How Important are Trade Prices for Trade Flows?

Logan T. Lewis*

Federal Reserve Board

February, 2016

Abstract

U.S. imports and exports respond little to exchange rate changes in the short run. Firms' pricing behavior is thought central to explaining this response: if local prices do not respond to exchange rates, neither will trade flows. Sticky prices, strategic complementarities, and imported intermediates can reduce the trade response, and they are necessary to match newly available international micro price data. Using trade flow data, I test models designed to match these trade price data. Even with significant pricing frictions, the models imply a stronger trade response to exchange rates than found in the data. Moreover, despite substantial cross-sector heterogeneity, comparative statics implied by the model find little to no support in the data. These results suggest that while complementarity in price setting and sticky prices can explain pricing patterns, some other short-run friction is needed to match actual trade flows. Furthermore, the muted trade response found for sectors with high long-run substitutability implies that simply assuming low elasticities of substitution may be inappropriate. Finally, there is evidence of an asymmetric response to exchange rate changes.

JEL classifications: F14, F31, F32, E31

Keywords: Trade Prices, Pass-through, Trade Elasticities

---

*This paper was previously circulated as "Menu Costs, Trade Flows, and Exchange Rate Volatility". Contact: logantlewis@ltlewis.net. The views in this paper are solely the responsibility of the author and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or other members of its staff. I thank Jen Baggs, Wenjie Chen, Andrei Levchenko, Jaime Marquez, Andrew McCallum, Brent Neiman, Todd Pugatch, Jagadeesh Sivadasan, Linda Tesar, Rob Vigfusson, Jing Zhang, and seminar participants at the Banque de France, Federal Reserve Board, DC Area Trade Study Group, Drexel, George Washington University, NBER IFM Fall Meetings, NBER ITI Winter Meetings, Rocky Mountain Empirical Trade Conference, Society for Economic Dynamics, and Washington Area International Trade Symposium for their comments and suggestions. I gratefully acknowledge the support of the Robert V. Roosa Dissertation Fellowship. All errors are mine.

1 Introduction

Why do international trade flows respond so little to exchange rate changes? This perennial question is relevant for current account imbalances and monetary policy transmission. The response depends both on how often and by how much destination prices move after a change in the exchange rate. In principle, both aspects can help explain the empirical finding that trade values (and volumes) are largely unresponsive to exchange rate changes in the short run. First, if prices are stuck in the local (destination) currency, exchange rate changes will not affect the trade value or volume. Second, even if prices change but exporters choose not to fully pass through the change in exchange rate, the trade response will also be dampened.

Recent product-level micro trade price data has improved our understanding U.S. import and export transactions. Gopinath and Rigobon (2008) find significant heterogeneity in the frequency of price adjustment in BLS micro trade price data, with an average price duration of about one year. Using the same data, Gopinath and Itskhoki (2010) find that a menu cost model with strategic complementarities in price setting can fit the observed long-run pass-through of exchange rates to U.S. import prices. That is, firms optimally choose to price closer to their competitors compared to a benchmark constant markup implied by models with a constant elasticity of substitution and monopolistic competition. Schoenle (2010) demonstrates that a menu cost model can fit U.S. domestic and export price data, but international menu costs must be significantly larger than domestic menu costs to rationalize the frequency of price changes. This underscores the idea that nominal frictions can be as important — if not more important — in international transactions than in domestic ones.

This literature, however, does not directly address trade flows. While these models are capable of fitting price facts, to my knowledge they have not been tested against actual trade flow data. This paper seeks to fill this gap, using detailed sectoral U.S. trade data and exploiting substantial heterogeneity in sectoral characteristics to look for evidence of the mechanisms at work in the model. As demonstrated by Gopinath and Rigobon (2008), price stickiness varies significantly by sector. By any measure, sectors also vary in their substitutability. For example, one might expect commodity sectors to have stronger exchange rate responses than machines tailored for a specific client.

Compared against U.S. data, I show that appropriately parameterized sticky price models are generally incapable of matching the short-run response of both imports and exports. By value, U.S. imports are essentially unresponsive to a dollar appreciation on impact, and they only slowly rise over two years. A menu cost model implies a stronger immediate response of imports which continues to rise over time. A model with Calvo-style time-dependent pricing, however, can produce a more muted initial response. By contrast, a Calvo model performs especially poorly for U.S. exports, which fall modestly in the data and stay flat over a two-year horizon. Since both U.S. imports and exports are priced and stuck in dollars, sticky prices make U.S. exports in the model *more* responsive to exchange rate changes. Thus, with the asymmetry in the currency denomination of trade, sticky price mechanisms that improve the fit of trade flows in one direction necessarily make the other direction worse. Still, sticky prices are essential for explaining micro trade price behavior, where if anything, U.S. export prices are more sticky than U.S. import prices.

The average response pooled across sectors might mask underlying heterogeneity in the trade response. I show, however, that several comparative statics implied by the model find little support in the data. First, I use the heterogeneity of price duration among sectors to compare the response of sectors with flexible prices against those with long price durations. Second, I compare sectors estimated to have higher elasticities of substitution against those with lower elasticities. These elasticities may be directly inferred from medium-run data or implicit in the method of price-setting: firms producing commodities have less pricing power and should face a larger demand elasticity than firms producing highly differentiated products. In each case, despite significant heterogeneity along these dimensions, I do not find a substantially lower import response for those sectors with longer price durations or less substitutable products. Likewise, I find that flexibly priced or less substitutable exports respond similarly to sectors with long price durations and greater substitutability.

While sticky prices are not a likely source for reducing the trade response to exchange rate changes, strategic complementarities in price setting are. That is, if firms optimally choose to not fully pass through the exchange rate shock into local prices based on the effective demand curve they face, the trade response will be suitably reduced. I show that strategic complementarities can reduce the trade response by about half, and that this dampened response is persistent.

Finally, I separate the response of trade values to exchange rate appreciations and depreciations and show evidence of an asymmetric response. U.S. exports appear more responsive to dollar appreciations, while U.S. imports actually increase in the short-run for dollar depreciations.[2] Existing models of trade pricing leave little scope for such asymmetries, though I explicitly allow for them by non-linearly solving the model.

This paper links a literature on the price elasticity of trade (often referred to as the Armington elasticity) with a more recent literature on trade price dynamics. Hooper, Johnson and Marquez (2000) document low price elasticities for exports and even lower elasticities for imports. Ruhl (2008) discusses how fairly large long-run elasticities can potentially be reconciled in a quantitative model with lower short-run elasticities and sunk costs of entry into export markets. Taking the opposite approach, Drozd and Nosal (2012) model short-run frictions to establishing trade relationships. They show that such a model can help explain international pricing puzzles; however, their approach calibrates the model mechanism to the observed elasticities. Their paper underscores the potential importance of correctly modeling the dynamic response of trade to price changes, as this helps resolve other international business cycle puzzles. On the empirical side, Berman, Martin and Mayer (2012) show how more productive firms in France have lower exchange rate pass-through than less-productive firms. Using Italian firm-level data, Bernard, Grazzi and Tomasi (2011) show that the trade response of wholesalers to exchange rate changes is less than that of manufacturing firms who export directly.

Our understanding of trade pricing has grown in the past several years. In addition to work with micro price data already mentioned, several papers contribute to estimating and explaining limited pass-through of exchange rate changes into import prices.[3] This includes Campa and Goldberg (2005) and Goldberg and Campa (2010), documenting low pass-through for OECD countries into aggregate trade price indices. The extent of imported intermediates is important in explaining some of this low pass-through, and this mechanism will be included in the model discussed in section

[2]Bussiere (2013) shows evidence that aggregate U.S. export prices respond more to appreciations, but finds less evidence for asymmetries in U.S. import prices.

[3]See Burstein and Gopinath (2014) for a more comprehensive overview.

3. Fitzgerald and Haller (2013) find that among exporters in Ireland, firms that invoice in the destination currency avoid passing through changes in the exchange rate and implicitly adjust their markups instead. In followup work, Fitzgerald and Haller (2014) document low exchange rate elasticities on firm-level data, and find that sunk costs of entry and the extensive margin are incapable of reconciling the low response of trade to exchange rates with the strong response of trade to tariff changes. On the theoretical side, Atkeson and Burstein (2008) show how firms with greater market share may optimally choose to have lower pass-through; this is one mechanism by which firms will face strategic complementarities in price setting. In related work, de Blas and Russ (2012) analytically characterize firm markup behavior with a finite number of firms. Gopinath, Itskhoki and Rigobon (2010) demonstrate that the optimal choice of currency in which to set (sticky) prices is a function of desired pass-through. Alessandria (2009) highlights the role of search frictions in finding the lowest available price for understanding variable markups over time and across destinations. Corsetti and Dedola (2005) and Corsetti, Dedola and Leduc (2008) emphasize the role of distribution costs in reducing exchange rate pass-through and generating variable markups. Gust, Leduc and Sheets (2009) show that limited pass-through does not substantively affect net export dynamics in a DSGE model with local currency pricing and time-dependent (Calvo) price setting.[4] In this paper, I examine imports and exports separately, using models more capable of matching micro price facts.

The rest of the paper is organized as follows: Section 2 analytically characterizes a flexible price baseline where firms optimally choose not to fully pass through exchange rate shocks due to strategic complementarities in price setting and imported intermediates. Section 3 lays out the benchmark model which can incorporate flexible, Calvo, or menu cost pricing. Section 4 describes the data and estimation procedure to be used with both actual and simulated data. Section 5 presents the results, and Section 6 concludes.

[4] Landry (2010) demonstrates the effects of state-dependent pricing in a DSGE setting with two countries.

2 A flexible price benchmark

In this section, I show analytically how strategic complementarities in price setting and imported intermediates combine to reduce both exchange rate pass-through and the response of trade to exchange rate changes, while allowing firms to flexibly choose their prices. Since strategic complementarities prove much more successful in explaining the muted response of trade to exchange rate changes, the flexible price benchmark provides useful insight before turning to the full menu cost model. The analysis of optimal price-setting and pass-through follows Gopinath and Itskhoki (2010) and Klenow and Willis (2006), though the focus here is on the response of trade to exchange rate changes, rather than its pass-through to prices.

Variable markups are important in producing the low exchange rate pass-through observed in micro trade price data. Typical explanations — nominal rigidity in the short run and local distribution costs — cannot sufficiently explain the observation that individual import prices at the dock do not pass through changes in the exchange rate, even after adjusting. Therefore, it is essential to move away from constant elasticity of substitution (CES) demand to a more general class of demand functions with variable markups.

Firms compete monopolistically within a sector; let $q(p)$ denote the quantity demanded by the destination given a price p, denominated in the destination (local) currency.[5].

Firms choose prices p to maximize profits each period:

$$\max_p q(p)(p - c(e,a)).$$

where firms have (constant) costs $c(e,a) = e^{\phi}/a$ which depend on the exchange rate e (in units of destination currency per producer currency) and their productivity a. In steady state, $a = e = 1$. The portion of the firm's costs in the firm's currency is denoted by ϕ, and $\phi < 1$ implies that the firm imports some intermediates from its destination.

With flexible prices, the firm optimally chooses to price at a markup over marginal costs, where

[5] In general, demand will depend on both the nominal price p and the aggregate sectoral price index P. In this section, I will essentially consider P to be unaffected by the exchange rate, but one can also consider the analytics in terms of the relative price $\tilde{p} = p/P$.

the markup is based on the effective demand elasticity $\tilde{\theta}$:

$$p = \frac{\tilde{\theta}}{\tilde{\theta}-1} c(e,a).$$

The pass-through of the exchange rate to destination prices is then:

$$\Psi \equiv \frac{\partial \ln p}{\partial \ln e} = \phi \left[1 + \frac{\tilde{\varepsilon}}{\tilde{\theta}-1}\right]^{-1},$$

where $\tilde{\varepsilon}$ denotes the super-elasticity. Note that if $\tilde{\varepsilon} = 0$, pass-through is simply dependent on the fraction of costs paid in the firm's currency (ϕ). Further, note that a positive super-elasticity lowers pass-through $\left(\frac{\partial \Psi}{\partial \tilde{\varepsilon}} < 0\right)$. This expression illustrates how even with flexible prices, these two mechanisms reduce the optimal degree of pass-through of exchange rates to destination prices.

The elasticity of trade values with respect to exchange rates, denoted by λ, can be shown to be a function of pass-through and the effective elasticity of demand $\tilde{\theta}$:

$$\lambda \equiv \frac{\partial \ln(pq(p))}{\partial \ln e} = -\Psi(\tilde{\theta}-1). \tag{1}$$

Reducing pass-through Ψ clearly reduces the elasticity of trade λ for any given effective demand elasticity $\tilde{\theta}$.

Note that nominal trade described above ($pq(p)$) is denominated in the destination (local) currency. Suppose instead we denominate trade in the firm's (producer) currency. Then the trade response becomes:

$$\lambda^{PCP} \equiv \frac{\partial ln \frac{pq(p)}{e}}{\partial \ln e} = -1 - \Psi(\tilde{\theta}-1), \tag{2}$$

which is simply $\lambda^{PCP} = \lambda - 1$. So all else equal, we would expect dollar-priced U.S. exports to respond with a nominal trade elasticity one unit higher than dollar-priced U.S. imports.

The source of these variables markups (in this framework $\tilde{\varepsilon} > 0$) can be generated from micro sources,[6] but it is often convenient to characterize them in a way consistent with the formulation in

[6] See, e.g. Atkeson and Burstein (2008).

Kimball (1995). Essentially, they are a broad class of demand aggregators which induce strategic complementarities in price setting: firms set their prices not only according to their own costs, but also relative to the prices of their competitors.

For concreteness, consider the demand aggregator to be used in the numerical model described in Section 3. The Klenow and Willis (2006) aggregator takes the form (normalizing real demand $C \equiv 1$):

$$q(p) = \left[1 - \varepsilon \ln\left(\frac{p}{P}\right)\right]^{\theta/\varepsilon}$$

This generates an effective elasticity which is a function of both the elasticity of substitution and the log difference of the price relative to the sectoral price index:

$$\tilde{\theta} = \frac{\theta}{1 - \varepsilon \ln(\frac{p}{P})}.$$

where the parameter ε controls the super-elasticity, and P is approximately a geometric average of individual prices within the sector.[7] As $\varepsilon \to 0$, the demand specification collapses to CES. As $p \to P$, the elasticity returns to θ, leading to a steady state markup equivalent to the CES case.[8] One way to think of ε is that it controls the degree to which firms desire to keep their price close to their competitors as determined by the sectoral price index P.

While the implications for imported intermediates and strategic complementarities are clear analytically in a flexible price framework, trade prices are clearly not flexible. In order to match the frequency and dynamics of trade prices, I turn to a numerical model with menu costs for changing prices. Furthermore, by simulating a sector with both exporters and their competition in the destination market, I can explicitly consider the competitive effects implied by the demand aggregator via the sectoral price index.

[7] See the appendix of Gopinath and Itskhoki (2010) for a proof of the approximate aggregation.

[8] With trade costs and $\varepsilon > 0$, this specification implies that the markup for foreign firms permanently differs from the markup for domestic firms.

3 Model

The benchmark setup is a partial equilibrium model of a monopolistically competitive sector, including both home (local) firms and foreign exporters. This level of aggregation is consistent with the bilateral, disaggregated data described in Section 4. The (nominal) exchange rate process is taken to be exogenous, a reasonable assumption given the general lack of connection between exchange rate movements and underlying fundamentals at higher frequencies.[9] The setup of the model follows that of Gopinath and Itskhoki (2010), but similar models can be found in Schoenle (2010) and Neiman (2011).[10] This class of models is generally capable of reproducing the basic known properties of international price setting and exchange rate pass-through.

3.1 The firm's problem

Demand takes the form of the Klenow-Willis aggregator described in Section 2, which provides two parameters to govern demand. θ governs the demand elasticity in the neighborhood of $p = P$, where a firms' price matches the sectoral price. ε, the super-elasticity of demand, governs the degree to which the effective demand elasticity changes as an individual price deviates from the sectoral price.

Given this demand, firms choose whether to change their price each period. In a flexible price setting, the cost of changing the price is zero. In a menu cost setting, however, the cost of changing a firm's price is set sufficiently high to match the frequency of price changes observed in transaction-level international price data. By contrast, a time-dependent Calvo price framework can be implemented in the same model by making this menu cost stochastic, taking a zero value a small portion of the time and a prohibitively high value otherwise. Firms meet demand at their current price by hiring labor at an exogenous wage.

All three price-setting formulations can be characterized by the same set of Bellman equations. Let $V^a(p,e,a)$ denote the value of the firm that adjusts its price to p, faces nominal exchange rate e (defined as units of destination currency per unit of producer currency), and has productivity a.

[9] It is also common in the literature, where generating plausible exchange rate volatility is difficult in general equilibrium. See, e.g., Alessandria, Kaboski and Midrigan (2010).

[10] Note that each of these papers addresses either exports *or* imports.

V^n is the value if the firm does not adjust its price. A firm pays f_{mc} to change its price, and it earns profit $\pi(p,e,a)$. The Bellman equations can be characterized as:

$$V^a(p,e,a) = \max_{p'} \pi(p',e,a) - f_{mc} + \beta E[\max\{V^a(p',e',a'),V^n(p',e',a')\}], \tag{3}$$

$$V^n(p,e,a) = \pi(p,e,a) + \beta E[\max\{V^a(p,e',a'),V^n(p,e',a')\}]. \tag{4}$$

where primes denote the next period, and β is a constant discount rate. The value of the firm at any time is simply $V = \max\{V^a,V^n\}$. Flow profit in each period is $\pi(p,e,a) = epq - qe^{\phi}/a$ for a firm which sets its price in its own currency (PCP or producer cost pricing), and ϕ denotes the degree to which costs are in the exporter's currency. This captures a degree of vertical production using intermediate goods or foreign labor to produce a good for a particular market. If on the other hand a firm prices its products in the foreign currency, the local currency priced (LCP) profit is $\pi(p,e,a) = pq - qe^{\phi}/a$. When comparing to U.S. data in section 5, U.S. exports will be modeled as PCP, and U.S. imports modeled as LCP, reflecting the dominance of dollar-denominated trade for both flows (Gopinath and Rigobon 2008).

This formulation embeds all three price setting types: with flexible prices $f_{mc} = 0\ \forall t$ and $V = V^a$, and with menu costs firms choose between V^a and V^n each period. With Calvo-style price setting, f_{mc} takes a prohibitively high value with probability ψ, and a value of 0 with probability $1-\psi$.

The nominal exchange rate is exogenous and assumed to follow a persistent AR(1) process:

$$\ln e' = \rho_e \ln e + \varepsilon_e. \tag{5}$$

Similarly, for each firm, their idiosyncratic productivity follows an AR(1) process, with their shocks drawn independently:

$$\ln a_i' = \rho_a \ln a_i + \varepsilon_{a,i}. \tag{6}$$

Given that demand q depends on the relative price of a good to the overall price index P, firms must know its expected evolution. I assume as in Gopinath and Itskhoki (2010) that firms forecast the sectoral price index based on the current sectoral price and the exchange rate. I extend their forecasting equation by allowing the forecast to respond asymmetrically to exchange rate appreciations and depreciations:

$$\ln P' = \mu_1 + \mu_2 \ln P + \mu_3 \ln e^+ + \mu_4 \ln e^-. \tag{7}$$

where e^+ indicates an increase in the exchange rate relative to the previous period and e^- indicates a decrease. This potential asymmetry is added to give the model a better chance at reproducing the asymmetric responses seen in the data in Section 5.5. The coefficients $\{\mu\}$ must be endogenously determined for each calibration, a process detailed in the appendix.

A sectoral equilibrium consists of:

1. Home and foreign firm prices $\{p_{it}\}$ maximize firm value V given their productivities $\{a_{it}\}$, the exchange rate e_{it}, (fixed) wages, a fraction ϕ of which are denominated in the foreign currency, the sectoral price P_t, and the menu cost $f_{mc,t}$.

2. The sectoral price P_t, a geometric average of individual firm prices.

The model is solved numerically with value function iteration, detailed in Appendix B. Once the model solution converges and the sectoral price forecasting equation (7) is sufficiently accurate, I simulate trade values comparable to the data. This simulated trade data are then aggregated to a single sector at a quarterly frequency and estimated similarly to (8), discussed below.[11] The resulting impulse responses can then be plotted alongside the impulse responses estimated from the data.

3.2 Calibration

Table 1 provides the benchmark calibration. Where feasible, I adopt the calibration generally following Gopinath and Itskhoki (2010) and Gopinath et al. (2010), though I must separately calibrate

[11] Sectoral demand is held constant and assumed to be independent of the exchange rate shocks. This is broadly consistent with the exchange-rate disconnect literature, e.g. Obstfeld and Rogoff (2000).

Table 1: Model parameters (export calibration in parentheses)

β	$0.94^{1/12}$	Monthly discount rate
θ	4	Elasticity of substitution
ϕ	0.75	25% of production costs in foreign currency
ε	3	Super-elasticity of demand for KW demand
f_{mc}	0.047 (0.135)	Menu cost
ρ_a	0.96	Persistence of idiosyncratic shocks
ρ_e	0.99	Persistence of exchange rate shocks
σ_a	0.045 (0.06)	Std. dev. of idiosyncratic shocks
σ_e	0.025	Std. dev. of exchange rate shocks
N_h	9000	Number of home firms
N_f	1000	Number of foreign firms

exports and imports, while they only work with U.S. import prices. Of utmost importance is the elasticity of substitution, which I calibrate in the baseline to be 4. This is on the low end of average estimates from disaggregated trade data based on price changes rather than exchange rate changes, but higher than most calibrations of international real business cycle models. It is also notably lower than the $\theta = 5$ used by Gopinath and Itskhoki (2010). In practice, a lower value does not sacrifice the model's ability to match the frequency and size of price changes, though it is difficult to generate a sufficiently high autocorrelation of new prices without an extremely persistent productivity process. The model's results with both lower and higher elasticities are explored in Section 5.4.

The super-elasticity $\varepsilon = 3$ is high enough to reduce medium run pass-through (pass-through conditional on a price change) to a realistic level relative to micro import price data. I set the autocorrelation of the productivity process to 0.96, similar to that in Schoenle (2010) as estimated in productivity as well as used by Gopinath et al. (2010) and Gopinath and Itskhoki (2010). I jointly set the menu cost f_{mc} and standard deviation of the idiosyncratic productivity process σ_a to match the frequency (9% for imports and 7% for exports) and median size (8%) of price changes. The exchange rate process is very persistent ($\rho_e = 0.99$) with a standard deviation similar to that between the U.S. and developed countries like the U.K.[12] I follow Gopinath et al. (2010) and set 25% of production costs to be in foreign currency terms, which they derive from input-output tables. Finally, I make foreign competitors 10% of the sectoral market, and perform robustness in Section

[12]The average exchange rate volatility in the sample of OECD countries is somewhat higher.

5.2.1.

4 Data

To exploit the heterogeneity across sectors, I use disaggregated, quarterly U.S. trade value data. Unlike U.S. trade price data, which is sampled by the BLS and available only for a few large bilateral groups (e.g. Near East Asia), the Census records the universe of bilateral trade in goods.[13] The bilateral nature of the data allows exploitation of cross-country heterogeneity in exchange rate movements, rather than average trade-weighted changes in the exchange rate. Sources and aggregation methods for the data are described in more detail in Appendix A.

The most comprehensive data are available from 1989, which begins the sample. This analysis focuses on bilateral pairs which are members of the OECD. These include the largest trading partners, with the obvious exception of China. In the case of China, however, there is not a great deal of nominal exchange rate variability in much of this sample period. Focusing on relatively developed countries also emphasizes the presumably substitutable nature of these (largely manufactured) goods. Unless otherwise stated, the trade data used here are comprised of HS 4-digit categories.[14]

4.1 Estimation strategy

Bilateral, disaggregated data allows the use of sector-time fixed effects, which capture the sector-specific supply and demand changes occurring within the United States and the world as a whole. In this way, the regressions isolate the common effect on trade flows of different industries for a relative exchange rate change between two U.S. trading partners.[15] Appendix C shows how these fixed effects are equivalent to filtering out the common component of the bilateral exchange rates, leaving

[13]The underlying confidential BLS micro data identifies the country of origin/destination, but the data are still insufficiently detailed to construct reliable price indices for each bilateral pair by sector.

[14]Though trade data are obviously available at a more disaggregated bilateral level for the United States, HS4-level analysis is a trade-off between sectoral heterogeneity and the noisiness of more disaggregated data. There are over 1200 distinct HS4 categories. Using SITC4 categories, which provide a comparable level of disaggregation and is used for the substitutability exercises, lead to very similar results.

[15]Feenstra, Obstfeld and Russ (2012) estimate elasticities between foreign partners separately from the usual home-foreign elasticity, and report that the foreign-foreign elasticity is significantly higher. This further supports the benchmark calibration of the elasticity parameter to be more in line with trade estimates.

only their relative changes. Thus, the substitutability implicit in the estimation strategy is between different foreign trading partners. It seems reasonable that goods within the same disaggregated category from two different trading partners are fairly substitutable, rather than the typical home versus foreign substitutability considered in many two-country international macro models.

The estimation strategy takes several parts: pooled regressions to determine an "average" effect of exchange rate changes on imports and exports, and splitting the sample according to classifications of the goods' frequency of price changes, their medium-run elasticity of substitution or their price-setting classification from Rauch (1999), and their use of imported intermediates. The first exercise can be thought of as a macro (albeit partial equilibrium) analysis of the average effects, while the other exercises inform the comparative statics of the model presented in section 3. Finally, I also examine whether the average responses to imports and exports are asymmetric in exchange rate appreciations and depreciations.

The basic estimating equation for sector i, country j, at time t is:

$$\Delta \ln Trade_{ijt} = \beta_0 + \sum_{k=0}^{8} \beta_{e,k} \Delta \ln e_{jt-k} + \sum_{k=0}^{8} \beta_{y,k} \Delta \ln y_{jt-k} + Z_{ijt} + \varepsilon_{it}, \tag{8}$$

where $Trade_{ijt}$ are either imports or exports, y is the nominal GDP of country j, and Z is a series of dummies (country and sector-time).[16] The estimating equation follows the standard pass-through literature as in Campa and Goldberg (2005), but applied to trade values. The exchange rate variables have a long lag, acknowledging the possibility that given price stickiness and strategic complementarities, exchange rate changes may take up to two years to fully take effect. For imports, foreign income helps proxy for supply side effects. For exports, foreign income plays a direct role proxying for changes in demand from the business cycle.[17] For data generated from the model, only the

[16] At this level of disaggregation, there are a significant number of zeros in the data set. Traditional gravity equation estimations tend to drop these zeros, but this can lead to inconsistent estimates as argued by Silva and Tenreyro (2006). Since the estimating strategy here uses (log) differences, I conduct robustness exercises using an alternative difference formula which explicitly allows for zero observations; this follows from work in the labor literature, including Davis, Haltiwanger, Jarmin, Miranda, Foote and Nagypal (2006). The log differences are replaced by $2\frac{x_{ij,t}-x_{ij,t-1}}{x_{ij,t}+x_{ij,t-1}}$. The estimates are generally similar to those with log differences. For ease of interpretation, I report log differences. In addition, since foreign GDP encompasses net exports, I re-estimate (8) omitting $\Delta \ln y_{jt}$ and $\Delta \ln y_{jt-1}$, which could in principle be correlated with $\Delta \ln Trade_{ijt}$. The resulting $\hat{\beta}_{e,k}$ are basically unaffected. Detailed results available upon request.

[17] While these proxies are not perfect, they are implied by most international business cycle models as indicators of supply and demand changes.

exchange rate coefficients are estimated, as there are no aggregate income shocks.

4.2 Sectoral heterogeneity

Disaggregated data allows the exploration of sectoral heterogeneity along the dimensions considered in the model. To do this, I obtain measures of price stickiness, substitutability, and the use of imported intermediates.

Price duration

Recent analysis of BLS micro data on U.S. import and export prices by Gopinath and Rigobon (2008) reveals substantial sectoral heterogeneity in the duration of prices.[18] The duration of prices ranges from 1 month (the unit of observation) to 27.8 months, but their listing does not encompass all of goods trade.[19] Still, the model has significant implications for price durations over this range, so I match the trade data to the most disaggregated HS2- or 4-digit classification provided by Gopinath and Rigobon (2008) for this exercise.

Elasticity of substitution/Pricing classification

The elasticity of substitution is a crucial parameter of the model, regardless of other underlying price-setting frictions. The focus of this paper is essentially on the short-run elasticity of trade values to exchange rate changes, which is generally influenced by short-run price-setting frictions. Yet a sector's "true" elasticity is perhaps better captured by longer-run data, and one such estimation strategy can be found in Broda and Weinstein (2006). I use these estimates to classify SITC4 categories into "high", "medium", and "low" elasticities. Grouping elasticities into bins allows for a large number of sectors to be averaged into estimating each set of impulse responses. In addition, it does not depend on precise estimates of the elasticities, instead using the estimates primarily to establish a ranking.

As an alternative to measured elasticities, we can also consider the nature of price setting, which varies across sectors. Rauch (1999) classifies goods into three categories: goods traded on an organized exchange (homogeneous goods), goods for which a published "reference price" is available,

[18]They point out, however, that there is more heterogeneity of price duration within sectors than between.

[19]This is likely due to confidentiality of the underlying data as well as a consequence of sampling.

and differentiated goods. Clearly, sticky prices with lower elasticities of substitution are likely to be found in the last group. We should expect the first two groups to have relatively more-flexible prices and higher elasticities of substitution.

Imported intermediates

At its heart, the trade response to changes in an exchange rate stems from a good being sold in the destination currency and its production costs being paid in another currency. To the extent a firm imports its intermediates (especially from the same country to which it is exporting), this effect is reduced. This phenomenon is commonly found in trade price literature. .[20] It has also been recently emphasized by the IMF and others as a reason why exchange rate movements may be less consequential for trade as globalization increases (IMF 2015). Using 2002 BEA Input-Output tables for the United States, I calculate the ratio of imported intermediates as a share of total intermediates and employee compensation for 282 industries. There is significant variation across sectors, ranging from 0.5% to 45% of production costs being imported.[21]

5 Results

In this section, I contrast the trade value responses of exchange rate changes from simulated data in the model to actual U.S. import and export data. First, I focus in turn on the three principal mechanisms at work in the model: sticky prices (either in the local or producer currency), strategic complementarities, and imported intermediates. Next, I show how despite substantial heterogeneity in the substitutability of sectors, the responsiveness of trade to exchange rate changes is remarkably similar. Finally, I provide evidence of an asymmetric response.[22]

[20]For example, Goldberg and Campa (2010) document the variation in imported intermediates across OECD countries along with variation in distribution margins, another source of destination-currency production costs. Amiti, Itskhoki and Konings (2012) focus on a combination of larger, more productive firms optimally choosing a larger share of imported intermediates to reduce its own-currency production costs.

[21]Note that this calculation is an upper-bound of imported intermediates coming from the destination market, as many imported intermediates can come from a third country.

[22]Three additional exercises are provided in an appendix. Given fixed capital, sectors which use labor relatively more should be more responsive to exchange rate changes. In addition, consumers are likely to be more cost sensitive toward durable goods purchases; they can substitute both between suppliers and over time. Neither of these explanations can reasonably explain the small response of trade to exchange rate changes. The final exercise considers whether related-party trade might explain the lack of a response. This does not appear to be the case, as sectors with a relatively higher

5.1 Price stickiness

The distinction between flexible, state-dependent (menu cost), and time-dependent (Calvo) pricing is dramatic in terms of the value of trade, a result that echos the closed-economy literature regarding the response of output to monetary policy shocks.[23] The central reasoning is similar: a strong selection effect occurs under menu cost pricing, where the firms that most need to adjust their price will; with a time-invariant menu cost, this leads firms to not stray far from their profit-maximizing price.

Here, I consider two extreme cases of the selection effect: the time-invariant menu cost model where the selection effect is very strong, and a Calvo pricing model where the selection effect is essentially eliminated. Modeling techniques such as multi-product firms, stochastic menu costs, etc. that help reduce the selection effect can generally be seen as some combination of these extremes.

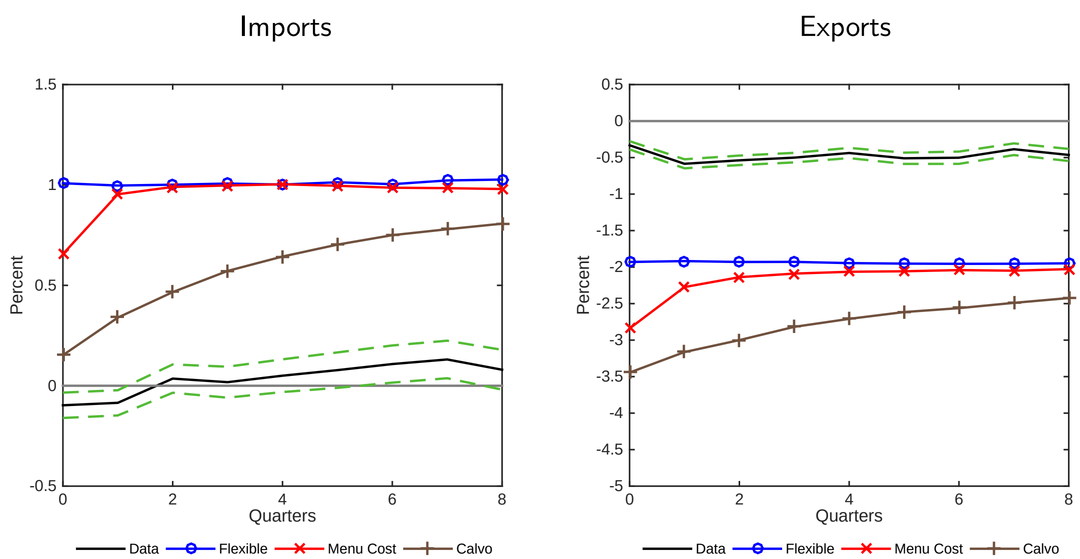

Figure 1: Impulse responses to 1% exchange rate appreciation for pooled HS4 categories with baseline model results

Consider the results of estimating (8) pooled across HS4 sectors. Rather than presenting the regression results in table form, it is easier to consider the implied impulse responses for horizon h

share of related-party trade have a similar trade response as other sectors.

[23]For a detailed discussion of this in a closed-economy context, see Midrigan (2011).

by calculating $\sum_{k=0}^{h} \beta_{e,k}$.[24] These empirical impulse responses of imports and exports are shown for a 1% exchange rate appreciation with 95% confidence bands in Figure 1.[25]

First, note that in the data, the response of imports is quite low, even negative for the first two quarters. This would be consistent, for example, with import prices falling slightly and quantities not responding at all. In the models, imports rise as the exchange rate appreciation makes them relatively cheaper. With flexible prices, dollar-priced goods are adjusted to be relatively cheaper and their demand rises immediately. In the menu cost model, this reaction is not complete as some firms choose not to update their price right away. In the Calvo model, firms slowly respond and when they do, the strategic complementarities induce them not to respond fully as well. This combination implies a smaller response of trade flows relative to flexible prices, but quantitatively they are still positive and significantly different from the data.

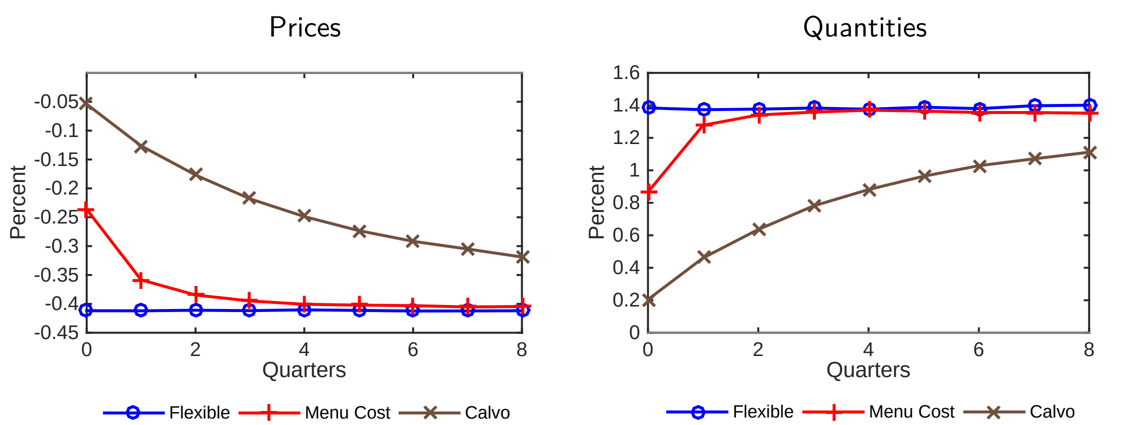

Figure 2: Impulse responses of import prices and real import quantities to 1% exchange rate appreciation

Trade value responses represent a combination of both prices and quantities. Unlike the data, where separating trade prices and quantities is prone to additional measurement error, the model has no such limitation. I run (8) replacing nominal trade with trade prices and real quantities separately. Figure 2 shows the separate import responses of the baseline models (menu cost, flexible price, and

[24] I report summarized regression coefficients in Appendix D.

[25] These confidence bands are generated by asymptotic Wald-based tests of the of the summed coefficients, where the standard errors of the coefficients are calculated clustering by HS category. Experiments with cluster-based bootstrapped confidence intervals yielded similar results.

Calvo) to the same dollar exchange rate appreciation. The left panel of the figure demonstrates that each model produces low exchange rate pass-through: for a 1% exchange rate appreciation, the Calvo model has dollar import prices dropping less than 0.1%, menu cost prices dropping 0.2%, and flexible prices dropping 0.4% on impact. Over time the differences subside, but the strategic complementarities and imported intermediates reduce even long-run pass-through to a factor of about 0.4. Even this muted pass-through generates non-trivial quantity movements, seen in the right panel of Figure 2. Together, these responses add up to the nominal trade responses plotted in the left panel of Figure 1.

As seen in the right panel of Figure 1, the export response in the data is substantially stronger, at almost half a percent in the first quarter compared to a near-zero result for imports. The result is also of the expected (negative) sign, but note that given (2), we should expect the response to be 1 percentage point larger than the import response. In this sense, exports have an even weaker response than expected compared to imports. Yet the models with producer-cost priced (PCP) exports imply very strong responses. Here, flexible prices fit best, because the quick response to the exchange rate change implies that the prices faced by foreigners do not automatically rise because of the domestic exchange rate appreciation. The menu cost model and Calvo models have dramatic responses due to this price stickiness. While stickier prices worsen the model fit for exports, in the data, export prices are more sticky than import or domestic prices (Gopinath and Rigobon 2008, Schoenle 2010).

Separating prices and quantities in Figure 3, we see that the menu cost model more quickly mimics the flexible price model than in the case of imports. This is due to the automatic pass-through of the exchange rate to *destination* prices if the dollar price does not change. This provides a strong incentive for exporters to change their dollar price so as to not fully pass through this appreciation, and in the menu cost model they have that option. On the other hand, the time-dependent Calvo framework produces a very muted response, though exporters are free to adjust their prices by a greater magnitude when they are allowed to change their price.

Clearly, these standard modeling techniques do not fit the trade data well. Indeed, while the Calvo model fits the import pattern best, it performs worst for exports. This general pattern underscores the importance of simultaneously — but separately — considering both imports and exports for the U.S. In each exercise from this point forward, I use the menu cost model as the benchmark, as it is the model most capable of matching the stylized facts about trade prices.

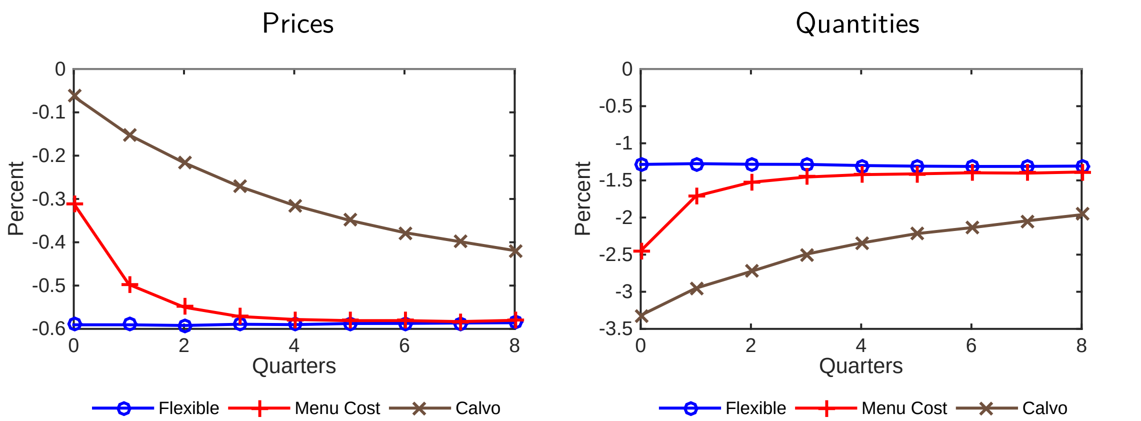

Figure 3: Impulse responses of (dollar) export prices and real export quantities to 1% exchange rate appreciation

5.2 Strategic complementarities

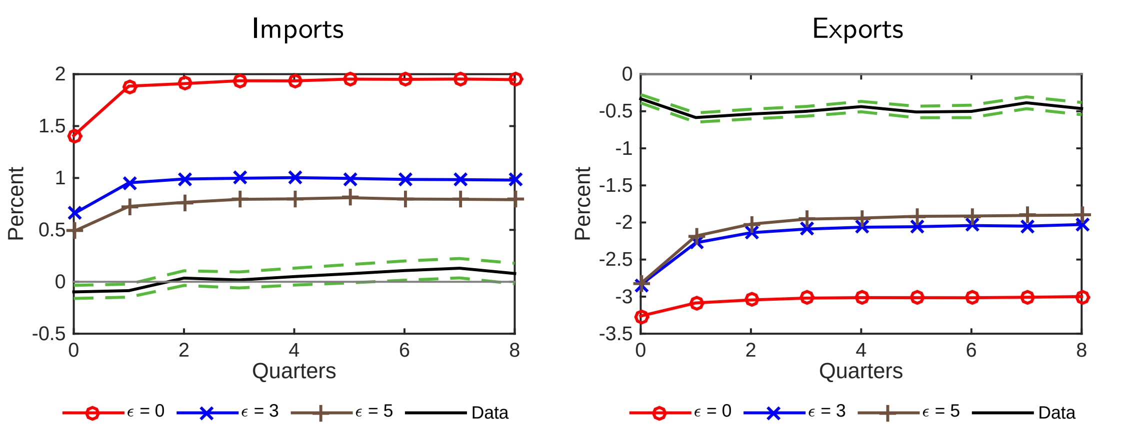

Figure 4: Impulse responses to 1% exchange rate appreciation by super-elasticity of demand

As discussed in Section 2, strategic complementarities in price setting are important to replicate the low exchange rate pass-through to import prices, even conditional on a price change. For imports, adding further sluggishness to the responsiveness of dollar prices will tend to reduce the trade response. For dollar-priced exports, on the other hand, keeping one's price unchanged implies complete exchange rate pass-through. Strategic complementarities encourage firms to keep their price closer to that of the sectoral average. Given the share of imports into the sector (discussed in the next section), these largely consist of domestic competitors.

Figure 4 depicts the impulse responses for the benchmark menu cost model, varying the super-elasticity of demand ε. $\varepsilon = 0$ corresponds to the constant elasticity case while $\varepsilon = 3$ is the benchmark calibration. Clearly, strategic complementarities in price setting work to dramatically reduce the import response to prices by a factor of nearly 3. For exports, the result is somewhat weaker, reducing the response by about 0.5 percentage points on impact and 1 percentage point over longer horizons. The result is not linear; a super-elasticity of 5 generates only a slightly more-muted response.[26]

5.2.1 Competition and import shares

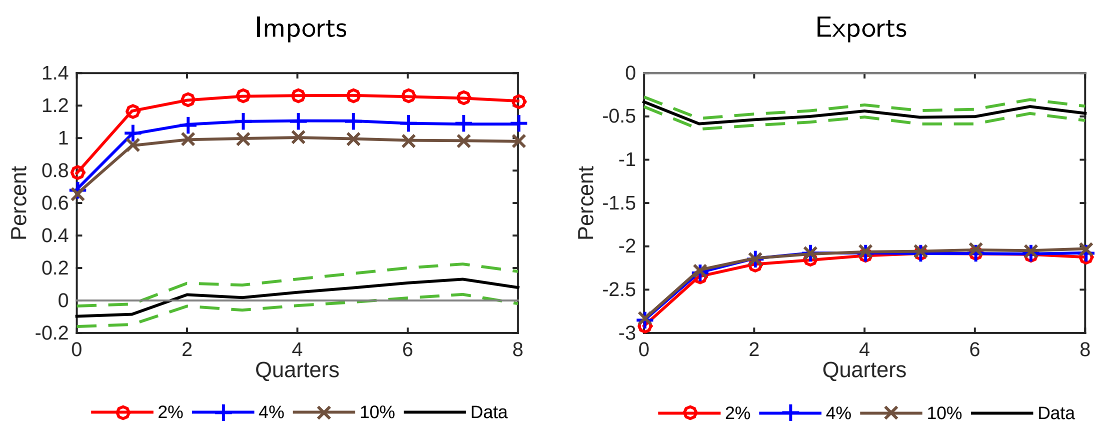

Figure 5: Impulse responses to 1% exchange rate appreciation by import shares

Given the strategic complementarities, the nature of an exporter's competition is important.

[26]It is important to keep in mind that the demand curve itself is changing in ε, and exporting firms face a trade-off between paying the menu cost to adjust their price to prevent full pass-through or facing the significantly lower demand by having a too-high price.

I conduct robustness exercises in Figure 5 for different import shares into the domestic market. Market shares are varied by changing the exogenous number of foreign firms relative to the number of domestic firms operating in the market. As the share of imported goods relative to domestic goods rises, both imports and exports become less responsive to exchange rates. The sectoral price index reflects more of a change from the exchange rates. A 2% import share implies a sectoral price index coefficient of $\hat{\mu}_3 \approx 0$, while the benchmark 10% import share generates $\hat{\mu}_3 = 0.01$ for imports and $\hat{\mu}_3 = 0.04$ for exports.[27] Quantitatively, the difference in response is too small to attempt to distinguish in the data, though this illustrates that the choice of import share is not driving the results. In the data, the import share from any bilateral trading partner for the U.S. is below 2%. For U.S. exports, there is potentially greater heterogeneity. OECD countries tend to be more open and the estimation procedure identifies more of a broad exchange rate change from the foreign country's perspective than a bilateral one.

5.3 Imported intermediates

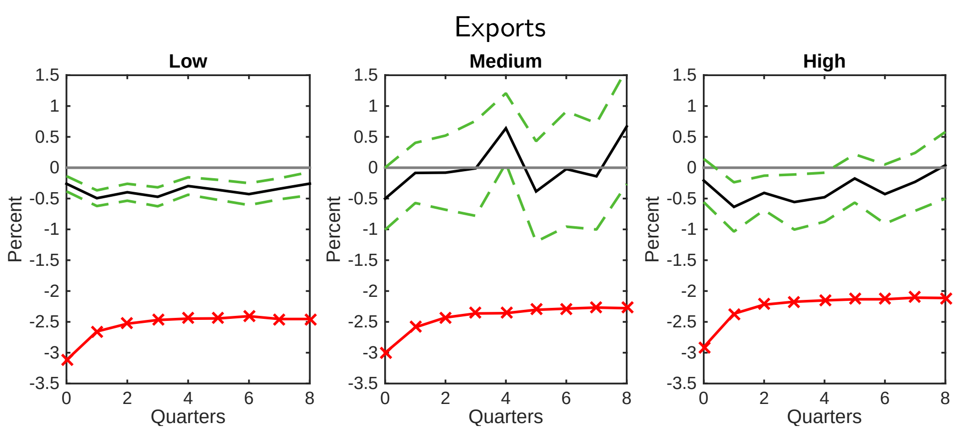

Figure 6: Impulse responses to 1% exchange rate appreciation by degree of imported intermediates (solid), and the menu cost IRF (with markers)

As analytically demonstrated by (1), The most straightforward way to reduce the trade response from exchange rate movements is if the costs of production are in the same currency as the importing

[27] $\hat{\mu}_4$ is roughly equal to $\hat{\mu}_3$ in practice, suggesting that the model's ability to generate aggregate asymmetric responses in the sectoral price level is limited.

country.

Figure 6 shows the results across U.S. exports.[28] To maximize the potential variation, I group U.S. exports into three bins, in this case by deciles. That is, I select the lowest 10%, middle 10%, and top 10% of industries. Overall, firms use on average 8.9% imported intermediates, a number consistent with Goldberg and Campa (2010). In the lowest decile, firms use on average about 2.5% imported intermediates. In the middle decile, firms use 7.2%, and in the top decile, firms use 20.8%. Note that these numbers are significantly below the 25% used in the baseline, a number more consistent with the average OECD country. The data show only modest differences across bins: sectors which use the least imported intermediates have a very similar response to the overall pooled response for U.S. exports. The "medium" group has a response statistically insignificant from zero, but with imprecise standard errors. By contrast, the "high" group, those sectors with the highest share of imported intermediates have a larger-magnitude trade response, rather than the expected muted response. At these modest percentages, however, the model shows almost no difference across bins. So while plausible in theory, imported intermediates are unlikely to be a major source of a reduced U.S. export response to exchange rate changes in the data.

5.4 Substitutability

I turn now to the central parameter of the model governing the trade response: the elasticity of substitution between products, θ. As section 5.1 makes clear, the average response of disaggregated sectors is quite muted. But some sectors are undoubtedly more substitutable than others. I present two distinct ways of classifying sectors as potentially more substitutable, and show that in both cases the exchange rate response is similar to the average case.

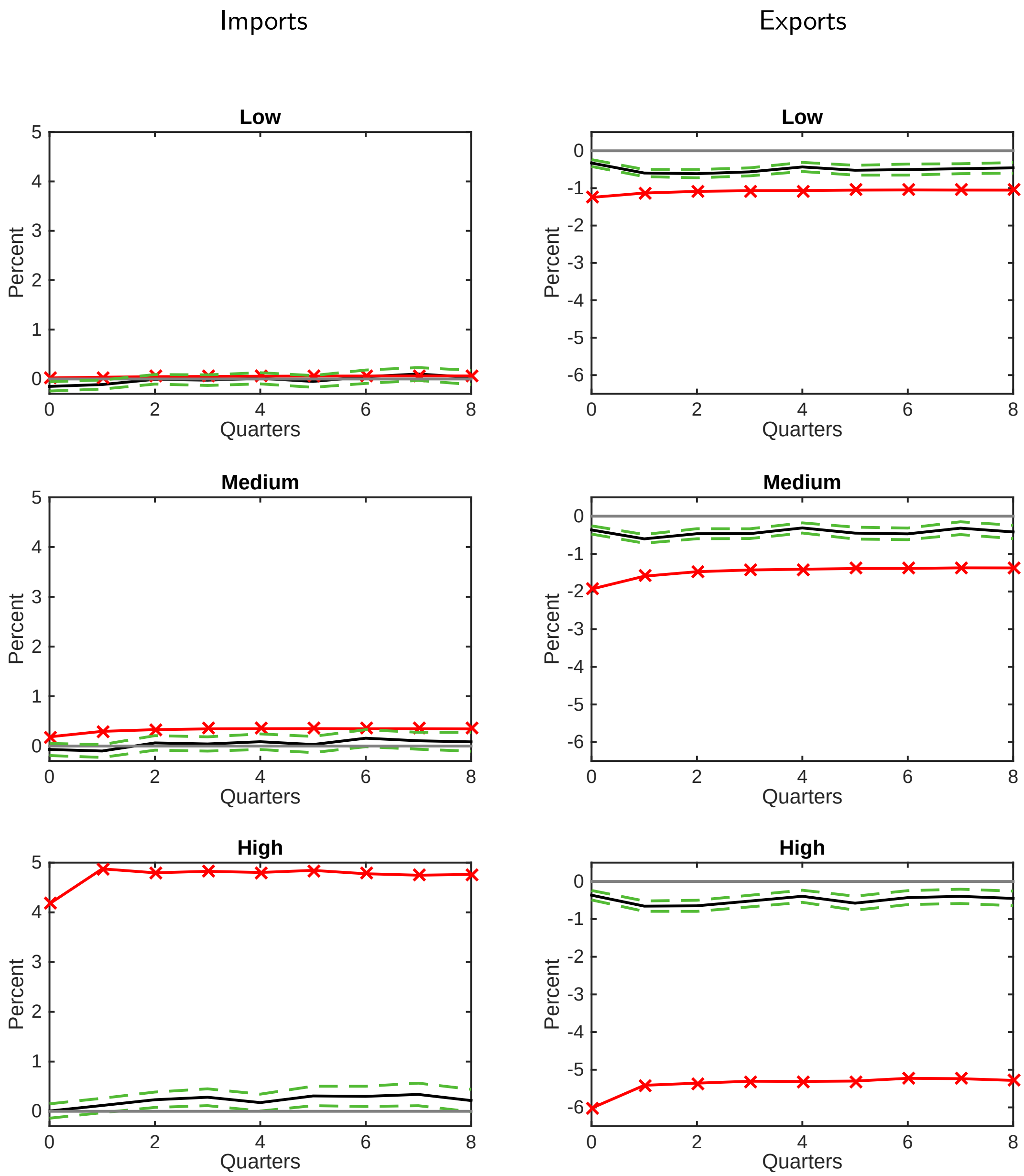

Figure 7: Impulse responses to 1% exchange rate appreciation by elasticity bins (solid), and the menu cost model IRF (with markers)

5.4.1 Broda-Weinstein elasticities

Broda and Weinstein (2006) estimate U.S. import price elasticities by SITC4 sector inferred from realized changes in unit values. These elasticities are generally in the vicinity of those found in the trade literature using a variety of techniques and assumptions. I split the sample into three bins; these are: low (average elasticity 1.6 for imports and exports), medium (average elasticity 2.6 for imports and exports), and high (average elasticity 12.3 for imports and 13.6 for exports). Thus, there is substantial heterogeneity at the SITC4 level.

The results are plotted in Figure 7. The data show little variation in the response of imports by elasticity. The model, on the other hand, implies dramatic changes. In addition, the model's dynamics imply an increase in trade over time as firms choose to change their prices and the sectoral price responds to the exchange rate.

With exports, again there is little variation in the data between bins of sectors. Yet the model's changes are dramatic, as there is very high pass-through of exchange rate changes, since prices are set in dollars. With higher elasticities of substitution, the trade response is dramatic and unsupported by the data. Only with the lowest elasticity of 1.6, in line with those used by macro models does the model's import response appear in line with the data, but the model's export response is still far too strong.[29]

5.4.2 Rauch pricing classification

An alternative measure of substitutability is the degree to which producers have pricing power. Commodity producers are much closer to price-takers than producers of specialized machinery. Figure 8 plots estimated impulse responses for three types of good, as defined by Rauch (1999). Organized exchange goods are most homogeneous, with firms having little pricing power. Since prices are set on organized exchanges, they exhibit little stickiness. Differentiated goods are those most

[28] Quantitatively, the U.S. I-O tables are not comparable across trading partners, so this cannot be directly translated to U.S. imports. Using the bins only as a measure of ranking across sectors still reveals little difference in the trade response between the sectors that use the least imported intermediates compared to those that use the most. Results are available upon request.

[29] 1.5 is often used for the elasticity of home versus foreign goods, rather than between foreign goods as considered here.

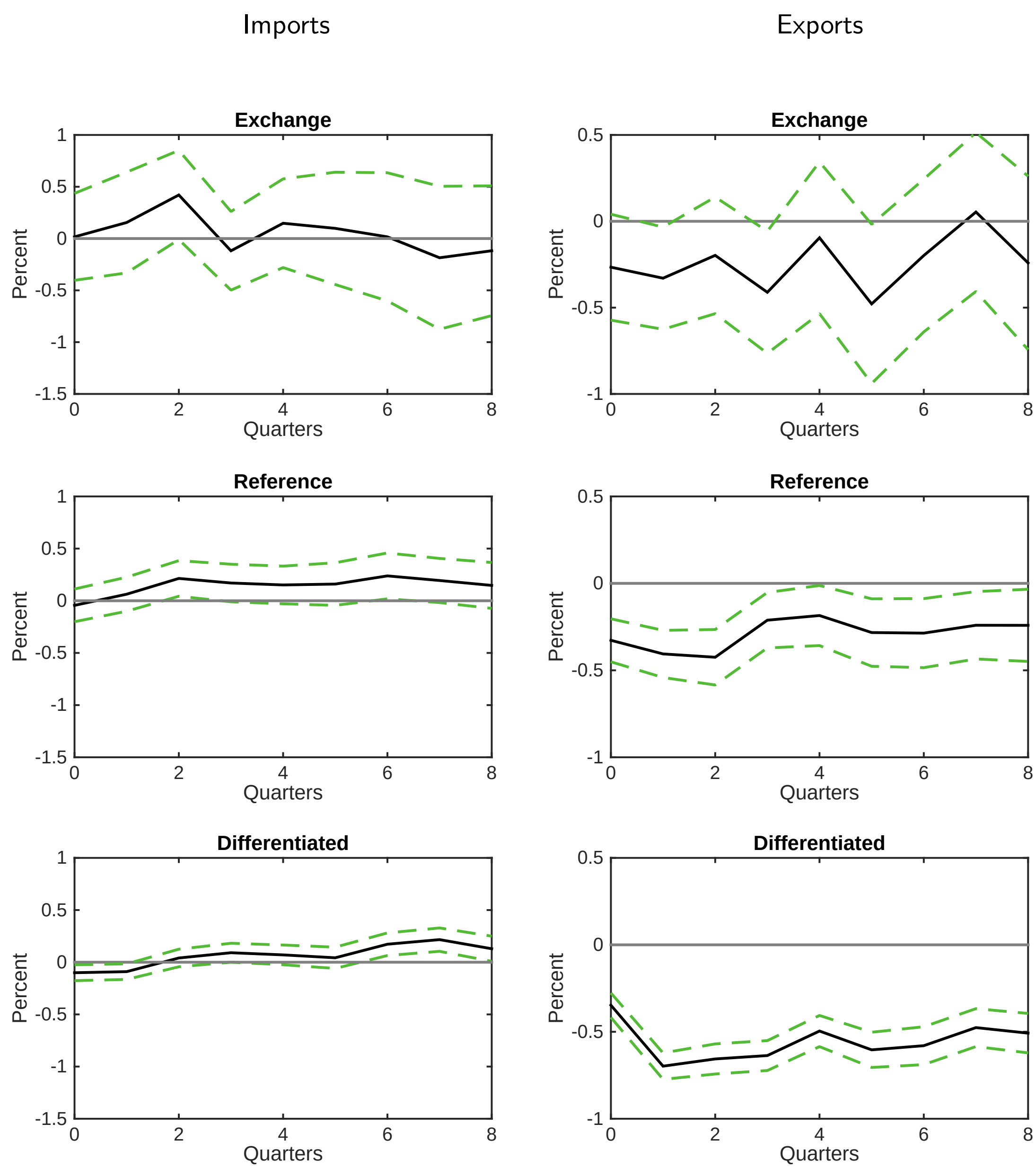

Figure 8: Impulse responses to 1% exchange rate appreciation by pricing type

likely to have sticky prices and lower elasticities of substitution. Finally, reference-priced goods are those for which a published price for that type of good is available, separate from a particular supplier. It might best be thought of as a type of good somewhere in between homogeneous goods and differentiated goods.

As the figure shows, there is little difference in the import response of the three types of goods. Qualitatively, differentiated goods look much like the pooled response in the left panel of Figure 1, with a negative initial response and only a small positive response over time. Exports, on the other hand, show a clear pattern. The more differentiated the good, the more negative and significant the response. Once again, however, this is contrary to the prediction of the model with regard to the elasticity of substitution. Highly differentiated goods should imply a low elasticity of substitution, and thus a smaller response. On the other hand, the right panel of Figure 1 shows that the stickier the prices, the larger the response given producer cost pricing. To replicate the pattern seen in the data, the exchange-traded and reference-priced goods must have effectively low demand elasticities, despite their relative homogeneity. The greater response of differentiated goods could be the result of sticky prices with an otherwise similarly low elasticity of substitution. Of course, economically such low elasticities are contrary to the notion of homogeneous goods; this suggests that other frictions in the economy are dominating trade flows, and that these frictions are important even for exchange-traded and reference-priced goods.

5.5 Asymmetric responses

Figure 9 shows the response of imports and exports when the effects of an appreciation and depreciation are estimated separately. This is done by estimating

$$\Delta \ln Trade_{ijt} = \beta_0 + \sum_{k=0}^{8} \beta_{1,k} \Delta^+ \ln e_{jt-k} + \sum_{k=0}^{8} \beta_{2,k} \Delta^- \ln e_{jt-k} + \sum_{k=0}^{8} \beta_{3,k} \Delta \ln y_{jt-k} + Z_{ijt} + \varepsilon_{ijt}, \quad (9)$$

where Δ^+ has the value of the change in exchange rate if the change is positive, and zero otherwise, with Δ^- similarly defined. As Kilian and Vigfusson (2011) demonstrate, these impulse responses represent not the average impulse response but the response for a large shock. Still, they are instructive, including for comparison to the model.

For imports, an appreciation increases imports but only after about a 4 quarter lag. For a depreciation, imports puzzlingly rise on impact; this suggests that it is exchange rate depreciation

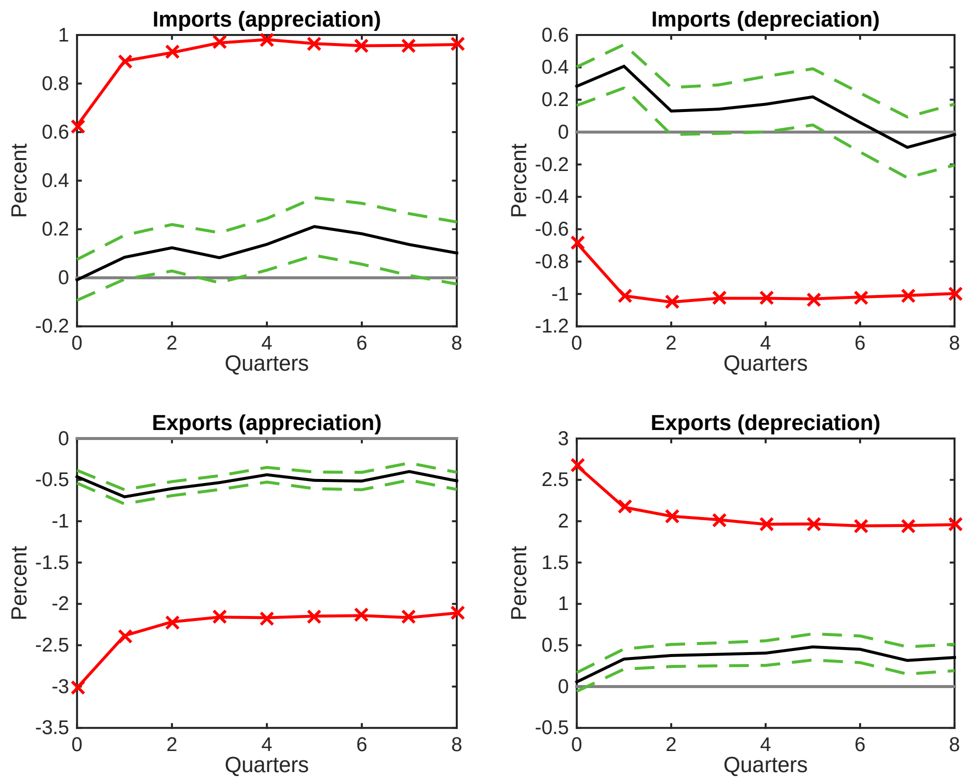

Figure 9: Asymmetric impulse responses to 1% exchange rate change. Pooled empirical responses are solid, and the benchmark menu cost model have markers.

episodes in the data which help produce the average pooled response in Figure 1. The benchmark menu cost model, shown with markers, shows little sign of asymmetry.[30] Therefore, the nature of this asymmetry may help inform the mechanism which reduces the overall short-run response.

For exports, an appreciation has a large, immediate impact. On the other hand, a depreciation has a smaller, hump-shaped response. Neither have the immediate response implied by the menu cost model, where full exchange rate pass-through implies the strongest response contemporaneously to the exchange rate shock.

[30]The same holds for flexible and Calvo priced models, not shown.

6 Conclusion

Using disaggregated sector-level, bilateral U.S. imports and exports, I test the trade value implications of models designed to match firm-level trade price data. Even restricting the analysis to those goods which should be more sensitive to exchange rate changes — commodities, sectors with higher estimated price elasticities, and sectors with a smaller share of imported intermediates — the response is muted.

For imports, time-dependent pricing and strategic complementarities combined provide a fairly small positive import response to an appreciation of the dollar, even given an underlying elasticity of substitution of 4. Still, the data show that import value, if anything, *falls* in response to an appreciation. Since U.S. exports are priced and stuck in dollars, any nominal rigidities, especially time-dependent rigidities, work in the opposite direction for U.S. exports, producing stronger trade responses with greater price stickiness.

While there is clear heterogeneity in the underlying elasticity of substitution or the pricing power of firms across sectors, these translate into fairly mild differences in their trade responses to exchange rate changes in the data. Imported intermediates are also not sufficiently large in magnitude to explain the low average response, especially for U.S. exports. There is, however, evidence that trade responds asymmetrically to exchange rate changes: exports are more responsive in the short run to dollar appreciations, and imports initially rise in response to dollar depreciations.

Standard trade models are not capable of lessening trade responses to exchange rates sufficiently without assuming that even the highly substitutable goods identified in the data have a low price elasticity. Further work is required to identify the pricing or demand mechanisms which might dampen this response without resorting to a low structural elasticity inconsistent with the response identified from other sources such as tariff changes. Modern international macro models like Engel and Wang (2011) assume a fixed cost of adjustment of trade flows, like that of capital. Arkolakis, Eaton and Kortum (2012) construct a dynamic trade model with a time-dependent Calvo-style switching mechanism to slow short-run adjustments in quantity. While such modeling mechanisms can improve the fit of aggregate models, it is crucial to understand the precise channels involved. Other possibilities outside of the scope of the model in this paper include distribution contracts, firm-specific production, and search costs to find new suppliers. Ideally, such mechanisms are tested not only via models and aggregate data but tested explicitly using disaggregated data and the large heterogeneity between sectors and firms. This is a fruitful direction for future work.

References

Adda, Jerome and Russell W. Cooper, *Dynamic Economics: Quantitative Methods and Applications*, The MIT Press, 2003.

Alessandria, George, "Consumer Search, Price Dispersion, and International Relative Price Fluctuations," *International Economic Review*, 2009, *50* (3), 803–829.

____, Joseph P. Kaboski, and Virgiliu Midrigan, "Inventories, Lumpy Trade, and Large Devaluations," *American Economic Review*, December 2010, *100* (5), 2304–2339.

Amiti, Mary, Oleg Itskhoki, and Jozef Konings, "Importers, Exporters, and Exchange Rate Disconnect," November 2012.

Arkolakis, Costas, Jonathan Eaton, and Samuel S. Kortum, "Staggered Adjustment and Trade Dynamics," July 2012. Mimeo.

Atkeson, Andrew and Ariel Burstein, "Pricing-to-Market, Trade Costs, and International Relative Prices," *American Economic Review*, December 2008, *98* (5), 1998–2031.

Barsky, Robert B., Christopher L. House, and Miles S. Kimball, "Sticky-Price Models and Durable Goods," *The American Economic Review*, June 2007, *97* (3), 984–998.

Berman, Nicolas, Philippe Martin, and Thierry Mayer, "How do different exporters react to exchange rate changes?," *Quarterly Journal of Economics*, February 2012, *127* (1), 437–492.

Bernard, Andrew B., Marco Grazzi, and Chiara Tomasi, "Intermediaries in International Trade: Direct versus indirect modes of export," *National Bureau of Economic Research Working Paper Series*, 2011, *No. 17711.*

Broda, Christian and David E. Weinstein, "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, May 2006, *121* (2), 541–585.

Burstein, Ariel and Gita Gopinath, "Chapter 7 - International Prices and Exchange Rates," in Elhanan Helpman and Kenneth Rogoff Gita Gopinath, ed., *Handbook of International Economics*, Vol. 4 of *Handbook of International Economics*, Elsevier, 2014, pp. 391–451.

Bussiere, Matthieu, "Exchange Rate Pass-through to Trade Prices: The Role of Nonlinearities and Asymmetries*," *Oxford Bulletin of Economics and Statistics*, 2013, *75* (5), 731–758.

Campa, Jose Manuel and Linda S. Goldberg, "Exchange Rate Pass-Through into Import Prices," *Review of Economics and Statistics*, November 2005, *87* (4), 679–690.

Corsetti, Giancarlo and Luca Dedola, "A macroeconomic model of international price discrimination," *Journal of International Economics*, September 2005, *67* (1), 129–155.

____, ____, and Sylvain Leduc, "High exchange-rate volatility and low pass-through," *Journal of Monetary Economics*, September 2008, *55* (6), 1113–1128.

Davis, Steven J., John Haltiwanger, Ron Jarmin, Javier Miranda, Christopher Foote, and Eva Nagypal, "Volatility and Dispersion in Business Growth Rates: Publicly Traded versus Privately Held Firms," *NBER Macroeconomics Annual*, 2006, *21*, 107–179.

de Blas, Beatriz and Katheryn Niles Russ, "Understanding Markups in the Open Economy," July 2012. Mimeo.

Drozd, Lukasz A. and Jaromir B. Nosal, "Understanding International Prices: Customers as Capital," *American Economic Review*, February 2012, *102* (1), 364–95.

Engel, Charles and Jian Wang, "International trade in durable goods: Understanding volatility, cyclicality, and elasticities," *Journal of International Economics*, January 2011, *83* (1), 37–52.

Feenstra, Robert C., Maurice Obstfeld, and Katheryn N. Russ, "In Search of the Armington Elasticity," 2012. Mimeo.

Fitzgerald, Doireann and Stefanie Haller, "Pricing-to-Market: Evidence From Plant-Level Prices," February 2013.

____ and ____ , "Exporters and Shocks: Dissecting the International Elasticity Puzzle," March 2014.

Goldberg, Linda S and Jose Manuel Campa, "The Sensitivity of the CPI to Exchange Rates: Distribution Margins, Imported Inputs, and Trade Exposure," *Review of Economics and Statistics*, May 2010, *92* (2), 392–407.

Gopinath, Gita and Oleg Itskhoki, "Frequency of Price Adjustment and Pass-Through," *Quarterly Journal of Economics*, May 2010, *125* (2), 675–727.

____ and Roberto Rigobon, "Sticky Borders," *Quarterly Journal of Economics*, May 2008, *123* (2), 531–575.

____, Oleg Itskhoki, and Roberto Rigobon, "Currency Choice and Exchange Rate Pass-Through," *American Economic Review*, March 2010, *100* (1), 304–336.

Gust, Christopher, Sylvain Leduc, and Nathan Sheets, "The adjustment of global external balances: Does partial exchange-rate pass-through to trade prices matter?," *Journal of International Economics*, November 2009, *79* (2), 173–185.

Hooper, Peter, Karen Johnson, and Jaime Marquez, "Trade elasticities for the G-7 countries," 2000.

IMF, "Exchange Rate and Trade Flows: Disconnected?," in "IMF World Economic Outlook" October 2015.

Kilian, Lutz and Robert J Vigfusson, "Are the responses of the U.S. economy asymmetric in energy price increases and decreases?," *Quantitative Economics*, November 2011, *2* (3).

Kimball, Miles S., "The Quantitative Analytics of the Basic Neomonetarist Model," *Journal of Money, Credit and Banking*, November 1995, *27* (4), 1241–1277.

Klenow, Peter J. and Jonathan L. Willis, "Real rigidities and nominal price changes," 2006. Mimeo.

Landry, Anthony, "State-dependent pricing, local-currency pricing, and exchange rate pass-through," *Journal of Economic Dynamics and Control*, October 2010, *34* (10), 1859–1871.

Levchenko, Andrei A., Logan T. Lewis, and Linda L. Tesar, "The Collapse of International Trade during the 2008-09 Crisis: In Search of the Smoking Gun," *IMF Economic Review*, December 2010, *58* (2), 214–253.

Midrigan, Virgiliu, "Menu Costs, Multi-Product Firms and Aggregate Fluctuations," *Econometrica*, July 2011, *79* (4), 1139–1180.

Neiman, Brent, "A State-Dependent Model of Intermediate Goods Pricing," *Journal of International Economics*, September 2011, *85* (1), 1–13.

Obstfeld, Maurice and Kenneth Rogoff, "The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?," *NBER Macroeconomics Annual*, 2000, *15*, 339–390.

Rauch, James E., "Networks versus markets in international trade," *Journal of International Economics*, June 1999, *48* (1), 7–35.

Ruhl, Kim J., "The International Elasticity Puzzle," 2008. Mimeo.

Schoenle, Raphael, "International Menu Costs and Price Dynamics," January 2010. Mimeo.

Silva, J. M. C. Santos and Silvana Tenreyro, "The Log of Gravity," *Review of Economics and Statistics*, November 2006, *88* (4), 641–658.

A Data appendix

Bilateral, nominal trade value data are collected from the USITC at the HS4 and SITC4 level from 1989 through 2009. The partner countries defined as OECD for the purposes of this exercise are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany,[31] Greece, Hungary, Iceland, Ireland, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, and Great Britain. These countries have been members of the OECD since at least 1995. Nominal GDP data, in foreign currency terms, and the nominal exchange rate are collected from the IMF International Financial Statistics database.

Gopinath and Rigobon (2008) report price durations for 85 import sectors and 71 export sectors at the 2- or 4-digit level of aggregation. Broda and Weinstein (2006) report import demand elasticities using U.S. trade data for SITC 4-digit categories. Rauch (1999) classifies goods by SITC categories, The "conservative" classification is used (categories are more likely to be classified as "differentiated" or "reference-priced").

B Computational algorithm

The computational model in Section 3 is solved via discretization of the state space and value function iteration for each set of calibrated parameters.[32] The basic solution method is similar to Gopinath and Itskhoki (2010).[33] The (log) sectoral price level is centered around $\ln(\theta/(\theta-1))$, with 81 grid points used for the individual firm price, 75 for the sectoral price level, 31 for the exchange rate, and 15 for the idiosyncratic productivity. The AR(1) processes for the exchange rate and productivity have grid points and transition matrices calculated with the method described in Adda and Cooper (2003).

The demand function defined by Klenow and Willis (2006) has the potential to be negative for a sufficiently large relative price, so I follow Gopinath et al. (2010) and set demand to be nil if the price is sufficiently high. Profits are denominated and maximized in the destination currency, though the results are similar with profits maximized in the exporter's currency.

The procedure is iterative, as follows:

1. Guess values for μ_1, μ_2, μ_3, and μ_4. In practice, I start with $\mu_1 = 0$, $\mu_2 = 1$, $\mu_3 = 0$, $\mu_4 = 0$.

2. Solve for four value functions via iteration: $\{V^a, V^n\}$ for an exporter, and $\{V^a, V^n\}$ for a domestic firm competing with the exporter.

3. Simulate N_f exporters and $N - N_f$ domestic competitors for 2100 months, dropping the first 100. In each quarter, endogenously determine the aggregate price index as the geometric average of firms' prices as expressed in the destination currency.

4. Regress the price index on its lag, the exchange rate, and a constant, as in (7).

[31] Pre-unification Germany observations are dropped.

[32] I also experimented with collocation methods, but the value functions were not well approximated by the commonly used Chebyshev polynomials, requiring spline interpolation; the computational speed was substantially slower than the more common discretization method with relatively few benefits in numerical precision.

[33] I thank Gita Gopinath and Oleg Itskhoki for making their model's code available for comparison.

5. If the assumed values for μ are all within 1% of the estimated values, continue. Otherwise, update the guess for μ and go back to step 2.

6. Re-estimate the model for M independent countries, each of which have 376 months, dropping the first 100 (leaving 23 years).

7. Calculate price statistics for the importers/exporters in each country, and average over them.

8. Aggregate the trade flows to quarterly frequency, and run (8) on the pooled sample.

In practice, the value functions in step 2 converge quickly after the first time by using the previous value function.

C Regression equivalence: pre-filtering exchange rate

The regression model (8) is equivalent to one in which the exchange rate series are pre-filtered with time dummies to remove their common component. This common component can be thought of as a U.S. component. This relationship is obvious for the case in which only the contemporaneous exchange rate is included in (8), but less obvious that the sector-time dummies included there fully replicate the case in which the exchange rate series are pre-filtered.

To consider that case, I ignore sectoral heterogeneity for notational convenience. Suppose that instead of (8), one first pre-filters the exchange rate series by running:

$$\ln e_{it} = \sum_{k=0}^{T} \gamma_k \mathbb{I}_k + \varepsilon_{it}, \tag{10}$$

where $\mathbb{I}_k$ is an indicator variable taking the value 1 if $k = t$, and 0 otherwise. The filtered series is then ε_{it}. With this series, we can run the following regression:

$$\Delta \ln T_{it} = \sum_{k=0}^{8} \beta_{it-k} \varepsilon_{it-k} + \sum_{k=0}^{T} \alpha_k \mathbb{I}_k + \delta_{it}.$$

Substituting in for ε_{it-k} with equation (10), one obtains:

$$\Delta \ln T_{it} = \sum_{k=0}^{8} \beta_{it-k} \ln e_{it-k} + \sum_{k=0}^{8} \beta_{it-k} \gamma_{t-k} + \sum_{k=0}^{T} \alpha_k \mathbb{I}_k + \delta_t. \tag{11}$$

Compare this to the estimation without pre-filtering, which (abstracting from the GDP entries) takes the form:

$$\Delta \ln T_{it} = \sum_{k=0}^{8} \beta_{it-k} \ln e_{it-k} + \sum_{k=0}^{T} \tau_k \mathbb{I}_k + \delta_t. \tag{12}$$

Thus, $\tau_t = \sum_{k=0}^{T} \beta_{t-k} \gamma_{t-k} + \alpha_t$, and the estimates of β are unchanged.

Additional Appendix for Online Publication

D Regression tables

Table 2 reports the coefficients from the baseline regressions depicted in Figure 1. The coefficients on nominal GDP are also reported; for U.S. imports, it is unsurprising that the coefficients on foreign GDP are insignificant. For exports, however, they are all highly significant. Since the model holds the level of demand constant, these coefficients are not estimated (the demand equation essentially assumes an aggregate real elasticity of unity).

In addition, (2) and (5) report the results of a robustness exercise in which large changes in imports and exports are dropped; specifically, I drop those where $|\Delta \ln \text{Trade}| > 1$. For imports, we see that while the initial negative response is smaller in magnitude, the rise over time is even smaller. Similarly for exports, the magnitude of the response is halved, proving even more difficult for the model to match.

Table 2: Pooled regression results

	Imports			*Exports*		
	Data		Model	Data		Model
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln \text{exrate}_0$	-0.097***	-0.083***	0.656***	-0.332***	-0.167***	-2.840***
	(0.032)	(0.015)	(0.014)	(0.029)	(0.014)	(0.025)
$\sum_{k=0}^{4} \Delta \ln \text{exrate}_k$	0.05	-0.034	1.003***	-0.437***	-0.237***	-2.064***
	(0.042)	(0.025)	(0.021)	(0.036)	(0.025)	(0.032)
$\sum_{k=0}^{8} \Delta \ln \text{exrate}_k$	0.08	0.046	0.980***	-0.464***	-0.222***	-2.027***
	(0.051)	(0.033)	(0.026)	(0.042)	(0.032)	(0.042)
$\Delta \ln \text{nom GDP}_0$	0.073	0.084***		0.237***	0.149***	
	(0.062)	(0.03)		(0.056)	(0.028)	
$\sum_{k=0}^{4} \Delta \ln \text{nom GDP}_k$	-0.066	-0.086		0.295***	0.233***	
	(0.086)	(0.054)		(0.073)	(0.053)	
$\sum_{k=0}^{8} \Delta \ln \text{nom GDP}_k$	0.06	-0.01		0.295***	0.152***	
	(0.072)	(0.05)		(0.056)	(0.048)	
Observations	1,135,983	904,218	2,158	1,312,096	1,011,717	2,158
R^2	0.13	0.15	0.84	0.11	0.12	0.96

Notes: (1) and (4) are the regressions corresponding to the pooled data in Figure 1. (2) and (5) drop those observations where $|\Delta \ln \text{Trade}| > 1$. (3) and (6) correspond to the benchmark menu cost simulation, also shown in Figure 1.

E Labor intensity

Fixed capital may make production decisions more difficult to adjust in response to a change in the exchange rate. For example, given an exchange rate depreciation, production for an exporter may not be able to ramp up quickly given time-to-build constraints on capital. If capital is relatively more difficult to adjust in the short run than labor, sectors with relatively labor intensive production processes should be more responsive to exchange rate changes.

I use a measure of labor intensity calculated from the BEA Input-Output tables, measured as employee compensation divided by value added. These are mapped to NAICS 6-digit industries, as in Levchenko, Lewis and Tesar (2010). These industries are then pooled into "high" (0.88), "medium" (0.68), and "low"(0.4) intensity by percentile.

For comparable model simulations, I assume that capital is completely fixed and profits take the form $\pi(p,e,a) = pq - (qe^{\phi}/a)^{1/\psi}$, where $\psi \in \{0.88, 0.68, 0.4\}$ to match each bin.

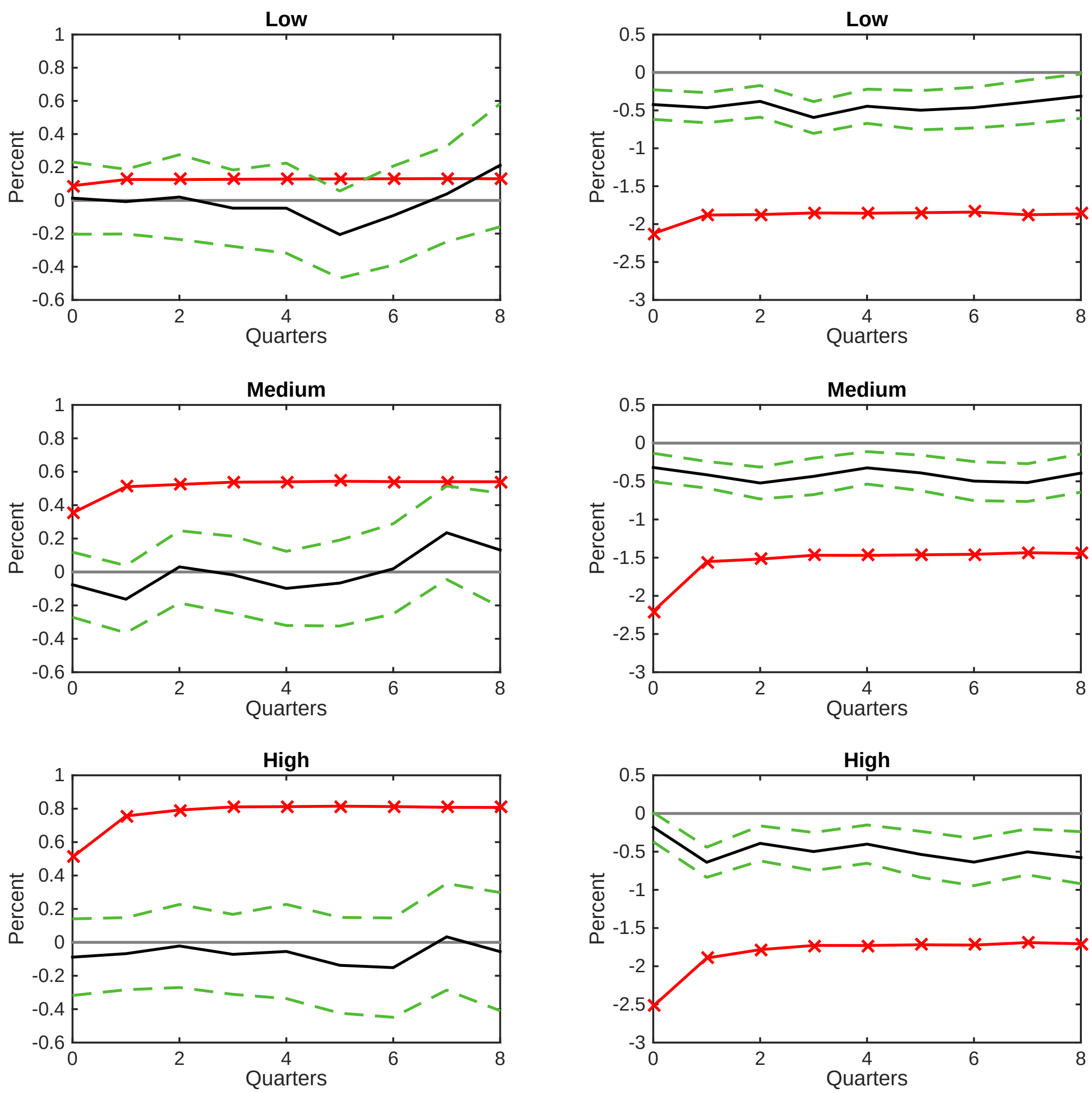

Figure 10: Impulse responses to 1% exchange rate appreciation by labor intensity bins (solid), and the menu cost model IRF (with markers)

Figure 10 shows the response of imports and exports by labor intensity group. For imports, there is no discernible difference in the response across categories, and no indication that sectors with relatively large labor intensity are more responsive than those with low labor intensity. For exports, the results are also very similar, and in the short run the high labor intensity sectors are, if anything, less responsive to the exchange rate appreciation.

F Durable goods

Alternatively, consumer demand may respond differently to price changes based on whether they consume it as a non-durable or hold a stock of it as a durable. While the model does not speak directly to how durable goods might be different, a number of scenarios are plausible. First, durable goods consist of larger goods, for which consumers may be making more deliberate, discrete purchasing choices. When buying an automobile, for example, price is an important consideration between a car produced in Japan and Germany. A change between the relative exchange rates of the yen and euro that filters into dollar prices would lead consumers on the margin to switch their purchases relatively freely. A second possibility is that a potential car buyer has some ability to re-time her purchase if pricing is currently unfavorable.[34] On the flip side, durable goods tend to be more complex and require several stages of production. Since trade largely consists of intermediate goods, a car manufacturer might be stuck with a specific supplier of a car part in the short run; either the buyer or the seller would be exposed to the exchange rate change depending on the currency of pricing, and it would not be feasible to quickly shift from a Japanese supplier to a German or Canadian one.

In terms of the model, such considerations are essentially reduced down to changes in the elasticity of substitution between varieties, with the caveat that the short-run elasticity may differ from the long-run elasticity.

I use the same classification of durable goods as in Levchenko et al. (2010). This is a simple classification at the 3-digit NAICS level. Sectors 23X (construction) and 325-339 (chemical, plastics, mineral, metal, machinery, computer/electronic, transportation, and miscellaneous manufacturing) are durable. Non-durable sectors are all other 1XX, 2XX, and 3XX categories.

Figure 11 plots the results. Again, there is essentially no difference between durable and non-durable sectors with both imports and exports.

G Related-party trade

Much of international trade is conducted between related parties: in 2007, 47 percent of imports and 29 percent of exports were classified as related-party by Census. It is not clear whether related-party trade should be more or less responsive to exchange rate changes than arms-length transactions. If a multinational firm is able to source from several partner countries, for example, it might be able to switch more quickly between its suppliers than a smaller firm that has to find a new partner in the now-cheaper country. On the other hand, these multinationals might be more capable and interested in hedging short-term exchange rate fluctuations and is able to move profits between subsidiaries independent of movements of goods.

[34]For further discussion of the intertemporal substitution of durable goods in a sticky-price environment, see Barsky, House and Kimball (2007).

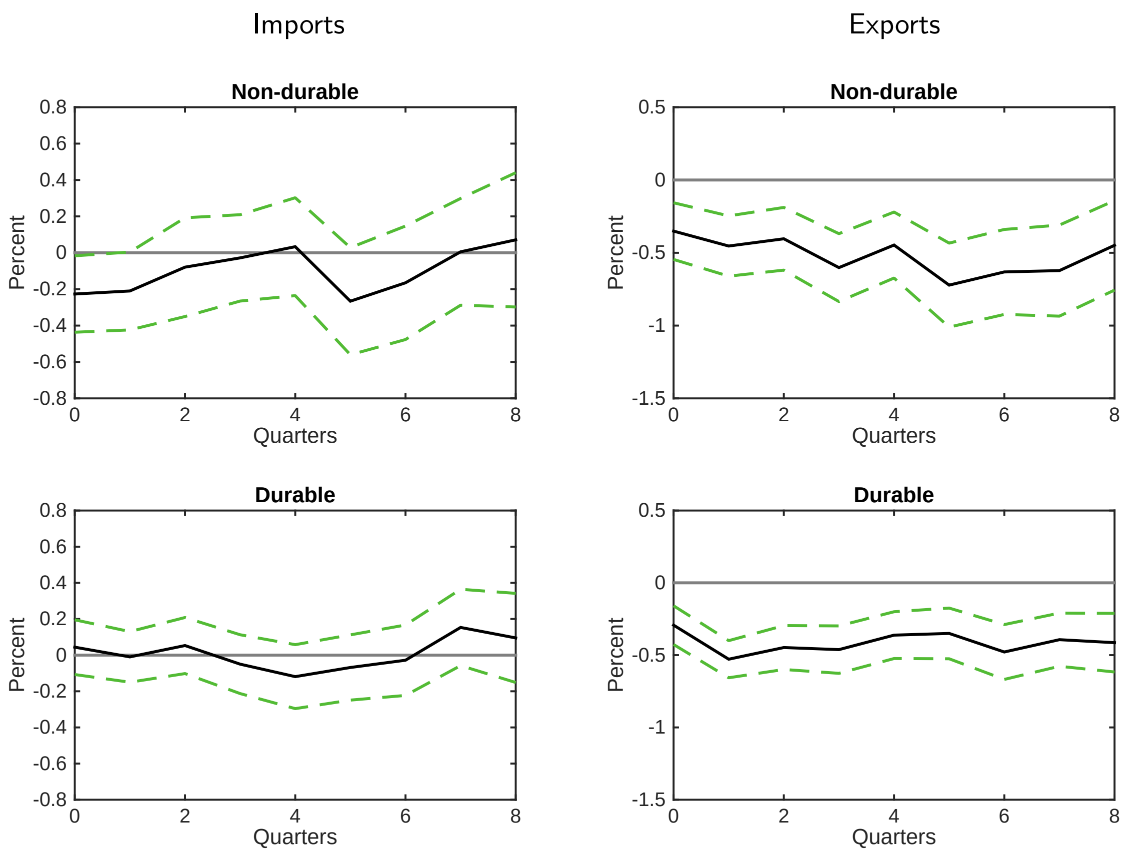

Figure 11: Impulse responses to 1% exchange rate appreciation by durable classification

The Census only releases data splitting related-party from arms-length trade on an annual basis for NAICS6 categories since 2002. Nonetheless, using this annual data it is possible to split the bilateral quarterly NAICS6 categories into bins by the degree to which trade in related-party. The variation across industries is substantial. For imports, the bin with the lowest related-party trade has on average 6 percent related-party trade, while the bin with the highest related-party trade has on average 63 percent related-party trade. For exports, this range is 1 percent to 32 percent.

Figure 12 shows the response of imports and exports split into categories of low, medium, and high related-party trade. While the point estimates of low related-party trade are the strongest in the expected direction, the distinction between categories is minor, particularly for exports.

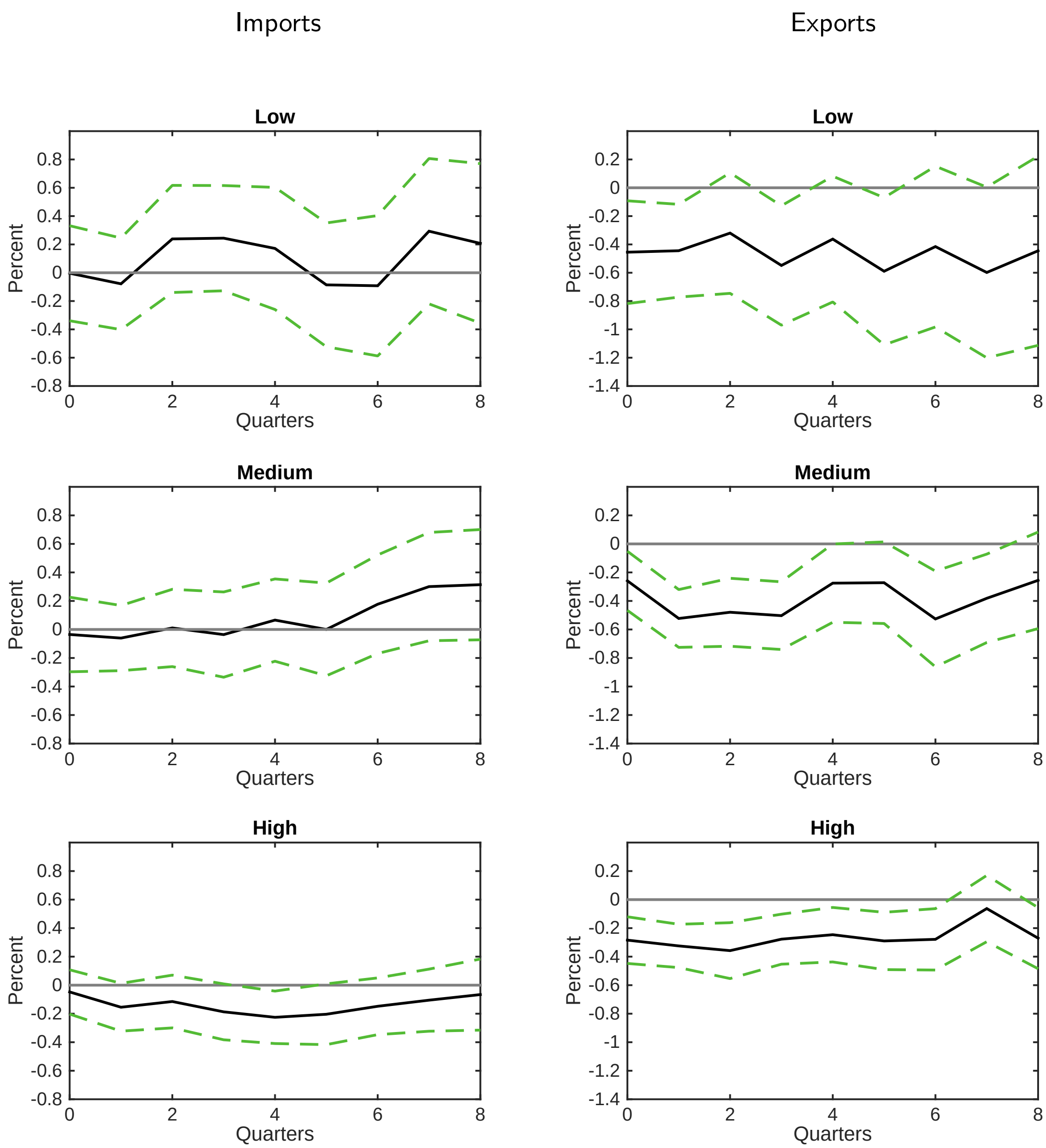

Figure 12: Impulse responses to 1% exchange rate appreciation by ratio of related party trade to total trade.