina: Imports of Goods & Services (C213GM@IFS, Mil.Pesos); Gross Domestic Product (C213GDP@IFS, Mil.Pesos, AR); Imports deflated by Unit Value of Imports (C213TL@IFS, US$, 2005=100, NSA) times Nominal Exchange Rate: Market or Par (C213ECMA@IFS, Average, Pesos/US$); GDP deflated by GDP Deflator (C213GJ@IFS, 2005=100)
- Brazil: From Fundaçâo Instituto Brasileiro de Geografia e Estatastica/Haver Select. Real GDP: Chained Index (S223GPI@EMERGELA, SA, 1995=100); Real Imports: Chained In-

dex (S223NMI@EMERGELA, SA, 1995=100); GDP at Mkt Prices (F223GP@EMERGELA, SA, nat. currency); GDP: Imports (F223NM@EMERGELA, SA, nat. currency). GDP and Import price deflator constructed implicitly as nominal series divide by real series.

- Korea: From OECD. Real Imports of goods and services (KOR.VNBQRSA.2000.S2); Real Gross domestic product (KOR.VNBQRSA.2000.S2); Nominal Imports of Goods & Services (KOR.CQRSA.S2); Nominal Gross domestic product (KOR.CQRSA.S2) GDP and Import price deflator constructed implicitly as nominal series divide by real series.
- Mexico: Imports of Goods & Services (C273GM@IFS Bil. Pesos); GDP (C273GDP@IFS Bil. Pesos); Imports are deflated by Nominal Exchange rate (C273ECM@IFS, Pesos/US$). GDP is deflated by GDP deflator (C273GJ@IFS national currency, 2005=100).
- Russia: Imports of Goods & Services (C922GM@IFS, Bil.Rubles, NSA); Private Consumption (C922GC@IFS, Bil.Rubles, NSA); Consumption deflated by CPI (C922PC@IFS, 2005=100); Imports deflated by Nominal Exchange Rate: Market or Par (C922ECMA@IFS, Average, Rubles/US$)
- Thailand: Imports of Goods & Services (C578GM@IFS, Bil.Baht); Gross Domestic Product (C578GDP@IFS, Bil.Baht); Imports deflated by Unit Value of Imports (C578TL@IFS, US$, 2005=100, NSA) times Nomional Exchange Rate: Market or Par (C578ECMA@IFS, Average, Baht/US$); GDP deflated by GDP Deflator (C578GJ@IFS, 2005=100).

8. Labor share at Chilean plants: for plant j let $\alpha_{jt} = \frac{w_{jt} * l_{jt}}{w_{jt} * l_{jt} + M_{jt}}$, where $w_{jt} l_{jt}$ measures salary payments to white and blue collar workers in the current period and M_{jt} measures current materials purchases. The top panel of the following table reports the sample averages for importers, nonimporters and all plants. We measure both simple averages and sales-weighted averages. In total, using simple averages, the labor share is approximately 23.2 percent; however, when we weight by sales, we find a substantially lower share of 13.6 percent. However, the weighted regression of labor share on import content predicts that labor share is higher, the larger a plant's import content. A plant that imports all of its raw materials thus has a labor share of about 17.8 percent.

Labor share in Chilean Plants

A. Mean Labor share		
	Unweighted	Weighted
Importers	0.211	0.137
Total	0.232	0.136
B. Controlling for import content and log employment		
Constant	-0.043*	0.042*
Import content	0.25*	0.136*

* Significant at 99 percent

Table 1: Time and Monetary Costs of Importing

Country	Number of Days	Import Cost	US Export Cost	Median Shipment Value from the US	Total Costs as a Fraction Median Shipment	Mean Shipment Value from the US	Total Costs as a Fraction of Mean Shipment
Argentina	19	$1,500	$625	$12,400	0.17	$37,500	0.06
Brazil	23	$945	$625	$13,900	0.11	$63,000	0.02
Korea	11	$440	$625	$14,700	0.07	$89,300	0.01
Mexico	23	$595	$625	$10,900	0.11	$39,700	0.03
Russia	33	$937	$625	$21,000	0.07	$85,510	0.02
Thailand	20	$903	$625	$12,000	0.13	$46,147	0.03
Mean					0.11		0.03

Notes: Import and Export Costs are US dollar costs for 2006. Average shipment values are for 2004. Costs include all costs accrued between the contractual agreement and the delivery of goods, excluding international shipping time/costs, tariffs, and inland transportation time/costs. Russian import costs exclude port/terminal handling fees. US export costs do not vary by destination country.
Source: World Bank (2007), http://www.doingbusiness.org/ExploreTopics/TradingAcrossBorders/

Table 2: Regression Results of Inventory Holdings on Import Content (1990 to 2001)

	Unweighted		Weighted		Robust		Fixed	
	s^{im}	c	s^{im}	c	s^{im}	c	s^{im}	c
Inventory	0.196	0.213	0.103	0.157	0.219	0.133	0.074	0.226
	(17.6)	(75.6)	(20.1)	(83.1)	(49.6)	(119.0)	(6.3)	(84.4)
Materials inventory	0.139	0.16	0.081	0.106	0.154	0.087	0.051	0.169
	(14.9)	(67.6)	(20.2)	(72.0)	(50.3)	(113.4)	(5.0)	(73.1)
Finished inventory	0.057	0.053	0.022	0.051	0.041	0.012	0.023	0.057
	(12.9)	(47.6)	(9.6)	(60.5)	(51.5)	(58.2)	(5.0)	(54.2)
Inventory controlling for ln employment	0.184	0.18	0.106	0.2	0.176	0.033	0.094	0.279
	(15.6)	(18.4)	(20.5)	(25.3)	(40.1)	(9.1)	(7.6)	(27.2)

Notes: T-stats in parentheses. "Weighted" results are by total sales. "Robust" uses a robust regression algorithm to control for outliers. "Fixed" includes industry fixed effects.

Table 3: Statistics on Lumpiness at a US Steel Wholesaler

A: Summary Statistics

	Domestic		Foreign	
Goods	Purchases	Value	Purchases	Value
3573	12472	$134 mln	5632	$87.8 mln

B: Premium on Imported Goods (good-yr fixed effects)

Amount	Weight	Price
0.211	0.345	-0.08
(7.0)	(12.8)	(5.6)

C: Import size premium controlling for price (good-yr fixed effects)

Price	Weight premium
-2.1	0.48
(39.0)	(19.1)

D: Mean and Median Interval (Days)

	Domestic	Foreign
Mean	100	204.5
Median	55.9	140.5

Notes: T-stats in parentheses.

Table 4: Lumpiness Statistics of Disaggregate U.S. Exports to Different Destination Countries

	Argentina	Brazil	Korea	Mexico	Russia	Thailand
# of transactions (in months with trade)	2.2	3.0	4.8	32.3	2.7	3.2
fraction of months good exported	0.27	0.33	0.40	0.81	0.13	0.26
fraction of months in year good exported	0.47	0.55	0.70	0.90	0.43	0.55
Herfindahl-Hirschman index	0.40	0.37	0.28	0.21	0.45	0.35
fract. of ann. trade in top mo.	0.50	0.47	0.38	0.27	0.53	0.45
fract. of ann. trade in top 3 mos.	0.83	0.78	0.70	0.53	0.85	0.79
fract. of ann. trade in top 5 mos.	0.94	0.91	0.85	0.71	0.95	0.92

Table 5: Moments and Parameters

Moments

	Data	Benchmark	Domestic	No fixed cost	No lag	High deprec.
Used for calibration						
Herfindhal-Hirschmann ratio	0.44	0.44	0.23	0.14	0.32	0.33
Inventory to annual purchases ratio	0.36	0.36	0.21	0.29	0.12	0.25
Additional implications						
Tariff equivalent of frictions	-	0.20	0.09	0.13	0.08	0.32
f (relative to mean shipment)		0.036	0.017	0	0.050	0.047

Parameters

Calibrated					
f (fixed cost, rel. median revenue)	0.095	0.025	0	0.095	0.095
Std. dev. of demand, σ	1.15	1.15	1.15	1.15	1.15

Assigned					
Period length	1 month	1/2 month	1 month	1 month	1 month
Shipping lag	1 month	1/2 month	1 month	0 months	1 month
Elasticity of demand for imports, θ	1.5	1.5	1.5	1.5	1.5
Elasticity of subs. across imported goods	-	-	-	-	-
Monthly discount factor, β	0.995	0.995	0.995	0.995	0.995
Monthly depreciation rate, δ	0.025	0.025	0.025	0.025	0.05

Parameters characterizing devaluation

Change in wholesale import price: $\Delta\log\omega = 0.50$
Interest rate change: β=0.70 (annually)
Change in consumption: $\Delta\log C = -0.15$
Local labor share: 25%

Table 6: Salient Features of Large Devaluations

A: Relative price of imports, Trade drop and share due to extensive margin in month with worst trade drop

	max Δ (IPI/PPI)	Trade drop	Extensive Margin: Method 1 # cards	Method 1 # goods	Method 2 # cards	Method 2 # goods	Method 3 # cards	Method 3 # goods
Argentina	0.47	-0.80	1.12	0.84	1.25	0.60	1.33	0.71
Brazil	0.49	-0.44	0.78	0.47	1.07	0.30	1.08	0.43
Korea	0.34	-0.64	0.89	0.67	0.57	0.23	0.74	0.33
Mexico	0.55	-0.34	1.35	0.54	1.09	0.02	1.31	0.12
Thailand	0.50	-0.52	0.66	0.58	0.29	0.06	0.53	0.29
Russia	1.01	-1.51	0.58	0.39	0.95	0.38	1.10	0.57
Average	0.56	-0.71	0.90	0.58	0.87	0.26	1.02	0.41

B: Average Trade drop and share due to extensive margin in three month window around worst month

	Trade drop	Extensive Margin: Method 1 # cards	Method 1 # goods	Method 2 # cards	Method 2 # goods	Method 3 # cards	Method 3 # goods
Argentina	-0.72	0.90	0.74	0.97	0.52	1.06	0.62
Brazil	-0.36	0.54	0.36	0.49	0.20	0.51	0.30
Korea	-0.49	0.95	0.70	0.78	0.21	0.90	0.32
Mexico	-0.27	1.55	0.31	1.36	-0.02	1.63	0.09
Thailand	-0.49	0.75	0.71	0.27	0.06	0.52	0.34
Russia	-1.11	0.63	0.44	1.00	0.45	1.18	0.62
Average	-0.57	0.89	0.54	0.81	0.24	0.96	0.38

Notes: Goods denote distinct HS10 categories, and cards represent total number of transactions across all categories.

Method 1: no weighting; method 2: weight by total value of imports 1990-2004; method 3: weight by total value of imports 1990-devaluation.

* For Mexico, to remove the effect of NAFTA in methods 2 and 3 we base the weighting/filtering on the pre-devaluation period. Also, to remove changes in HS10 codes and transactions from changes in the classification system, we forced the change from December to January each year to equal the average change in the previous three months.

Table 7: Effect of Recent Shipments on Value Traded in the Crisis Years

	Country					
Regressors	**Argentina**	**Brazil**	**Korea**	**Mexico**	**Russia**	**Thailand**
	2.46	0.79	2.55	2.14	5.66	1.91
Recent Shipment	(20.7)	(9.3)	(16.9)	(21.4)	(15.1)	(11.5)
	-1.51	**-0.91**	**-2.34**	**-0.60**	**-6.17**	**-0.67**
Recent Shipment before Crisis	**(-6.1)**	**(-5.3)**	**(-8.2)**	**(-3.0)**	**(-8.9)**	**(-2.1)**
	0.535	0.969	0.718	0.730	0.393	0.763
Lagged Imports	(196.6)	(511.5)	(293.5)	(365)	(100.1)	(327.1)
R-squared	0.41	0.55	0.51	0.42	0.28	0.75

Notes: T-stats in parentheses. The dependent variable is value imported$_{ijt}$, where i=commodity, j=exit port, t=year relative to devaluation. Here we annualize the data for value of trade and positive shipments (constructing years around the crisis date rather than calendar years). Using five years of data, we regress value traded on the amount of trade in the last three months of the year (i.e., preceding the crisis) interacted with the year. We control for commodity-year fixed effects, and therefore use variation in port to identify the effect. We also control for the value traded in the previous year (to control for differential levels and trends among ports). The omitted year is the year before the crisis; the interaction effect in year three is the impact in the 12 months following the devaluation.

Table 8: Short-run Pass-through
On Depreciation, Lumpiness, and Inventories

	Months after crisis		
	3 months	**6 months**	**9 months**
Depreciation	-0.047	-0.031	-0.011
	(-3.6)	(-1.8)	(-0.8)
Lumpiness (*HH*)	-0.146	-0.068	-0.001
	(-4.2)	(-1.5)	(-0.0)
Inventory	-0.091	-0.005	0.013
	(-3.0)	(-0.1)	(-0.4)
Constant	-0.014	0.714	0.962
	(0.2)	(-6.4)	(-10.5)
# obs.	538	538	538
R^2	0.247	0.14	0.009

Notes: T-stats in parentheses. All regressions include dummies for tradability (imported, with some import share, exportable etc.), coefficients are not reported. All variables are in logs. The dependent variable is the change in log price over t (=3, 6, or 9) months from the devaluation over the long-run (15-month) price change.

Figure 1: Devaluation in Argentina 2002

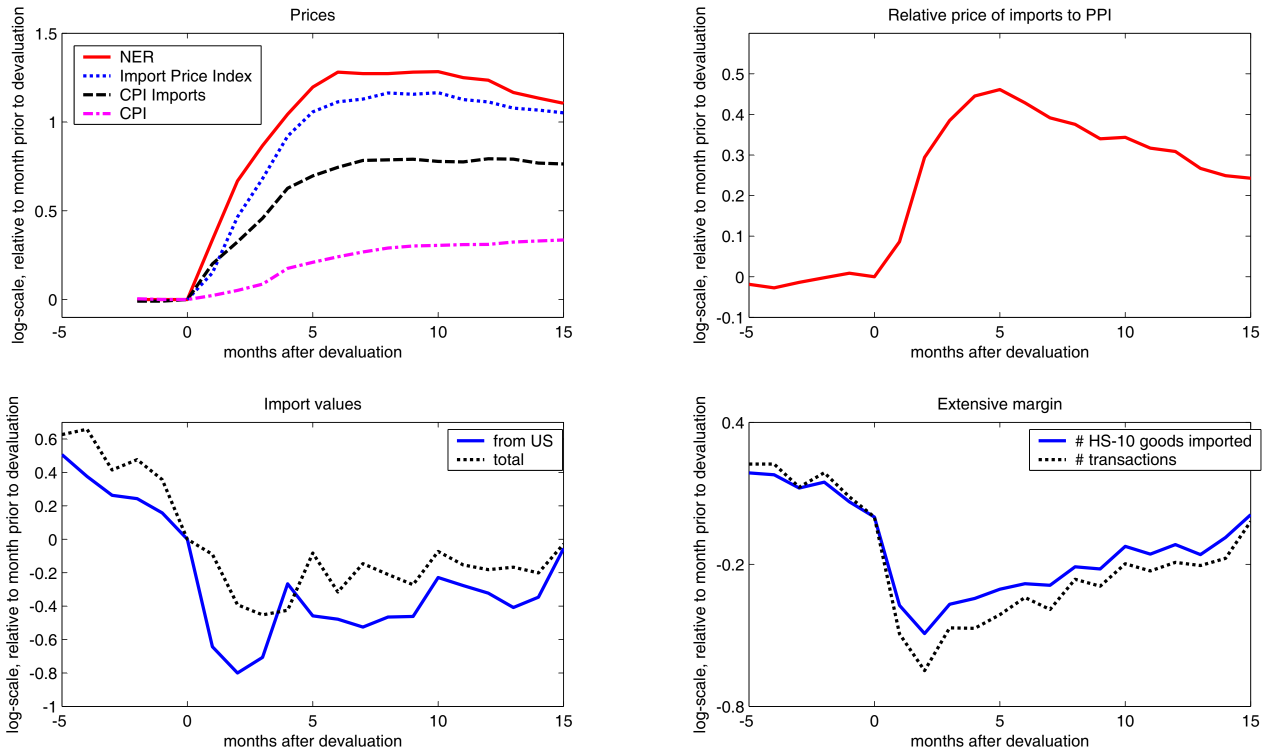


Figure 2: Optimal Import Rules

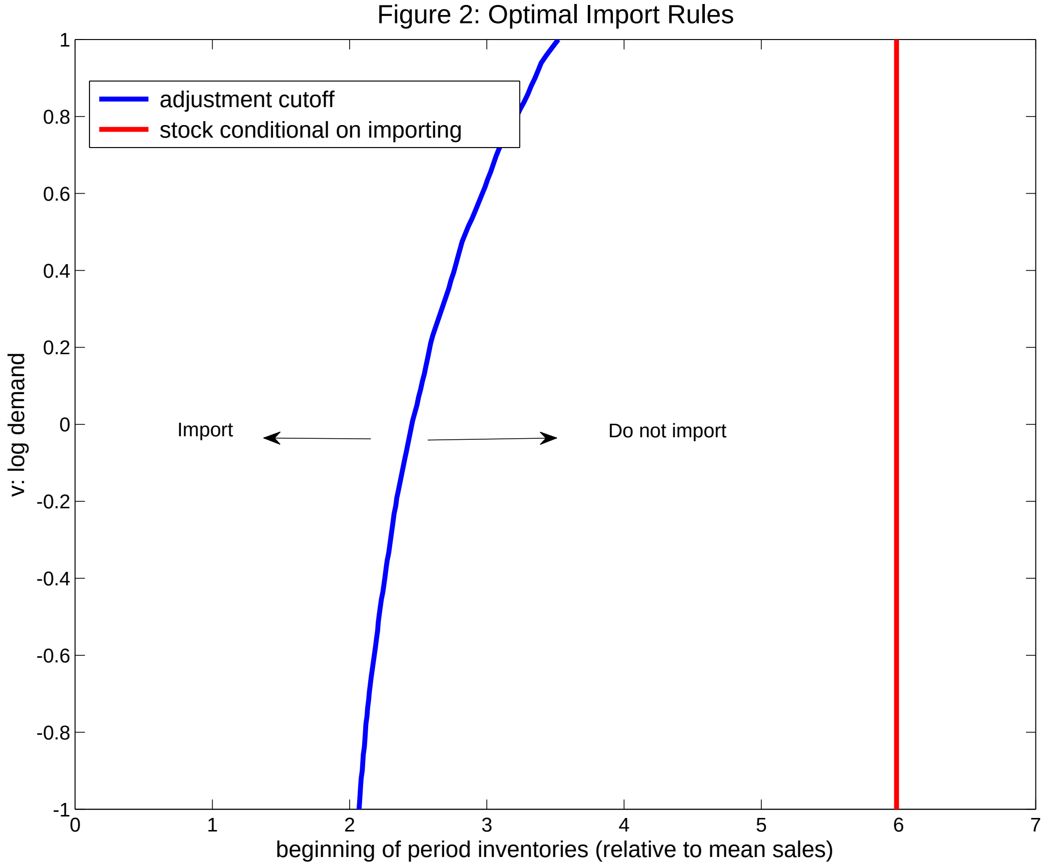


Figure 3: Optimal Price Functions

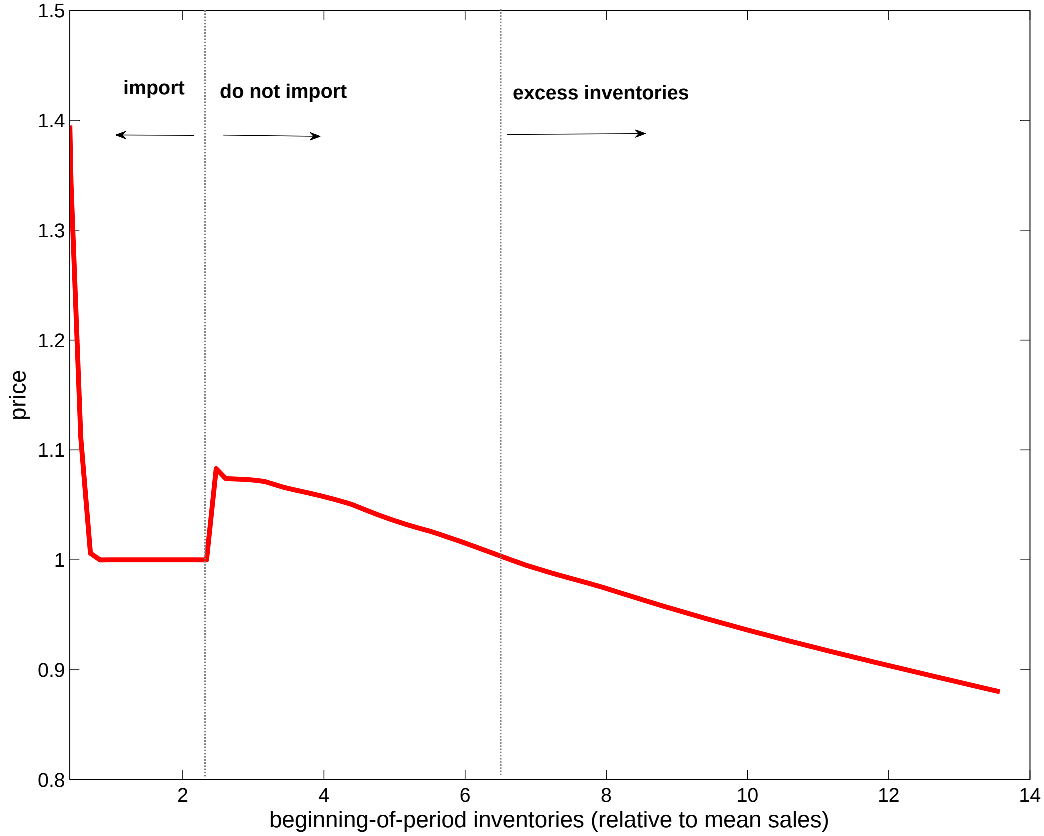


Figure 4: Median Import Price Elasticity over Time

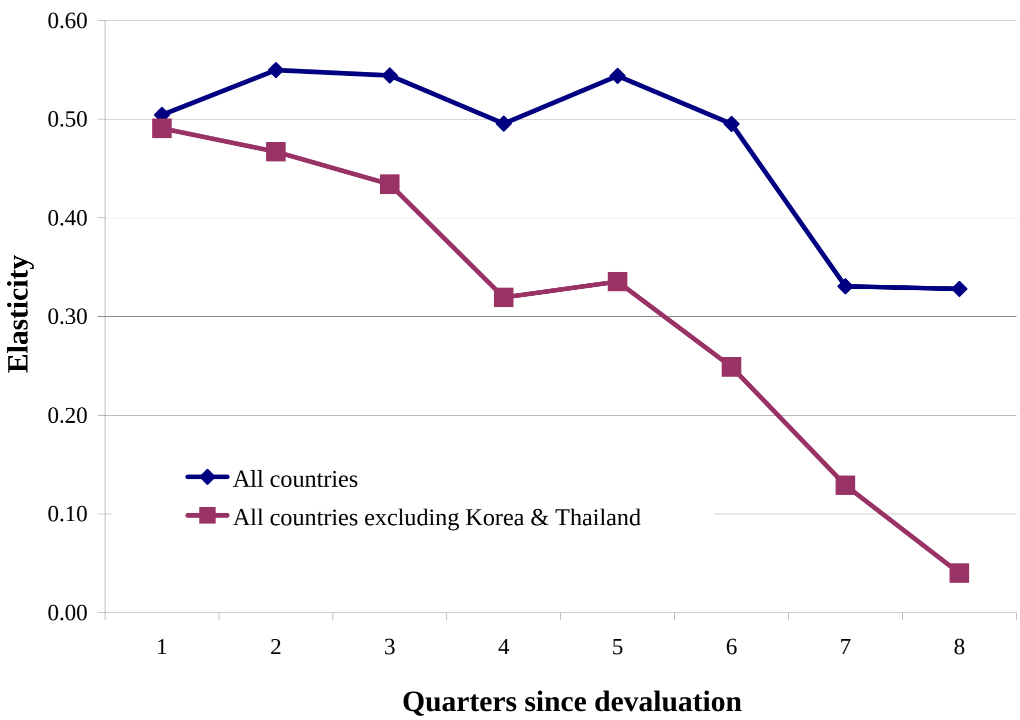


Figure 5a: Ergodic distribution of inventories and adjustment hazard
pre-devaluation

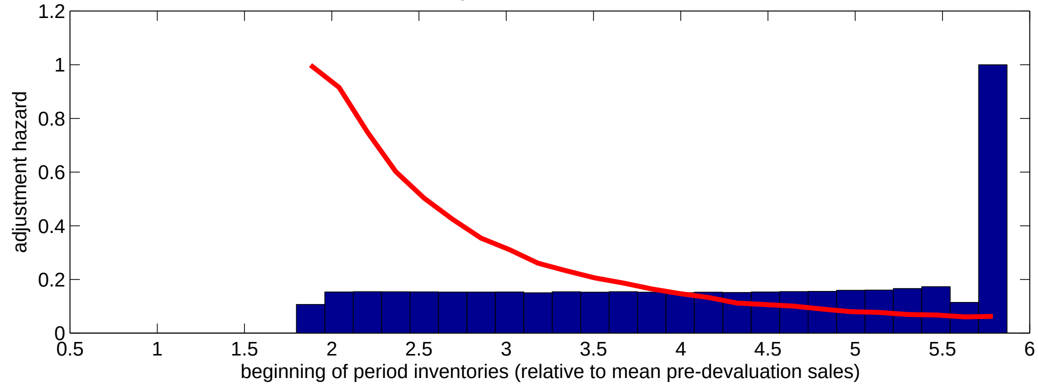


Figure 5b: post-devaluation

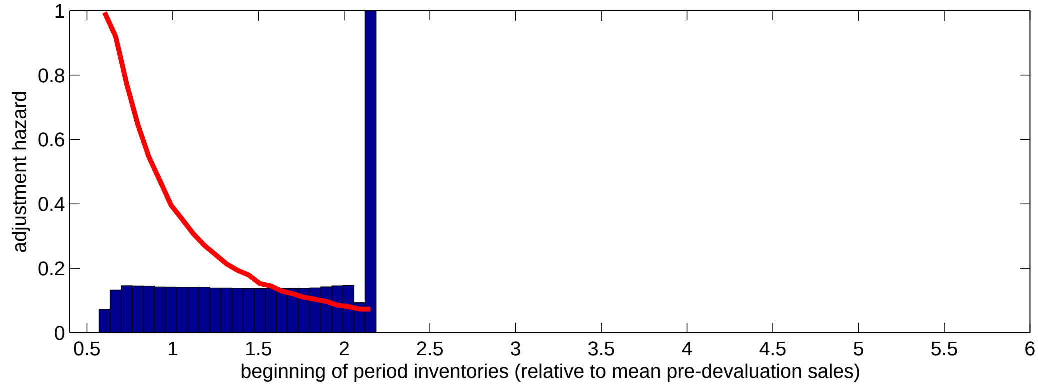


Figure 6: Response of model economy to devaluation

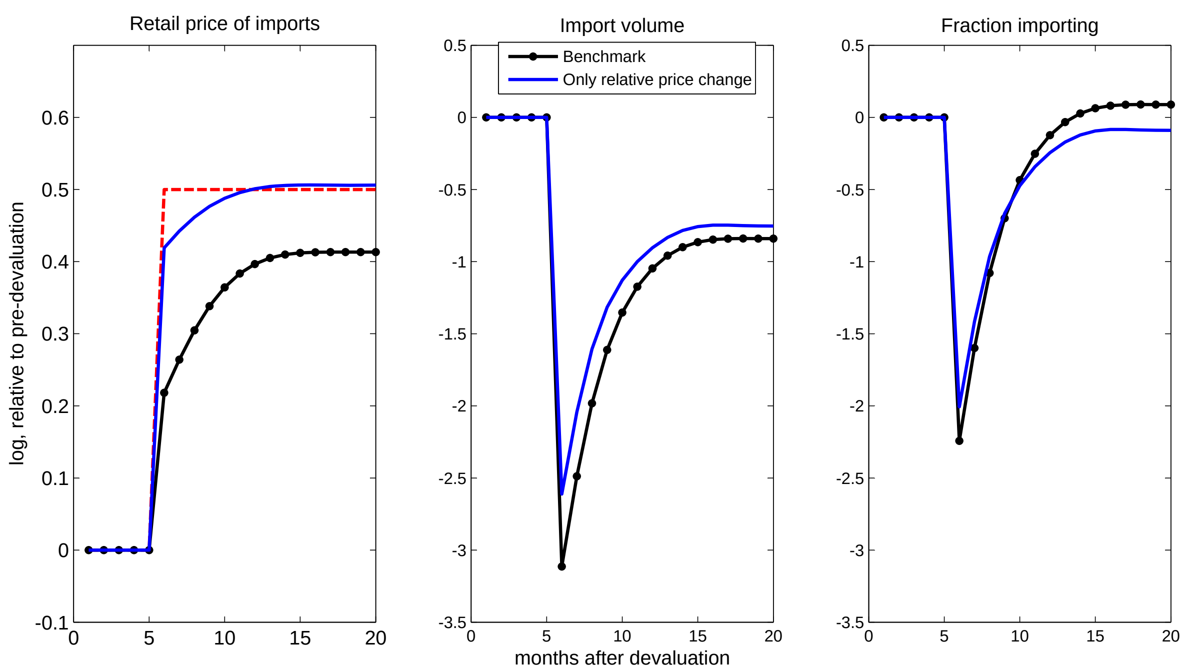


Figure 7: C drops 3 mos prior to devaluation

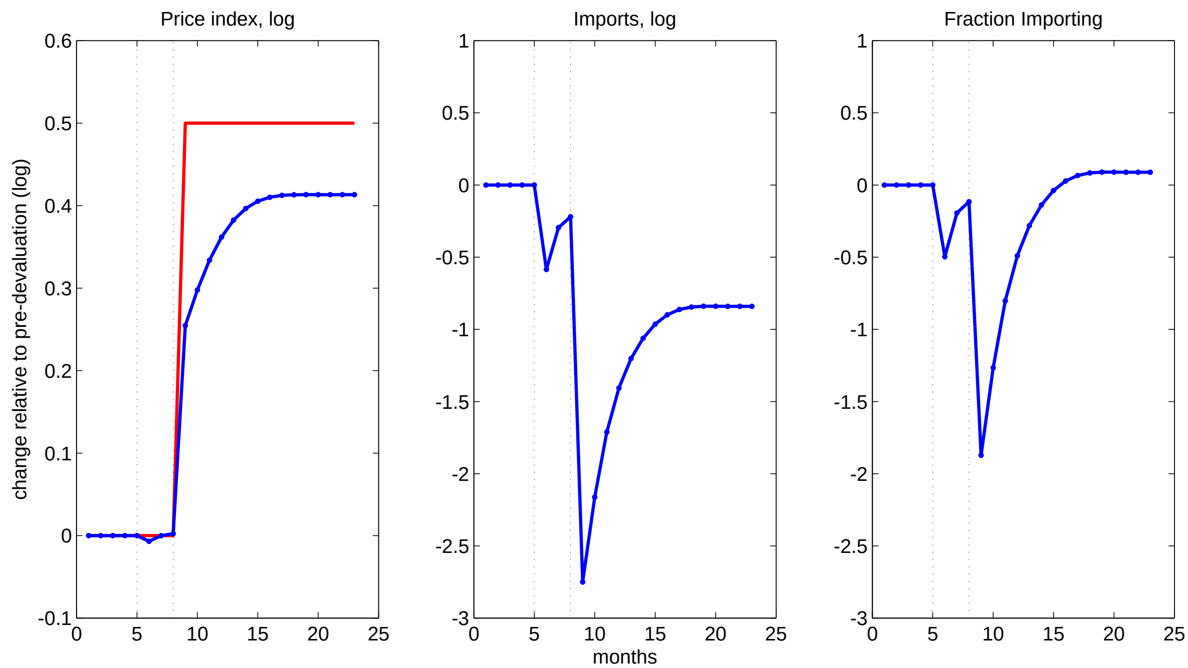


Figure 8: Response to a gradual devaluation

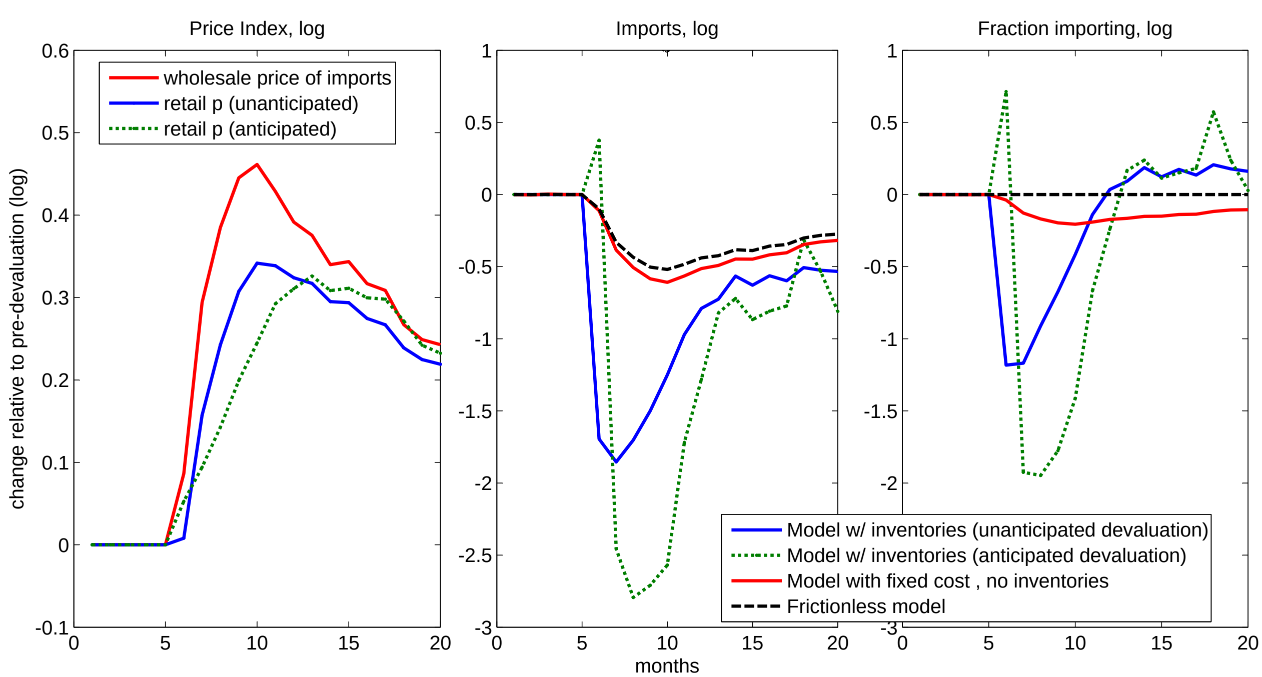


Figure 9: Imports vs. Date of Last pre-devaluation Import

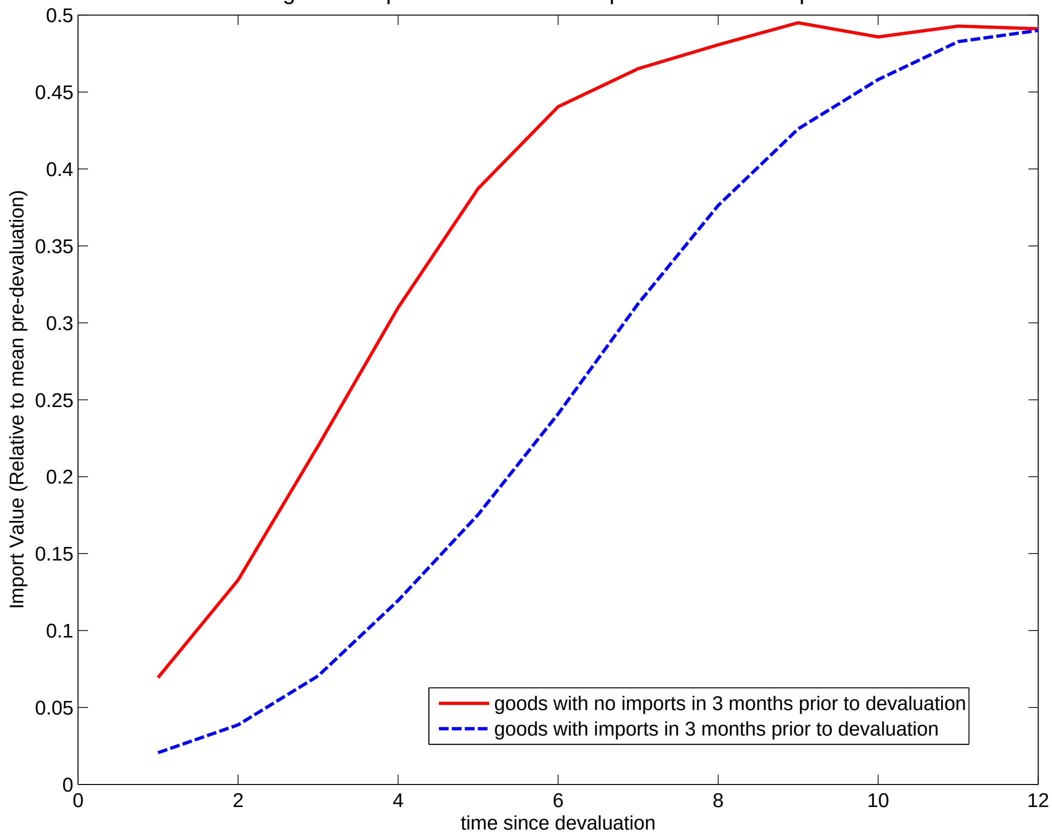


Figure 10: Effect of Depreciation and Inventory Holdings on Pass-through.
Benchmark Setup.

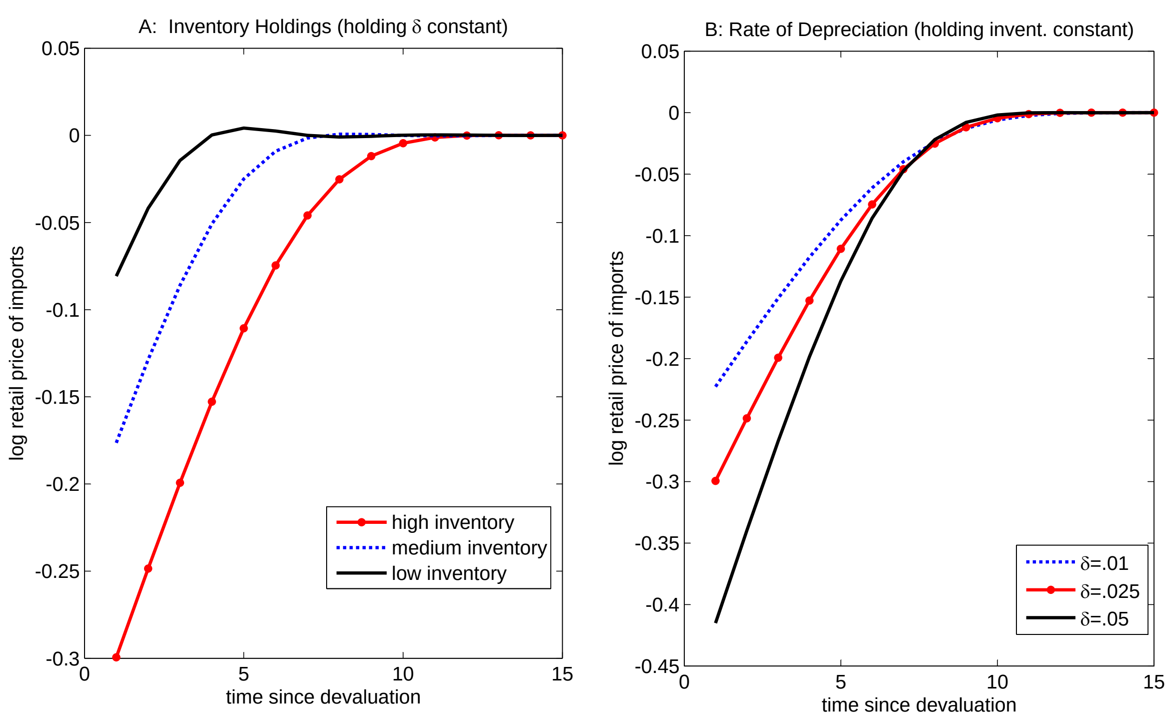
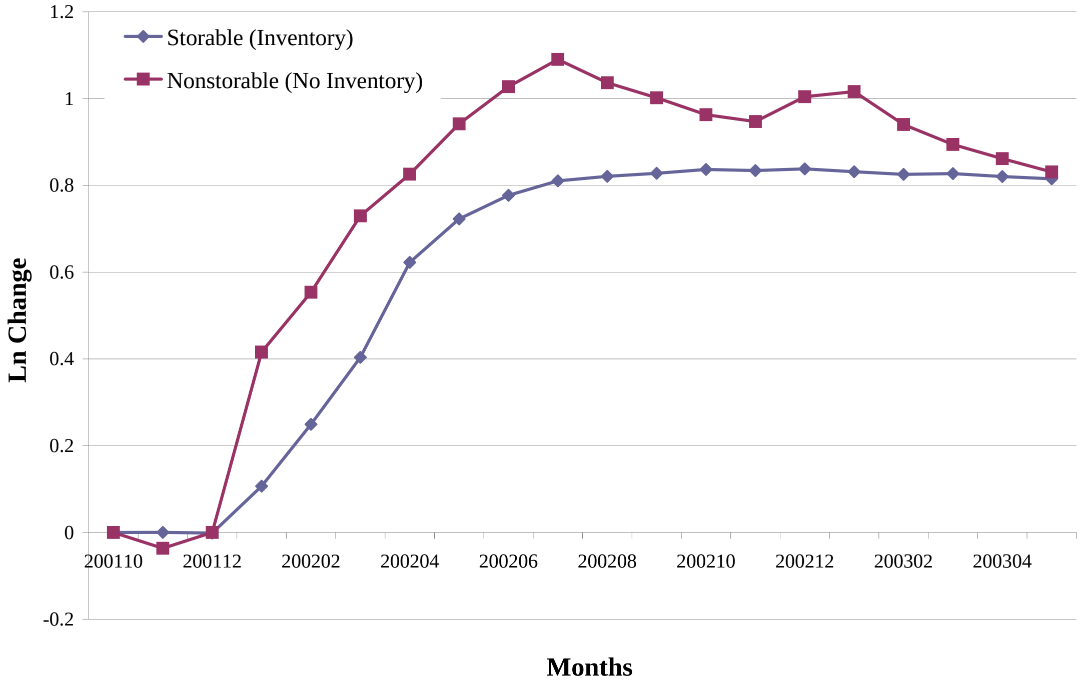


Figure 11: Argentine Price Dynamics by Inventory: Storable and Nonstorable Goods



Not for Publication

Appendix: Inventories, Lumpy Trade, and Large Devaluations

This appendix presents additional empirical, theoretical, and quantitative results. First, we show that lumpiness in the trade data is not driven by seasonalities and is pervasive across many goods. Next, we present a simplified model that yields closed form results for pricing and pass-through. Third, we show that the relatively high short-run response of trade in devaluations is even sharper in US exports to these countries. Finally, we report the sensitivity of our results to an alternative calibration with low markups.

1. Lumpiness of International Transactions

The high level of concentration in the import data does not appear to be driven by seasonalities, as Table 4B shows. The top half of the table reproduces the HH index and fraction of trade numbers from Table 4, where the fractions are the fraction of trade in a given year. The numbers in the bottom half reproduce the analogous numbers for the fraction of trade in a given month (e.g., December) across years in the data. For these numbers, trade is normalized by annual trade to prevent concentrations from developing by secular changes in trade.[1] The numbers show that, except for Mexico, there is even more concentration within a given month, but across years. The numbers are not strictly comparable, however, since the bottom row shows that there are fewer years when a good is imported than months in a year. Nevertheless, the HH numbers greatly exceed 1/(total number of years traded), so there is still a great deal of concentration. Hence, lumpiness does not appear to be a result of seasonalities in which goods are traded only in certain months every year,

[1]Shares for month i in year j are defined as follows:

$$\tilde{v}_{i,j} = value_{i,j} / \left(\sum_{i=1}^{12} value_{i,j} \right) \qquad \tilde{s}_{i,j} = \tilde{v}_{i,j} / \left(\sum_{j=1990}^{2004} \tilde{v}_{i,j} \right)$$

and the HH index is computed: $\widetilde{HH}_i = \sum_{j=1990}^{2004} \tilde{s}_{i,j}^2$

but consistently each year.

Table 4C presents lumpiness statistics by end-use categories (for Argentina). It shows that lumpiness is also not driven by one particular type of good but is pervasive across different types of goods. There is some variation, with food being the most lumpy ($HH = 0.53$) and automobiles and automotive parts being the least lumpy ($HH = 0.35$), but even these numbers are similar to the overall number ($HH = 0.40$). The fraction of trade accounted for by the top one, three, and five months is also similar across end-use categories.

2. Simplified Model with Analytical Solution

We show analytically[2] that a model with shipping lags and inventory generates incomplete pass-through following shocks to the cost of inputs. We simplify the problem by assuming that there is no fixed cost, $f = 0$ and no idiosyncratic demand shock, $\nu = 0$. Below, we substitute in $p = q^{-\frac{1}{\theta}}$, and write the firm's problem recursively.

$$\begin{aligned}
V(s;\omega) &= \max_{q,i} \left(q^{\frac{\theta-1}{\theta}} - \omega i\right) + \beta V\left((1-\delta)(s-q+i)\right) \\
st &: \\
q &\leq s \\
0 &\leq i
\end{aligned}$$

Reformulating the problem with multipliers, the first order conditions are:

$$\begin{aligned}
V(s;\omega) &= \max_{q,i} \left(q^{\frac{\theta-1}{\theta}} - \omega i\right) + \beta V\left((1-\delta)(s-q+i)\right) + \lambda\left[s-q\right] + \mu\left[i\right] \\
q &: \frac{\theta-1}{\theta} q^{-\frac{1}{\theta}} = \beta(1-\delta)\frac{dV}{ds}(s') + \lambda \\
i &: \omega - \mu = \beta(1-\delta)\frac{dV}{ds}(s') \\
s &: \frac{dV}{ds}(s) = \beta(1-\delta)\frac{dV}{ds}(s') + \lambda
\end{aligned}$$

A. Steady State

We start by characterizing the steady state. Let s^* be the steady state value of s. In the steady state:

$$\lambda^* = \left[1 - \beta(1-\delta)\right]\frac{dV}{ds}(s^*),$$

[2]These notes build on an analytical exercise suggested by Ariel Burstein in a discussion of our paper.

$$
\begin{aligned}
\frac{dV}{ds}(s^*) &= \frac{\theta-1}{\theta} q^{*-\frac{1}{\theta}}, \\
\omega - \mu^* &= \beta(1-\delta)\frac{dV}{ds}(s^*).
\end{aligned}
$$

It is straightforward to prove that at $\lambda > 0$ and $s^* = q^*$ by assuming the contrary. If $\lambda^* = 0$, then $\frac{dV}{ds}(s^*) = 0$, and q^* is infinite but $\mu^* = \omega > 0$, which would then imply a contradiction that $i^* = 0$. Thus, in the steady:

$$
s^* = q^* = i^*/(1-\delta).
$$

Substituting in and combining first-order conditions, we can solve for the steady state sales and price as:

$$
\begin{aligned}
s^* &= \left(\frac{\theta}{\theta-1}\omega\right)^{-\theta} [\beta(1-\delta)]^{\theta} \\
p^* &= \left(\frac{\theta}{\theta-1}\frac{\omega}{\beta(1-\delta)}\right)
\end{aligned}
$$

The price equation shows that steady state prices are a gross markup $\frac{\theta}{\theta-1}$ over marginal cost $\frac{\omega}{\beta(1-\delta)}$, and marginal cost is increasing in the replacement price of goods, depreciation, and the time cost of goods $(1/\beta)$. Note that the latter two will be larger, the longer the shipping delay/period is. Similarly, steady state inventories are decreasing in the markup and marginal cost.

B. A General Solution

Given this general problem, we claim that the pricing function is

$$
p = \begin{cases}
s^{-\frac{1}{\theta}} & s \leq s_{a,1} \\
\frac{\theta}{\theta-1}\beta^{n-1}(1-\delta)^{n-1}\omega & s \in [s_{a,n}, s_{b,n}] \qquad \text{for } n > 1 \\
\beta^n (1-\delta)^n \left[\sum_{j=0}^{n} \frac{\left[\beta^j (1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right]^{\frac{1}{\theta}} s^{-\frac{1}{\theta}} & \text{for } s \in [s_{b,n}, s_{a,n+1}]
\end{cases}
$$

where

$$
\begin{aligned}
s_{a,n} &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta} \left[\sum_{j=0}^{n} \frac{\left[\beta^j (1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right] \\
s_{b,n} &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta} \left\{\sum_{j=0}^{n} \frac{(\beta(1-\delta))^{(j-1)\theta}}{(1-\delta)^{n-j}}\right\}
\end{aligned}
$$

Here n indicates the number of periods in which inventories will reach steady state. That is, the $s < s_{a,1}$ region indicates a stockout region, and inventories will be at their steady state in the next period (the steady state itself s^* is contained in this region.) In the $(s_{b,n}, s_{a,n+1})$ regions, inventories will eventually be stocked out in $n-1$ periods, while in the $(s_{a,n}, s_{b,n})$ regions, positive inventories will be carried forward from $n-1$ to n. In both cases, new shipments will first be ordered in period $n-1$ and arrive in period n.

C. Comparative Statics/Transition Dynamics

To examine the solution of this problem, it is useful to rewrite prices and inventory relative to their steady state level: i.e., define $\widehat{s} = s/s^* = s\left(\frac{\theta}{\theta-1}\omega\right)^{\theta}[\beta(1-\delta)]^{-\theta}$ and $\widehat{p} = p/p^* = p\left(\frac{\theta}{\theta-1}\frac{\omega}{\beta(1-\delta)}\right)^{-1}$, which lead to pricing rules of the following form

$$\widehat{p} = \begin{cases} \widehat{s}^{-\frac{1}{\theta}} & \widehat{s} \leq \widehat{s}_{a,1} \\ [\beta(1-\delta)]^n & \widehat{s} \in [\widehat{s}_{a,n}, \widehat{s}_{b,n}] \\ [\beta(1-\delta)]^n \left[\sum_{j=0}^{n} \frac{[\beta(1-\delta)]^{-j\theta}}{(1-\delta)^{n-j}}\right]^{\frac{1}{\theta}} \widehat{s}^{-\frac{1}{\theta}} & \widehat{s} \in [\widehat{s}_{b,n}, \widehat{s}_{a,n+1}] \end{cases} \quad \text{for } n > 1$$

where

$$\begin{aligned} \widehat{s}_{a,n} &= \left[\sum_{j=0}^{n} \frac{[\beta(1-\delta)]^{-(j+1)\theta}}{(1-\delta)^{n-j}}\right] \\ \widehat{s}_{b,n} &= \left\{\sum_{j=0}^{n} \frac{[\beta(1-\delta)]^{(j-2)\theta}}{(1-\delta)^{n-j}}\right\} \end{aligned}$$

By normalizing the price and inventory by their steady state levels, we can easily trace out the impact of a permanent change to the marginal cost of inputs by transforming the current inventory level into the current inventory steady state sales ratio $(\widehat{s})$ at the new marginal cost ω. Given the pricing policy and the law of motion of inventory holdings

$$\widehat{s}' = (1-\delta)\left(\widehat{s} - [\widehat{p}(\widehat{s})]^{-\theta}\right)$$

one can solve for the path of prices. Along the transition, prices will increase gradually as the stock of inventory converges to the steady state level.

Consider the effect of a permanent increase in ω on $\widehat{p}$ and $\widehat{s}$. An increase in ω will increase the steady state price by the same percentage (complete pass-through), and the sales level will fall with an elasticity of θ. In the transition to the new steady state, prices will be below the steady state level and sales will exceed the steady state level. To trace out the transition, we normalize the current inventory holdings by the lower steady state sales rate, $\widehat{s} = s/s^* = s\left(\frac{\theta}{\theta-1}\omega\right)^{\theta}[\beta(1-\delta)]^{-\theta}$. Assuming the model is in steady state prior to the shock, given a higher ω, the inventory-sales ratio will be greater than one and fall into one of the regions described above. If the increase in ω is not too large so that the inventory-sales ratio rises but remains $\widehat{s} \leq \widehat{s}_{a,1}$, then the firm will raise its price proportionally by less than the increase in costs and there is incomplete pass-through for one period. Pass-through will be smaller the larger is $\widehat{s}$. If the increase in ω is larger, so that $\widehat{s} \in (\widehat{s}_{a,1}, \widehat{s}_{b,1})$, then the firm will raise its price but lower its markup to $\beta(1-\delta)$ in the first period. In the next period, the firm will raise its price and pass-through will be complete. For cost increases that push $\widehat{s} > \widehat{s}_{b,1}$, the normalized price is weakly decreasing in $\widehat{s}$ and so there is even less pass-through initially. These inventory levels will require more than one period to converge to the new steady state and so the price charged in the first period will depend on the entire path of prices, particularly whether in the period prior to convergence, the inventory holdings are in the stockout region. For $\widehat{s} \in (\widehat{s}_{b,n}, \widehat{s}_{a,n+1})$, the firm's inventory holdings will eventually be in the stockout region while for $\widehat{s} \in (\widehat{s}_{a,n}, \widehat{s}_{b,n})$, the firm will not have an inventory level that is in the stockout region.

We can also consider the effect of a permanent decrease in β (capturing an increase in interest rates, for example). An increase in δ has a similar effect. Similar to an increase in ω, an increase in β increases the cost of selling goods, leading to a rise in the long-run price and a lowering of steady state sales. Since we have included the interest costs in the firms' cost, this implies no long-run change in markups and complete pass-through.[3] The decrease in β has a similar effect on $\widehat{s}$ as an increase in ω, and indeed for $\widehat{s} < \widehat{s}_{a,1}$, the effect is identical. However, by changing the carrying costs of inventories, a decline in β alters the incentive to carry inventory across periods. Thus, for a decrease in β that leads $\widehat{s} > \widehat{s}_{a,1}$, markups will be lower. In particular, following a change in β that leads the firm to not order for n periods pass-through will be lower initially than for a change in ω that leads a firm not to order for n periods (assuming both shocks lead to the same $\widehat{s}$ and that in the period prior to converging to the steady state the firm places an order). Additionally, a decrease in β also increases the cutoffs for each region, since it is now more costly for the firm to delay selling its products and so a firm will generally converge to the steady state faster following a change in β than a change in ω. Finally, one can see that a decrease in β and increase in ω that we model compound each other because they are effectively multiplicative.

Given these policy rules, one can also calculate the change in markups. For instance, consider a shock such that it takes five periods to converge to the steady state, and further suppose without loss of generality that the shock puts the firm on the flat portion of the pricing function. In this

[3] If one were to treat β as part of the markup, then the level of markups would vary with β.

case, by taking the log of the normalized pricing function, the firm will lower its markup by

$$\Delta\mu \approx -n\,(r+\delta)$$

where we have used $r \approx -\ln\beta$, $\delta \approx -\ln(1-\delta)$ for values close to one. Using the calibrated values from the model, such a shock would generate a cut in the markup of approximately 15 percent initially. Then over the next five months, the firm would increase its markup by 3.0 percent per period. Holding the time it takes to converge constant, it is clear that the decline in markups will be initially larger if the depreciation rate or discount rate $(1/\beta)$ is larger, but that markups will converge faster.

D. Solving for the General Pricing Formulas and Cutoffs

We start by solving for the cutoffs for $s_{a,n}$ and $s_{b,n}$. A couple of things should be noticed. First, in general, if the firm starts out with $s \in (s_{b,n}, s_{a,n+1})$, then in the penultimate period before converging $(n-1)$, the firm will come into the period with a stock, call it $s_{-1} \in (s^*, s_{a,1})$, and so the price will be determined strictly by $p_{-1} = (s_{-1})^{-\frac{1}{\theta}}$. We can use this price to solve for the price along the transition. Second, if the firm starts out with $s \in (s_{a,n}, s_{b,n})$, then in the penultimate period it will charge $p_{-1} = \frac{\theta}{\theta-1}\omega$. Now, we can determine $s_{a,n}$ and $s_{b,n}$ as the minimum and maximum stocks such that the firm optimally charges $p_{-1} = \frac{\theta}{\theta-1}\omega$.

Solving for $s_{b,n}$

Suppose that the firm has s such that it will not order for two periods, $i=0, i'=0$. In this case, the current stock has to last for three periods,

$$s_{b,2} = \frac{q''}{(1-\delta)^2} + \frac{q'}{(1-\delta)} + q.$$

Now, in the penultimate period, the firm will charge $p' = \frac{\theta}{\theta-1}\omega$ and in the last period, it will charge $p'' = \frac{\theta}{\theta-1}\frac{1}{\beta(1-\delta)}\omega$. Using the Euler Equation, $p = \beta(1-\delta)\,p'$. Substituting this in

$$\begin{aligned} s_{b,2} &= \frac{\left[\frac{\theta}{\theta-1}\frac{1}{\beta(1-\delta)}\omega\right]^{-\theta}}{(1-\delta)^2} + \frac{\left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}}{(1-\delta)} + \left[\frac{\theta}{\theta-1}\beta(1-\delta)\,\omega\right]^{-\theta}, \\ &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}\left\{\frac{\left[\frac{1}{\beta(1-\delta)}\right]^{-\theta}}{(1-\delta)^2} + \frac{[1]^{-\theta}}{(1-\delta)} + [\beta(1-\delta)]^{-\theta}\right\}, \\ &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}\left\{\frac{[\beta(1-\delta)]^{\theta}}{(1-\delta)^2} + \frac{[1]^{-\theta}}{(1-\delta)} + [\beta(1-\delta)]^{-\theta}\right\}. \end{aligned}$$

Following the pattern yields the general rule, when it takes n periods to converge to the new steady state,

$$s_{b,n} = \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta} \left\{\sum_{j=0}^{n} \frac{(\beta(1-\delta))^{(j-1)\theta}}{(1-\delta)^{n-j}}\right\}.$$

Solving for $s_{a,n}$ Suppose the firm has slightly more than $s_{b,2}$, so that $i = 0$, and $p' = \frac{p}{\beta(1-\delta)}$ but $i' > 0$. This means that today and tomorrow, the firm will sell more than the unconstrained optimal, i.e., $\{q, q', q^*\}$, where $q > q' > q^*$. Since we know that $q' = \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}$ since $p' = \frac{\theta}{\theta-1}\omega$ and so $p = \beta(1-\delta)\frac{\theta}{\theta-1}\omega$.

What is the maximum s such that the firm is indifferent to ordering in the second period $(i = 0, i\prime = 0, q > q\prime > q*)$? If in the second period, the firm sells only $s_{a,1}$, then

$$q + \frac{s_a}{(1-\delta)} = s$$

Recall that in period 2, the firm will charge a price of $\frac{\theta}{\theta-1}\omega$, and that its price in the first period has to be lower $\beta(1-\delta)p'$ so,

$$\begin{aligned} s_{a,2} &= q + \frac{s_a}{(1-\delta)} = [\beta(1-\delta)p']^{-\theta} + \frac{(p')^{-\theta}}{(1-\delta)} = p'^{-\theta}\left[[\beta(1-\delta)]^{-\theta} + \frac{1}{(1-\delta)}\right], \\ &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}\left[[\beta(1-\delta)]^{-\theta} + \frac{1}{(1-\delta)}\right]. \end{aligned}$$

Now let's suppose it takes three periods:

$$\begin{aligned} s_{a,3} &= \frac{s_a}{(1-\delta)^2} + \frac{q'}{(1-\delta)} + q = \frac{p''^{-\theta}}{(1-\delta)^2} + \frac{(\beta(1-\delta)p'')^{-\theta}}{(1-\delta)} + \left(\beta^2(1-\delta)^2 p''\right)^{-\theta}, \\ &= p''^{-\theta}\left[\frac{1}{(1-\delta)^2} + \frac{(\beta(1-\delta))^{-\theta}}{(1-\delta)} + \left(\beta^2(1-\delta)^2\right)^{-\theta}\right], \\ &= \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}\left(\frac{1}{(1-\delta)^2} + \frac{\beta^{-\theta}(1-\delta)^{-\theta}}{1-\delta} + \beta^{-2\theta}(1-\delta)^{-2\theta}\right). \end{aligned}$$

The general rule can be derived as:

$$s_{a,n} = \left[\frac{\theta}{\theta-1}\omega\right]^{-\theta}\left[\sum_{j=0}^{n}\frac{\left[\beta^j(1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right].$$

Solving for p on a Path That Leads to a Stockout Given the cutoffs $s_{a,n}$ and $s_{b,n}$, what is the pricing rule if $s \in (s_{b,1}, s_{a,2})$? To find this, we need to figure out how much the firm will sell in the penultimate period.

Consider a firm with enough inventory for one period. The firm will charge $p = \beta(1-\delta)p'$ and will initially need

$$s = q + \frac{q'}{1-\delta} = p^{-\theta} + \frac{p'^{-\theta}}{1-\delta} = p'^{-\theta}\left\{[\beta(1-\delta)]^{-\theta} + \frac{1}{1-\delta}\right\},$$

which can be rearranged

$$p' = \left(\frac{s}{\left\{[\beta(1-\delta)]^{-\theta} + \frac{1}{1-\delta}\right\}}\right)^{-\frac{1}{\theta}}.$$

and so

$$p = \beta(1-\delta)p' = \left(\frac{\beta^{-\theta}(1-\delta)^{-\theta}}{[\beta(1-\delta)]^{-\theta} + \frac{1}{1-\delta}}\right)^{-\frac{1}{\theta}} s^{-\frac{1}{\theta}} = \left(\frac{1-\delta}{1-\delta+\beta^{-\theta}(1-\delta)^{-\theta}}\right)^{-\frac{1}{\theta}} s^{-\frac{1}{\theta}}.$$

Next, suppose it takes 3 periods to work off the inventory, i.e $s \in (s_{b,2}, s_{a,3})$

$$\begin{aligned}
s &= p''^{-\theta}\left[\frac{1}{(1-\delta)^2} + \frac{(\beta(1-\delta))^{-\theta}}{(1-\delta)} + \left(\beta^2(1-\delta)^2\right)^{-\theta}\right], \\
s &= p''^{-\theta}\left(\frac{1}{(1-\delta)^2} + \beta^{-\theta}(1-\delta)^{-\theta-1} + \beta^{-2\theta}(1-\delta)^{-2\theta}\right), \\
p'' &= s^{-\frac{1}{\theta}}\left(\frac{1}{(1-\delta)^2} + \beta^{-\theta}(1-\delta)^{-\theta-1} + \beta^{-2\theta}(1-\delta)^{-2\theta}\right)^{\frac{1}{\theta}}.
\end{aligned}$$

To convert this into the current period, note that $p = \beta^2(1-\delta)^2 p''$ so

$$p = s^{-\frac{1}{\theta}}\beta^2(1-\delta)^2\left(\frac{1}{(1-\delta)^2} + \beta^{-\theta}(1-\delta)^{-\theta-1} + \beta^{-2\theta}(1-\delta)^{-2\theta}\right)^{\frac{1}{\theta}},$$

More generally, if it takes n periods, $s \in (s_{b,n-1}, s_{a,n})$

$$s = p_n^{-\theta}\left[\sum_{j=0}^{n}\frac{\left[\beta^j(1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right],$$

where p_n is the n period ahead price. Recall that $\frac{p}{\beta^n(1-\delta)^n} = p_n$, then

$$\begin{aligned}
s &= p_n^{-\theta}\left[\sum_{j=0}^{n}\frac{\left[\beta^j(1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right], \\
p_n &= s^{-\frac{1}{\theta}}\left[\sum_{j=0}^{n}\frac{\left[\beta^j(1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}}\right]^{\frac{1}{\theta}},
\end{aligned}$$

and recall that $p = \beta^n (1-\delta)^n p_n$ then

$$p = \beta^n (1-\delta)^n \left[\sum_{j=0}^{n} \frac{\left[\beta^j (1-\delta)^j\right]^{-\theta}}{(1-\delta)^{n-j}} \right]^{\frac{1}{\theta}} s^{-\frac{1}{\theta}}.$$

3. Price Elasticity Based on US Imports

We now report the elasticity of trade using just US exports to each developing country. The US data are ideal since they measures goods as they are exported from the US rather than when these goods arrive in the destination. We can also remove from the data shipments of aircrafts, which can have outsized effects on trade flows that are unrelated to relative price fluctuations. Figure 4b shows a similar pattern to Figure 4, with an even larger short-run response of trade flows in Argentina, Brazil, Mexico, and Russia.

4. Low Markups

Recall that the typical estimates of the Armington elasticity of substitution that we have used above, $\theta = 1.5$, imply counterfactually high markups. We next perform a robustness experiment to gauge whether our results are robust to our choice of this elasticity of substitution. In particular, we now assume that consumers have CES preferences over home, h, and imported, m, goods:

$$c = \left(h^{\frac{\theta-1}{\theta}} + \alpha m^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}$$

where m is a composite good made up of a continuum of varieties of imports:

$$m = \left(\int_0^1 m_j^{\frac{\gamma-1}{\gamma}} dj \right)^{\frac{\gamma}{\gamma-1}}$$

This choice of preferences allows us to maintain the empirically justified low Armington elasticity, by setting $\theta = 1.5$, but allows us to vary the markup that importers charge. In particular, we choose $\gamma = 4$, a number in the range of those estimated by David Hummels (1999), Michael Gallaway, Christine McDaniel and Sandra Rivera (2003), and Christian Broda and David Weinstein (2006), which corresponds to a frictionless markup of 33 percent. Given these preferences, consumers' demand for an importer's product is

$$m_j = \left(\frac{p_j}{P_m} \right)^{-\gamma} P_m^{-\theta}.$$

The column denoted low markup in Table 5B reports the result of a calibration in which the price elasticity is increased to $\theta = 4$. The high elasticity economy requires more volatile demand shocks and larger (relative to median sales, but not relative to mean sales) fixed costs. With the high elasticity, the fixed cost per shipment is now 2.2 percent and the tariff equivalent of the frictions is approximately 15 percent. While the frictions are smaller than our benchmark case, the trade distortion is even larger because the price elasticity is higher. For instance, in this, calibration trade would be 60 percent lower than without these frictions while in the benchmark case, these frictions lower trade by about 30 percent.

In terms of dynamics, Figure 6B illustrates that the response of our low markup economy to a devaluation is very similar to that of our benchmark setup. When solving for the transition path to the new steady state, we require consistency of firm decision rules with the path for P_m to derive these decision rules.[4]

References

[1] Broda, Christian and David Weinstein, 2006. "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, 121(2), 541-585.

[2] Gallaway, Michael, Christine McDaniel and Sandra Rivera, 2003. "Short-run and Long-run Industry-Level Estimates of US Armington Elasticities," *North-American Journal of Economics and Finance*, 14, 49-68.

[3] Hummels, David. 1999. "Toward a Geography of Trade Costs." Purdue University Global Trade Analysis Project Working Paper 1162.

[4] This economy features strategic complementarities in firms' decision rules: the lower the prices charged by a firm's competitors, the lower a firm's sales, and thus the larger the inventory-holding costs. Thus, firms find it optimal to lower their prices. These complementarities turn out to be weak in the model, since the firm's problem is dynamic and current P_m have a smaller effect on the firm's decision rules than in a static economy.

Table 4B: Concentrations Across Months (Within Years) vs. Across Years (Within Months)

	Argentina	Brazil	Korea	Mexico	Russia	Thailand
Within Year, Across Month						
Herfindahl-Hirschman index	0.40	0.37	0.28	0.21	0.45	0.35
fract. of ann. trade in top mo.	0.50	0.47	0.38	0.27	0.53	0.45
fract. of ann. trade in top 3 mos.	0.83	0.78	0.70	0.53	0.85	0.79
fract. of ann. trade in top 5 mos.	0.94	0.91	0.85	0.71	0.95	0.92
Across Year, Within Month						
Herfindahl-Hirschman index	0.50	0.44	0.34	0.17	0.75	0.46
fract. of trade in top mo.	0.60	0.54	0.45	0.26	0.80	0.56
fract. of trade in top 3 mos.	0.96	0.91	0.87	0.55	1.00	0.94
fract. of trade in top 5 mos.	1.00	1.00	0.99	0.76	1.00	1.00
median years traded	7	8	9	13	4	7

Table 4C: Lumpiness by End Use (Argentina)

Lumpiness Statistic	Overall	Food	Intermed. Goods	Capital Goods	Autos & Parts	Consumer Goods
fract. of mos. exported	0.27	0.14	0.33	0.23	0.42	0.33
fract. of mos. in year exported	0.47	0.33	0.48	0.37	0.65	0.51
Hirschman-Herfindahl index	0.40	0.51	0.38	0.51	0.31	0.39
fract. of ann. trade in top mo.	0.50	0.58	0.47	0.60	0.42	0.49
fract. of ann. trade in top 3 mos.	0.83	0.89	0.82	0.90	0.74	0.83
fract. of ann. trade in top 5 mos.	0.94	0.97	0.93	0.97	0.88	0.94
Fraction of Imports from U.S.	1.0	0.02	0.42	0.13	0.06	0.07

Notes: Lumpiness statistics reflect the country-specific, trade-weighted median good. Fractions of imports sum to only 0.70 across end uses shown. The remaining goods end uses were military (0.19), unclassified (0.10), and re-exports.

Table 5B: Moments and Parameters

Moments	Data	Benchmark	Domestic	No fixed cost	No lag	High deprec.	Low markup
used for calibration							
Herfindhal-Hirschmann ratio	0.44	0.44	0.23	0.14	0.32	0.33	0.44
inventory to annual purchases ratio	0.36	0.36	0.21	0.29	0.12	0.25	0.36
additional implications							
tariff equivalent of frictions	-	0.20	0.09	0.13	0.08	0.32	0.15
f (relative to mean shipment)		0.036	0.017	0	0.050	0.047	0.022
Parameters							
Calibrated							
f (fixed cost, rel. median revenue)		0.095	0.025	0	0.095	0.095	0.21
std. dev. of demand, σ		1.15	1.15	1.15	1.15	1.15	1.8
Assigned							
Period length		1 month	1/2 month	1 month	1 month	1 month	1 month
Shipping lag		1 month	1/2 month	1 month	0 months	1 month	1 month
Elasticity of demand for imports, θ		1.5	1.5	1.5	1.5	1.5	1.5
Elasticity of subs. across imported goods		-	-	-	-	-	4
Monthly discount factor, β		0.995	0.995	0.995	0.995	0.995	0.995
Monthly depreciation rate, δ		0.025	0.025	0.025	0.025	0.05	0.05

Parameters characterizing devaluation

Change in wholesale import price: $\Delta\log\omega = 0.50$
Interest rate change: β=0.70 (annually)
Change in consumption: $\Delta\log C = -0.15$
Local labor share: 25%

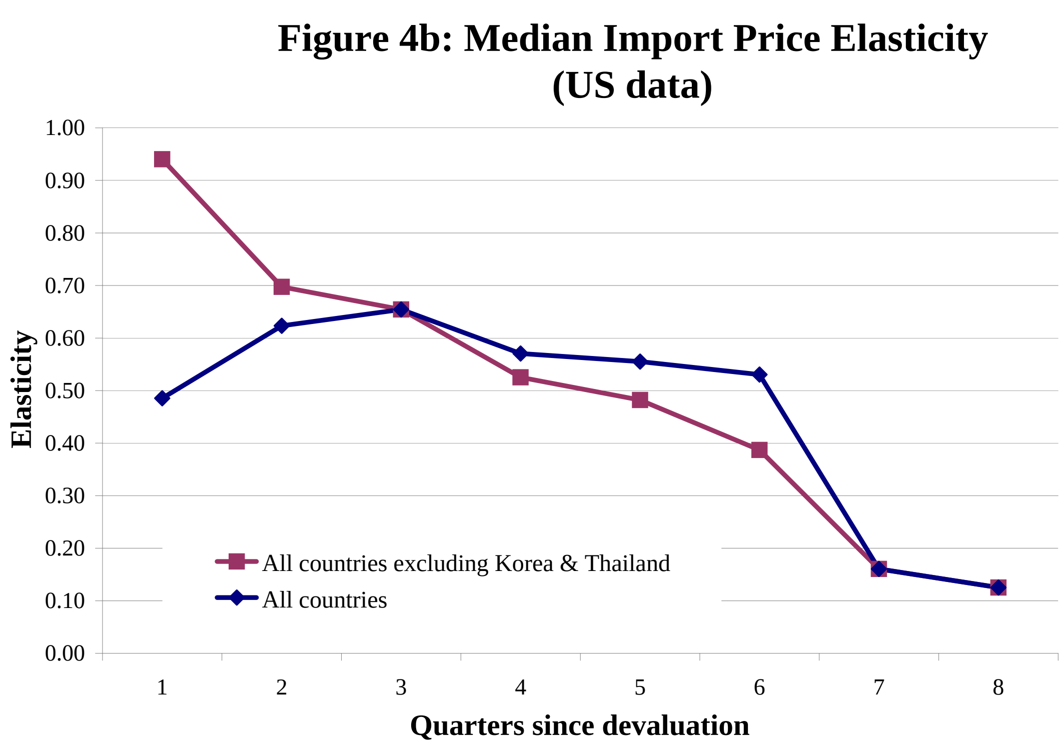


Figure 6b: Low markup economy