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Pass-through of Competitors' Exchange Rates to US Import and Producer Prices

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Abstract

This paper shows that in theory and BLS microdata, the prices of imported goods respond to the exchange rates (ER) of the producer's foreign competitors. In contrast, standard models have no role for competitors' ERs. Excluding the effects of competitors' exchange rates typically biases upwards estimates of bilateral exchange rate pass-through because competitors' ERs and bilateral ERs are positively correlated. A multi-country version of Atkeson and Burstein's (2008) industry aggregation model is able to explain a sizable proportion of pass-through of competitors' exchange rates to import prices, and also predicts pass-through of foreign competitors' prices and pass-through of competitors' ERs to US producer prices —both of which are supported in the data. The results suggest that pass-through will be larger for ER movements shared by a greater fraction of foreign competitor countries.

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PASS-THROUGH OF COMPETITORS' EXCHANGE RATES TO US IMPORT AND PRODUCER PRICES*

STEVEN PENNINGS

1. Introduction

Standard empirical and theoretical models focus on the bilateral exchange rate (between exporting and importing countries) as the key international macroeconomic variable determining prices. However, since the 1980s (e.g. Dornbusch 1987) it has been appreciated that competitors' *prices* will be an important determinant of international prices in models where firms price strategically. In this paper, I extend the literature to show that in a multi-country (>2) world, this general class of model (where markups depend on other firms' prices) implies that US import prices and producer prices will respond to the *exchange rates* of the producer's foreign competitors (Section 2). Using US microdata at the product level, I show that pass-through of competitors' exchange rates to import prices is large — often larger than pass-through of the bilateral exchange rate — and that US producer prices also respond significantly to competitors' exchange rates (Section 3). Consistent with this mechanism, pass-through of *foreign* competitors' prices is sizable. I develop a multi-country extension of the model of Atkeson and Burstein (2008) (henceforth AB), which is able to explain a large share of pass-through of competitors' exchange rates when regressions are run on simulated data (Sections 4 and 5). While some of these facts for import prices have been mentioned briefly elsewhere (e.g. Gopinath and Itskhoki 2011, henceforth GI2011), this paper is among the first to analyze them systematically.

An example To fix ideas, consider four car producers from the US, Europe, Japan and Canada competing in the US market. Standard bilateral exchange rate pass-through suggests that a real appreciation of the yen against the USD will raise the real price of Japanese cars imported into the US. However, models of strategic pricing also predict that the Japanese car producer will respond to the prices — and hence exchange rates — of its foreign competitors (from Europe, Canada, etc). That is, a real appreciation of the euro or Canadian dollar will lead the *Japanese* car producer to raise its prices in the US, even if the real bilateral yen-USD exchange rate is unchanged.

Figure 1 illustrates these patterns in the aggregate data for real import prices from Japan, Europe and Canada. On the left is the standard relationship in the literature between import prices (y-axis) and bilateral real exchange rates (RERs) (x-axis). On the right is the new relationship between the same import prices (y-axis) and competitors' RERs (x-axis) at the aggregate level, which turns out to be at least as strong. I show that similar patterns hold at the product level using Bureau of Labor Statistics (BLS) microdata. Quantitatively, standard univariate bilateral pass-through to import prices is around 0.23 in both the BLS microdata and in the aggregate (Figure 1 LHS) compared with pass-through of competitors' RERs to import prices of around 0.35 in the BLS microdata (after controlling for bilateral RERs).[1] This is consistent with

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[1]In the aggregate data in Figure 1, pass-though of competitors' RERs to import prices is about 0.32 ($t = 4$) in a simple univariate regression. After controlling for bilateral RERs (as I do the BLS microdata), aggregate pass-through of competitors' RERs falls to about 0.19 ($t = 2.5$) (see partial scatter plot in the online appendix). However, controlling for competitors' RER's also reduces aggregate bilateral PT to 0.195 ($t = 5$) (not reported). In the aggregate data, competitors' RERs are approximated

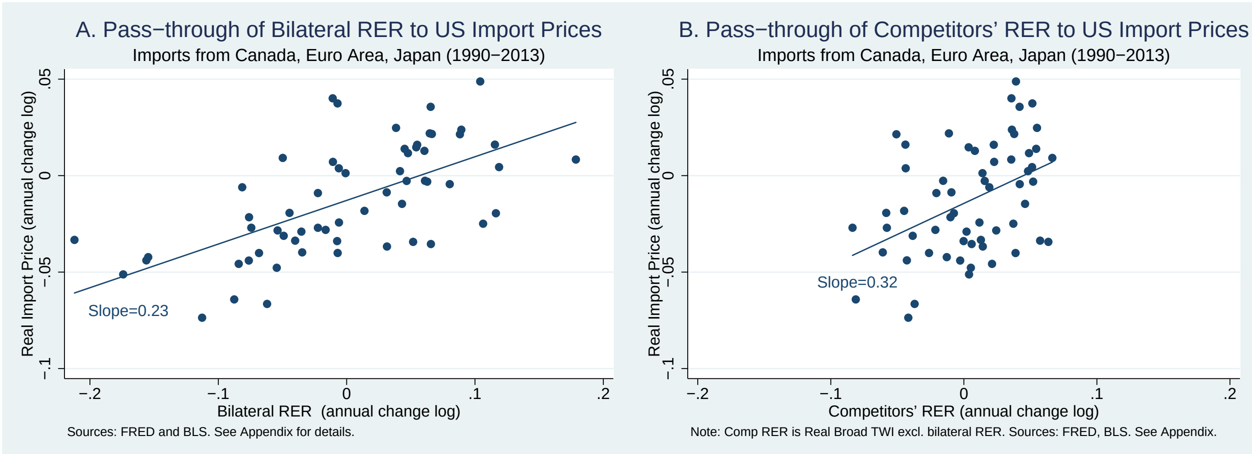

Figure 1. Aggregate-level pass-through of bilateral and competitors' RERs to US import prices

sizable pass-through of the trade weighted index (TWI) exchange rate to import prices as discussed briefly in GI2011. Pass-through of competitors' RERs to US producer prices is around 0.1 in the BLS microdata.[2]

Model To compare the quantitative size of these forces in theory and data, I develop a multi-country extension of AB where (i) goods are more substitutable within than between sectors, and (ii) the small number of firms in each sector engage in Cournot competition. A linearized version of the firm's pricing equation has the same form as the general class of models discussed above: firms respond to competitors' prices. Solving for those prices generates a linear "structural pass-through" representation where the firm's price responds to its own bilateral exchange rate and the exchange rates of its foreign competitors. The mechanism in the model suggests that firms face a changing elasticity of demand as their market share changes, and as a result, firms will adjust their prices to maintain their market share. For instance, in the previous example, a real appreciation of the Canadian dollar leads Canadian manufacturers to charge higher prices in the US, and so the manufacturer from Japan will raise its price to maintain its market share. The model also predicts that *US* producers will respond to the prices of their competitors.

Quantitatively, the model is able to explain a bit less than half of pass-through of competitors' exchange rates to import prices in the data (0.35 in the data, vs 0.15 in the model) and almost all of pass-through to producer prices (0.11 in the data vs 0.09 in the model). This is a substantial improvement on most models in the literature which have no role for foreign competitors' exchange rates.

However, one weakness of the baseline model (and others in the literature) is that it over-predicts bilateral pass-though – univariate bilateral pass-through is around 0.23 in the data vs 0.65 in the baseline model (without imported intermediates), or around 0.5 with imported intermediates (as an extension). This class of model also fails to match the combination of low short-run and high long-run price elasticities of trade (the "elasticity puzzle") in Drozd and Nosal (2012b). Drozd and Nosal (2012a) are able to match both but focus on explaining aggregate prices, rather than micro-level prices as I attempt to do here.

Imported Intermediates An alternative explanation of the empirical results is that intermediate goods are imported from third countries, which naturally makes the prices of final goods sensitive to third-country exchange rates, even if markups are (relatively) fixed. Amiti et al (2014, 2016) find that prices of imported inputs are important drivers of pass-through into domestic Belgian prices, and incomplete pass-though into Belgian export prices, with the imported input share being heterogeneous in firm size. I incorporate imported intermediates into the model in Appendix C as an extension. While imported intermediates do boost pass-through of competitors' RERs, its quantitative size depends whether imported inputs are sourced from countries that are also competitors in the same sector. This is likely to be sensitive to factors like country

by the trade-weighted exchange rate (TWI) excluding the bilateral rate. In the rest of the paper I use an import-weighed measure at the sectoral level.

[2]It is important to control for US materials costs in the data. These costs can be highly correlated with exchange rates, leading to large estimates of stand-alone pass-through of competitors' RERs to US producer prices, which the baseline model has difficulty rationalizing.

size, geographic proximity and industrial composition, and so might differ across Belgium, the US or other countries and is difficult to calibrate with available data. Nonetheless, indicative simulations suggest that the variable markup mechanism is still needed to explain estimates in the data.

Bias in bilateral pass-through One contribution of this paper is to show that simple measures of bilateral pass-through — defined in Section 2 as the response of import prices to producers' relative costs, other things constant — are generally *upward biased* in a multi-country world. For the US this exacerbates the puzzle of low pass-through documented in the literature (see Burstein and Gopinath 2014 for a survey of recent literature).[3] That is, standard bilateral pass-through regressions suffer from omitted variable bias because competitors' exchange rates also affect import prices and competitors' exchange rates and bilateral exchange rates are generally positively correlated. In the example above, if the yen, the euro and Canadian dollar all appreciate at the same time against the USD in real terms and the Japanese car manufacturer raises prices in the US, it might *appear* that the Japanese producer is responding strongly to the yen appreciation, when in fact it is responding partially to the yen appreciation and partially to the appreciation of its competitors' currencies. A corollary is that in order to better measure the *direct* effect of foreign producers' costs on import prices, researchers can include competitors' exchange rates (or a simpler proxy like the TWI excluding the bilateral rate) as an additional control.[4] Quantitatively, the bias in bilateral pass-through (PT) is about 7ppts, or around a third of bilateral PT in my sample of US import prices. However, its size depends on the estimate of pass-through of competitors' RERs, the correlation of RERs and also their variances which means the size of the bias will likely vary across samples and countries.

Competitors' Prices The main mechanism in the model works through changes in foreign competitors' prices — I show that pass-through of foreign competitors' prices is around 0.6 to import prices, and 0.16 to US producer prices. Quantitatively, the model is able to explain about a third of this for import prices and two-thirds for producer prices. As an extension in Section 6, I also show that importing firms respond particularly strongly to the prices of US firms in the same sector and, to a lesser extent, other compatriot firms' prices. This is consistent with a general model of variable markups discussed in Section 2.

1.1. **Related Literature.** My empirical evidence and multi-country model are related to a broad class of models of incomplete pass-through surveyed in Burstein and Gopinath (2014), where a firm's markup is falling in its price relative to some aggregate/sectoral price (described in Section 2).[5] An empirical role for competitors' RERs is consistent with this broad class of models, so long as the aggregate/sectoral price is correlated with competitors' exchange rates.

The results presented here are complementary to contemporaneous work by Auer and Schoenle (2016) and Amiti et al (2016). Using novel market share data, Auer and Schoenle (2016) show that in industry aggregation models and the BLS microdata, own cost pass-through is U-shaped in firm market shares, and competitors' price pass-through is hump-shaped in firm market shares. Although Auer and Schoenle don't discuss pass-through of competitors' exchange rates — and I don't discuss market shares — one might expect that many of the firms responding to competitors' prices in Auer and Schoenle are the same firms responding to competitors' RERs here.

Amiti et al (2016) use a new firm-level dataset matching Belgian domestic manufacturing prices, costs, imported intermediate input usage and competitors' prices, which allows them to control for firm-level marginal costs, and instrument competitors' prices (which they argue are endogenous due to the price-setting game). They find 2/3 cost pass-through and 1/3 competitors' price pass-though into Belgian domestic manufacturing prices, with higher rates of competitors' price pass-through in larger firms. They also find a 30% pass-through rate of the TWI into domestic prices, and use a calibrated model to argue that most of this is through the cost of intermediates. This is consistent with my finding of lower ER pass-through into the PPI after controlling for materials prices.

[3]Low bilateral pass-through is important because it underlies a disconnect between exchange rates and macroeconomic aggregates and, in many cases, a departure from the Law of One Price (Obstfeld and Rogoff 2000). Since Gopinath and Rigobon (2008) and Gopinath and Itskhoki (2010) found low pass-through *conditional* on a price change and over long horizons, research has focused on models including *real* rigidities.

[4]This finding is related, in an abstract sense, to Anderson and van Wincoop's (2003) argument for the inclusion of "multilateral resistance" terms in gravity regressions to remove omitted variable bias due to aggregate price indices.

[5]Specific mechanisms include industry aggregation (AB), additive local distribution costs (Corsetti and Dedola 2005), non-CES demand (Melitz and Ottaviano 2008, Kimball 1995), consumer search (Alessandria 2009), and customers-as-capital (Drozd and Nosal 2012a). In the final two cases, the firm's price can be written to reflect two forces: a marginal cost term and a second aggregate wage/price term.

The findings in this paper are also related to GI2011, who provide a range of evidence on the extent of real rigidities in pricing. One of their findings is a large response of import prices to the TWI (orthogonal to the bilateral RER), and another is sizable pass-through of import competitors' prices, both of which are consistent with evidence presented here. This paper provides a more systematic analysis by deriving a measure of competitors' RERs from theory, comparing magnitudes in theory vs data, considering implications for bilateral pass-through, examining pass-through to US producer prices (as predicted by theory) and testing the mechanism which works through *foreign* competitors' prices (rather than all competitors' prices).[6]

2. Simple Model

As a guide to the empirical work, I begin with a simple reduced-form model based on Burstein and Gopinath (2014) and GI2011 where the firm's markup depends on a sectoral/aggregate price, and then extended it to a three-country setting. The model produces four key *qualitative* predictions which are outlined in Testable Predictions 1-4, for which I find supporting evidence in BLS microdata in Section 3 (results summarized in Box 1). In Section 4, I show how a similar specification comes from a multi-country version of AB, which I use to produce *quantitative* estimates from regressions run on simulated data.

2.1. **Model set-up.** There are three countries: the US, country i and some other third country c (this could be the "competitor" country). Let p_{ijk} be the log of the price of an imported good k produced in country i, in sector j, at the docks in the US (I suppress the firm/good index k and the sector j), relative to some numeraire. Then:

$$p_i = \mu_i + mc_i$$

where $\mu_i \approx \bar{\mu}_i - \Gamma\left[p_i - p\right]$ is the log markup, which I assume is related to the relative price $p_i - p$, with reduced form elasticity $\Gamma \geq 0$ (which might depend on country-, sector- or firm-specific characteristics). That is, the higher is the price of good k from country i relative to the sectoral/aggregate price index p, the lower the desired markup. In the AB model (in Section 4), higher prices relative to the sectoral/aggregate price reduce market shares which reduce desired markups, though the microfoundation varies across models (I assume the firm's direct contribution to p here is small). Let the log marginal cost be $mc_i = \bar{mc}_i + (1-\phi_{us} - \phi_c)(w_i - a_i) + \phi_{us}v_{us} + \phi_c v_c$ which depends on unit labor costs $(w_i - a_i)$ in the country of production with weight $1 - \phi_{us} - \phi_c$ and the price of imported intermediate inputs from the US (v_{us}) or the third country (v_c). For simplicity, assume intermediate inputs produced in c or the US and sold in i are produced by competitive firms using only labor with constant returns to scale such that $v_c = w_c - a_c$ and $v_{us} = w_{us} - a_{us}$. Substituting and suppressing constants, the expression becomes:

$$p_i = -\Gamma\left[p_i - p\right] + (1-\phi_{us}-\phi_c)(w_i - a_i) + \phi_{us}v_{us} + \phi_c v_c \tag{1}$$

Adding Γp_i to both sides, rearranging, and subtracting log US unit labor costs (ULC, $w_{us} - a_{us}$) from both sides yields the pricing Equation 2.

$$p_{Ri} = \frac{\Gamma}{1+\Gamma}p_R + \frac{1-\phi_{us}-\phi_c}{1+\Gamma}rer_i + \frac{\phi_c}{1+\Gamma}v_{Rc} \tag{2}$$

Where $rer_i = w_i - a_i - [w_{us} - a_{us}]$ is the log real bilateral ULC-based real exchange rate, and p_{Ri}, p_R and v_{Rc} are respectively the log real import price of the firm, the sectoral/aggregate price and imported intermediate price (from c), relative to US ULC. Define $rer_c = w_c - a_c - [w_{us} - a_{us}]$ as the log bilateral real exchange rate of the US with the *other third country* (the competitors' RER). The two real exchange rate movements rer_i, rer_c are the only shocks in the model.[7]

[6] See Section 3.6 for a comparison with GI2011 and the online appendix for a discussion of how well the TWI proxies for competitors' RERs (they have a correlation of around 0.8). Using a model with a translog demand function, Bergin and Feenstra (2009) show that a change in the USD-Mexican peso exchange rate can affect the price of Chinese goods imported to the US, but they only discuss this result in passing.

[7] Relative to Burstein and Gopinath (2014) I assume marginal costs do not depend on output, and I only consider variations in the real exchange rate. Intermediate inputs from the US drop out of Equation 2 because they move one-for-one with US ULC. An increase the RER represents an appreciation of country i or c's exchange rate relative to the US.

2.2. **Pass-through of competitors' (third-country) exchange rates.** First, I consider an appreciation of the third-country exchange rate (an increase in rer_c), keeping constant the bilateral exchange rate rer_i.

Testable Prediction 1. Positive PT of competitors'/third country RERs ($\beta_C > 0$): *an appreciation of competitors/third country exchange rates (keeping the bilateral rate fixed) should increase US import prices (Equation 3).*

$$\beta_C \equiv \frac{\partial p_{Ri}}{\partial rer_c} = \underbrace{\frac{\Gamma}{1+\Gamma}\frac{\partial p_R}{\partial rer_c}}_{PT\ via\ markups} + \underbrace{\frac{\phi_c}{1+\Gamma}}_{PT\ via\ Imported\ Costs} \tag{3}$$

Pass-through of third-country exchange rates is given by Equation 3 and will be positive ($\beta_C > 0$) so long as (i) *importers respond to the sectoral price* ($\Gamma > 0$) *and the sectoral price is affected by the third-country RER* ($\partial p_R/\partial rer_c > 0$) and/or (ii) *the imported intermediate share from the third country is positive* ($\phi_c > 0$, *as* $\partial v_{Rc}/\partial rer_c = 1$). This follows immediately from taking the partial derivative of Equation 2, and suggests that multi-country ($n > 2$) models have a very natural role for pass-through of third-country exchange rates.

In the quantitative model presented in Section 4, I focus on the case where $\phi_{us} = \phi_c = 0$ (no imported intermediates) and so pass-through of competitors' exchange rates is the same as pass-through of third-country exchange rates (I relax this assumption in Appendix C) . In the rest of the paper, there are more than three countries and as such, I refer to all other exchange rates (other than the bilateral rate) as "competitors' RERs".

2.3. **The bias in bilateral pass-through (BPT).**

Definition 1. True Bilateral Pass-through (β_{BI}^{True}) The increase in import prices from country i in the US when *only* the bilateral exchange rate between the US and country i changes (other exchange rates are constant, Equation 4).

$$\beta_{BI}^{True} \equiv \frac{\partial p_{Ri}}{\partial rer_i} = \underbrace{\frac{1-\phi_{us}-\phi_c}{1+\Gamma}}_{Direct\ Cost\ PT} + \underbrace{\frac{\Gamma}{1+\Gamma}\frac{\partial p_R}{\partial rer_i}}_{Indirect\ Bilateral\ PT} \tag{4}$$

Definition 2. Measured Bilateral Pass-through ($\beta_{BI}^{Meas.}$) The increase import prices from country i in the US when the bilateral exchange rate between the US and country i changes, allowing other (third-country) exchange rates to move endogenously (Equation 5).

$$\begin{aligned} \beta_{BI}^{Meas.} \quad &\equiv \quad \frac{dp_{Ri}}{drer_i} = \frac{\partial p_{Ri}}{\partial rer_i} + \underbrace{\frac{\partial p_{Ri}}{\partial rer_c}\frac{\partial rer_c}{\partial rer_i}}_{Size\ of\ "bias"} \\ &= \quad \beta_{BI}^{True} + \left\{\frac{\Gamma}{1+\Gamma}\frac{\partial p_R}{\partial rer_c} + \frac{\phi_c}{1+\Gamma}\right\}\frac{\partial rer_c}{\partial rer_i} \end{aligned} \tag{5}$$

In a two-country version of the model, measured BPT equals true BPT by definition as there are no other exchange rates. True BPT is given by Equation 4. As described in Burstein and Gopinath (2014), bilateral exchange rates in a two country model have direct effects through costs, and indirect effects as the bilateral real exchange rate affects sectoral prices.

Testable Prediction 2. Bias in standard bilateral PT regressions. *Measured bilateral pass-through will be "biased" — it will differ from true bilateral pass-through ($\beta_{BI}^{Meas.} \neq \beta_{BI}^{True}$) — unless exchange rates do not co-move or PT of third-country exchange rates is zero ($\partial p_R/\partial rer_c = 0$, $\phi_c = 0$). In the empirically relevant case of that bilateral and competitors'/third country RERs are positively correlated, measured bilateral PT will be larger than true bilateral PT, with bilateral pass-through falling when competitors' RER are added as a control.*

In a stochastic version of the model, Testable Prediction 2 suggests that measured BPT (from a regression of import prices on bilateral exchange rates) will be biased due to the omitted variable of the third-country RER. Controlling for competitors' RERs eliminates (or reduces) this bias. The size of the bias in measured univariate bilateral pass-through in the three-country model can be written as $E\hat{\beta}_{BI} - \beta_{BI} =$

$\beta_C corr(rer_i, rer_c)\,[sd(rer_c)/sd(rer_i)]$. $corr(rer_i, rer_c)$ and β_C are usually positive (and $sd(rer_c)/sd(rer_i)$ is always positive), so measured BPT will generally be upward biased. In a GE model (such as that in the online appendix), a positive correlation is driven by shocks in the US which affect both bilateral RERs. However, the size and direction of the bias will depend on the correlation between bilateral and third-country RERs as well as the relative volatility of bilateral and third-country RERs, all of which are country and sample dependent.

2.4. **Pass-through to US producer prices.** Consider a simplified two country version of the model with just the US and country c. Suppressing constants, one can rewrite Equation 1 from the perspective of a US firm selling domestically in sector j but facing competitors from country c.

$$p_{us} = -\Gamma\,[p_{us} - p] + (1-\phi_c)(w_{us} - a_{us}) + \phi_c v_c \tag{6}$$

Rearranging as before, and taking a derivative:

$$PT\ PPI\ (\beta_C^{PPI}) \equiv \frac{\partial p_{Rus}}{\partial rer_c} = \underbrace{\frac{\Gamma}{1+\Gamma}\frac{\partial p_R}{\partial rer_c}}_{PT\ via\ markups} + \underbrace{\frac{\phi_c}{1+\Gamma}}_{PT\ via\ Imported\ Costs} \tag{7}$$

Testable Prediction 3. Positive PT of competitors'/third country RERs to US producer prices ($\beta_C^{PPI} > 0$): *US producer prices will respond positively to an appreciation of the foreign exchange rate (Equation 7).*

Testable Prediction 3 states that the same mechanisms identified above should lead to pass-through of competitors' RERs to US producer prices. This depends on US firms responding to the sectoral price ($\Gamma/(1+\Gamma) > 0$), and the sectoral price responding to foreign RERs ($\partial p_R/\partial rer_c > 0$), or alternatively US firms using imported intermediates, $\phi_c > 0$ (as $\partial v_{Rc}/\partial rer_c = 1$). The reduced form markup elasticity Γ is a function of model primitives (such as market shares) and is likely to vary across foreign and domestic producers.

2.5. **Pass-through of foreign competitors' prices.** Returning to the three-country model, let p_{Rc}^{FCP} be the sub-component of the sectoral price denoting the log price index of foreign competitors from country c. Define pass-through of foreign competitors' prices (FCP) as $\beta_{FCP} \equiv \partial p_{Ri}/\partial p_{Rc}^{FCP} = [\Gamma/(1+\Gamma)]\,\partial p_R/\partial p_{Rc}^{FCP}$.

Testable Prediction 4. ***Positive PT of foreign competitors' prices (β_{FCP}>0)*** *If pass-through of competitors' RERs is driven by the first term in Equation 3, one should also expect positive pass-through of foreign competitors' prices (and vice versa).*

Testable Prediction 4 follows from using the chain rule to rewrite the first term on the RHS of Equation 3 as $[\Gamma/(1+\Gamma)]\left[\partial p_R/\partial p_{Rc}^{FCP}\right]\left[\partial p_{Rc}^{FCP}/\partial rer_c\right]$. The final term is sector-level bilateral pass-through for country c, which is usually positive, and the first terms are pass-through of foreign competitors' prices. An analogous condition can be written for pass-through of foreign competitors' prices to US producer prices. One can test the mechanism in the model by estimating pass-through of foreign competitors' prices to US import and producer prices.

Note that pass-through of all import competitors' prices (as in GI2011) is not a sufficient condition for pass-through of competitors' RERs in Equation 3, though it is consistent with the general mechanism. While it is natural that firms will respond to their own relative costs ($\partial p_{Rc}^{FCP}/\partial rer_c > 0$), in sectors dominated by other importers from the same country, it is possible that $\partial p_R/\partial p_{Rc}^{FCP} \approx 0$, and so it is possible to get sizable pass-through of import competitors' prices without getting PT of foreign competitors' prices. I test pass-through of different components of the sectoral price in Section 6.

3. Main Empirical Results

Box 1: Summary of four testable predictions from the simple model (Section 2) and associated empirical stylized facts (see Section 5 for a quantitative comparison of the full model and data).

Testable Prediction 1: An appreciation of competitors' exchange rates should increase US import prices.
Evidence: Significant pass-through of competitors' exchange rates to US import prices, with a 1% increase in competitors' exchange rates associated with a 0.35% increase in import prices in the preferred specification — larger than estimated bilateral pass-through.

Testable Prediction 2: The coefficient on the bilateral RER will be "biased upwards" in univariate regressions, with bilateral pass-through falling when competitors' RERs are added as a control.
Evidence: When competitors' RERs are added as a control, bilateral pass-through falls by around a third (7ppts).

Testable Prediction 3: An appreciation of competitors' exchange rates should increase US producer prices.
Evidence: Significant pass-through of competitors' RERs to US producer prices: a 1% rise in competitors' RERs increases US producer prices by about 0.11% in the preferred specification.

Testable Prediction 4: An increase in *foreign* competitors' prices should increase (a) US import prices and (b) US producer prices.
Evidence: A 1% increase in foreign competitors' prices (in the same sector) raises import prices by 0.6% and US producer prices by 0.2% and lowers estimates of pass-through of competitors' RERs.

3.1. **Data.** I use confidential monthly US import and producer price data from the Bureau of Labor Statistics (BLS), which are measured at the individual good level for manufacturing sectors (NAICS31-33). I calculate changes in log prices over the life of the good in the sample (conditional on a price change) which Gopinath and Itskhoki (2010) argue is able to uncover the long-run structural pass-through coefficients in a menu cost model.[8] The sample is 1992-2007 for import goods from the top 10 US trade partners (which represent around 2/3 of US imports) and 1994-2006 for US producer prices. All prices are real (deflated by the US CPI). I drop the top and bottom 1% outliers. For US producer prices regressions, I control for materials costs (domestic and imported) using NBER-CES materials costs index in the same NAICS 6 digit sector. Unfortunately, I have no good data on source imported materials prices for import prices regressions, though I tried a few unsatisfactory proxies (see Section 3.5 for a discussion).

Competitors' RERs are the import-weighted average of bilateral RERs of all countries importing to the US in the same NAICS 6d sector (excluding the bilateral RER for import price regressions). The index of *foreign* competitors' prices is constructed from import price microdata from the same NAICS 6d sector using a similar method as GI2011 (though I remove prices of other goods from the same exporting country). Compatriots' prices are constructed from BLS microdata in a similar manner and aggregate US producer price indices by NAICS 6d sector are taken from the BLS website (both introduced in Section 6). See the appendix for more detail on data sources and the construction of key variables.

3.2. **Pass-through of competitors' RER to import prices.** I estimate Equation 8, with the results shown in Table 1 in columns 1-4 (change in log prices over the life of the good, conditional on a price change). $p_{R,ijk}$ is the log real import price from country i of firm k in sector j, rer_i is the log bilateral RER (for country i with the US), rer_c is log competitors' RER index across competitor countries c (which varies by importer and sector), p_{Rj}^{FCP} is the log real foreign competitors' price index. X includes a time trend, the life-length of the good and the growth rate of US GDP (as is common in the literature: Campa and Goldberg 2005; Gopinath et al 2010).

$$\Delta p_{R,ijkt} \quad = \quad \alpha_{i,j} + \beta_{BI}\Delta rer_{it} + \beta_c \Delta rer_{ct} + \beta_{FCP}\Delta p_{R,jt}^{FCP} + \Lambda X + e_{ijkt} \tag{8}$$

Table 1 (column 1) is the standard pass-through regression in the literature, with an estimate of measured bilateral pass-through of $\beta_{BI} = 0.23$ (a real appreciation of the producer's currency by 1% raises import prices

[8] The specification is designed to get the data as close to the model as possible: conditioning on price changes removes nominal rigidities in the firm's own price, and having a long period removes the effect of other firms' nominal rigidities through complementarities in pricing.

by 0.23%). As others have found, pass-through of the bilateral exchange rate is very low, even conditioning on a price change and over a long period, and is hard to justify using standard models.[9] Column 2 estimates the baseline specification for competitors' exchange rates, where $\beta_c = 0.35$ is large and highly statistically significant, verifying Testable Prediction 1. Moreover, pass-through of competitors' exchange rates is larger than pass-through of the bilateral rate that is standard in the literature. This suggests that a fall in the USD against a range of competitor currencies is associated with a much larger increase in import prices than a fall in the USD relative to only the producers' currency. Results in column 2 show that the addition of competitors' RERs leads to a reduction of bilateral pass-through by around 1/3 to $\beta_{BI} = 0.16$, verifying Testable Prediction 2. That is, measured bilateral pass-through is likely to be upward biased (as defined in Section 2) if one does not control for competitors' RERs.

3.3. **Pass-through of competitors' exchange rates to producer prices.** I estimate Equation 9 with the results displayed in Table 1 columns 5-8 (change in log over the life of the good, conditional on a price change). $p^{PPI}_{R,jk}$ is the real log US producer price, $rer_{c,t}$ is log competitors' RER (for all importers in the sector), $p^{FCP}_{R,jt}$ are the log real foreign competitors' prices, p^{M}_{Rjt} are log real US materials prices in the same sector j (some of which might be imported). X includes a time trend, the life-length of the good and the growth rate of US GDP as controls.

$$\Delta p^{PPI}_{R,jk} \quad = \quad \alpha + \beta^{PPI}_c \Delta rer_{ct} + \beta^{PPI}_{FCP} \Delta p^{FCP}_{R,jt} + \delta^{PPI}_M \Delta p^{M}_{R,jt} + \Lambda X + e_{jkt} \tag{9}$$

In the baseline specification (column 5), a 1% increase in competitors' exchange rates in a sector is associated with a statistically significant 0.11% increase in US producer prices (verifying Testable Prediction 3; $\beta^{PPI}_C = 0.11$). A 1% increase in materials prices (a control variable) is associated with a 0.5% increase in US producer prices ($\delta^{PPI}_M = 0.5$). The average share of materials costs across sectors in the US Producer Price Index (PPI) data is about 50%, which is broadly consistent with the estimated coefficient.[10] Column 6 shows that when materials prices are removed as a control, $\beta^{PPI}_c = 0.34$, which is very large. Goldberg and Campa (2010) argue that the aggregate CPI in the US is insensitive to exchange rates, which puts an upper bound on the degree of pass-through to producer prices. The higher estimate might be due to other variables: movements in materials prices could be correlated with competitors' RERs due to (i) imported intermediates or (ii) other shocks (e.g. oil prices) that jointly affect materials prices and RERs.[11]

3.4. **Pass-through of foreign competitors' *prices*.** Consistent with the simple model, importing firms respond strongly to the *prices* of their foreign competitors, and this reduces the explanatory power of competitors' exchange rates. In columns 3-4 and 7-8 of Table 1, I add foreign competitors' prices to import and producer price regressions (respectively) as an additional control. A 1% increase in foreign competitors' prices increases import prices by about 0.6%, verifying Testable Prediction 4(a).

US producer prices also respond to changes in the prices of foreign firms importing in the same sector. When I control for foreign competitors' prices in the same sector for the PPI regressions (columns 7-8), I find that a 1% increase in the price of a producers' foreign competitors is associated with a 0.16% increase in US producer prices (verifying Testable Prediction 4(b)). One explanation of the smaller coefficient (relative to that for importers) is that most US firms tend to be in sectors where they compete with other US firms, reducing the sensitivity of the sectoral price to foreign competitors' prices (this is also consistent with the lower estimate of β^{PPI}_C).

[9]GI2011 estimate lifelong pass-through at 0.31 for all goods, Burstein and Gopinath (2014) estimate 0.28, and Gopinath and Itskhoki (2010) estimate life-long pass-through between 0.21 (for low frequency goods) to 0.44 (for high-frequency goods). My estimate of $\beta_{BI} = 0.23$, is at the low end of this range, but that is mostly due to the inclusion of controls for US GDP growth as well as time/length trends. Without these additional controls, $\beta_{BI} = 0.29$ ($t = 5.4$), which is almost identical to the estimated coefficient from GI2011 and Burstein and Gopinath (2014). See the online appendix for additional robustness tests.

[10]Additional regressions (not reported) show that the coefficient on materials costs is larger for firms in high materials share sectors (0.78) than low materials share sectors (0.28), with the difference being statistically significant at the 1% level.

[11]The estimates of β_C are much smaller (0.04) without controlling for GDP growth, date and life-length (see online appendix for further details). The coefficient on GDP is positive and significant, the coefficient on life-length is negative and significant and the time trend is usually insignificant which suggests that US producers might price differently over the business cycle or over time.

Table 1. Main empirical results

Dependent Vble:	Real US Import Prices				Real US Producer Prices			
(Δp over life of good)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Bilateral RER (β_{BI})	0.23*** [4.5]	0.16*** [3.0]	0.15*** [3.3]	0.12** [2.6]	-	-	-	-
Competitors' RER (β_C)	-	0.35*** [3.9]	-	0.19*** [3.0]	0.11*** [6.6]	0.34*** [22.8]	-	0.09*** [3.7]
Foreign Comp Prices (β_{FCP})	-	-	0.58*** [8.0]	0.55*** [7.6]	-	-	0.16*** [13.2]	0.16*** [13.0]
US Materials Prices (δ_M)	-	-	-	-	0.49*** [24.7]	-	0.41*** [17.0]	0.38*** [14.6]
Observations	4953	4950	4573	4570	50513	50541	26934	26934

Notes: Robust t-statistics are in brackets. ***,**,* indicate significance at the 1, 5 and 10 per cent levels. 1% tails dropped. All import price specifications include BLS primary lower stratum × country fixed effects, with standard errors clustered at this level. Both empirical specifications include controls for US GDP growth over the life of the good, date and life-length controls (not reported). With a common sample (including foreign competitors' prices), estimates are very close to those in columns 2 and 5.

3.5. **Markup variation or imported intermediate inputs?** In the simple model, Equation 3 and Equation 7 show that third country RERs affect import and producer prices (respectively) via two channels: (i) a change in competitors' prices which affects markups, and/or (ii) changes in the cost of imported intermediates from competitor countries which affect marginal costs.

For US producer prices, I can account for imported intermediates by controlling for US materials prices at the NAICS 6 digit level. If an appreciation of foreign competitors' currencies raises imported intermediate costs, this will be reflected in total materials costs. Controlling for US materials prices in Table 1 reduces estimated pass-through of competitors' exchange rates to US producer prices by $2/3$ (from 0.34 to 0.11). This suggests that either the imported intermediates are quite important in explaining the univariate relationship between US producer prices and competitors' exchange rates; or alternatively other variables (like global business conditions) affect materials prices, competitors' RERs and US producer prices jointly.

For import prices, distinguishing between these two channels is difficult because I don't have good data on imported intermediate goods prices by foreign country of origin.[12] It is also difficult to know the importance of imported intermediates based on aggregate imported intermediate shares. As an extension in Appendix C, I incorporate intermediate inputs in the quantitative model, and show that the extent to which imported intermediates boost pass-through of competitors' RERs is sensitive not just to the total share of imported intermediates, but to the source country of the intermediates. For example, if intermediates are sourced from the US or from countries which are not competitors, bilateral RER pass-through is affected but pass-through of competitors' RER might not be. Moreover, the total imported intermediate share varies substantially across countries (Figure 4), so it is unwise to rely too much on data from one country.

An alternative approach is to measure the effect of adding foreign competitors' prices to the regression directly. Comparing Column 2 and Column 4 of Table 1, one can see that adding foreign competitors' prices as a control almost halves pass-through of competitors' exchange rates — however a residual effect is still significant and sizable. If foreign competitors' prices were a sufficient statistic for the markup channel, one could argue that around half of the original $\beta_C = 0.35$ coefficient were due to changes in markups via competitors' prices, and the other half due to changes in marginal costs due to imported intermediates. However, foreign competitors' prices are likely to be measured with some error (e.g. sampling error, or the

[12] I tried several imperfect proxies, which were either inconclusive, or failed to point to a large role of imported intermediates. Specifically, I tried to construct imported intermediate weights using the World Input Output Database (WIOD.org) and then create an imported-intermediate-weighted exchange rate (IIWER). However, the IIWER was highly collinear with competitors' RERs, leading to over-fitting when both variables were added to the regression. In an earlier draft, I also tried interacting the coefficients of interest with a dummy variable if the country × two-digit sector had an above average imported intermediate share (using data from OECD STAN). The interactions terms were insignificant.

difficulty of defining a sector), and so even the residual β_C could include some effects of variable markups. Moreover, some of the effects of competitors' RERs might be working through compatriots or US producer prices — when I add these as additional controls in Section 6, the competitors' RER variable becomes insignificant.

3.6. **The TWI and Comparison with Gopinath and Itskhoki (2011).** GI2011 focus on the extent of real rigidities in pricing, but have two related results — both of which are consistent with evidence presented here.

First, they show that pass-through of the TWI (orthogonal to the bilateral rate) to import prices is large. The TWI can be considered an alternative measure of competitors' RER (correlation around 0.8), which doesn't vary according to the structure of competition in the sector or by the producing country.[13] GI2011 do not examine the effect on bilateral pass-through of controlling for competitors' RER or the TWI, as they orthogonalize the TWI first. In the online appendix, I investigate the extent to which one would get similar results by approximating competitors' RERs with the TWI. For import prices, pass-through of the TWI is larger than β_c in Table 1, and bilateral pass-through is slightly lower (in part because the TWI includes the bilateral rate), but in general the results are similar (particularly after down-weighting influential observations). For producer price regressions, the TWI is highly correlated with US materials prices in the data, resulting in collinearity problems that one doesn't get using my measure of competitors' RERs. However, when materials prices are excluded, results are similar to those using the default measure of competitors' RERs. In the quantitative model (Sections 4 and 5), the TWI is a good approximation of competitors' RERs in both import and producer price regressions.

Second, GI2011 regress import prices on the prices of *all other* importing firms in the same sector (foreign and other compatriot firms combined) and find a large estimated coefficient of around 0.6. They also estimate (but do not discuss) a fall in bilateral PT from 0.3 to 0.15 when their measure of competitors' prices is added to a standard PT regression. As discussed in Section 2, GI2011's estimates are consistent with either high or low pass-through of foreign competitors' RER depending on the sensitivity of the sectoral price to foreign competitors' prices. However, the large coefficient on competitors' prices suggests an important role for variable markups more generally.

3.7. **Robustness.** In the online appendix, I present some robustness tests of the main empirical results in Table 1 using different specifications. In general, the key findings (Testable Predictions 1-4) are fairly robust, though estimated coefficients do vary a little. For import price regressions, I experiment with (i) dropping FE/clustering, (ii) a robust regression (which downweights influential observations), and (iii) dropping controls (GDP, life-length and the time trend). If anything, these variations usually increase the size of pass-through coefficients (β_{BI}, β_C and β_{FCP}).

For producer price regressions, I experiment with (i) adding FE/clustered standard errors at the NAICS3d level, (ii) a robust regression, and (iii) dropping controls (GDP, life-length and the time trend). The main differences (respectively) are (i) larger standard errors;[14] (ii) estimates of β_C^{PPI}, δ_M^{PPI} and β_{FCP}^{PPI} are smaller though still significant; (iii) when materials prices are added as a control, the estimate of β_C^{PPI} is smaller but still significant (and unchanged in the univariate regression).

4. Full Quantitative Model

While the model in Section 2 produces several *qualitative* predictions which I test empirically, it says nothing *quantitative* about whether these mechanisms are powerful enough to explain the estimates in the data. To do that, we need to take a stand on a particular microfoundation for the reduced-form relations in Section 2, and apply a parametrization in a full quantitative model. The full model is a multi-country extension of AB and features (i) a nested CES structure with goods that are more substitutable within sectors than between them, and (ii) a small number of firms in each sector that engage in Cournot competition. A linearized version has the same reduced form as the general class of model in Section 2: where firms respond to competitors' prices. Solving for those prices generates a linear "structural pass-through" equation where

[13] Quantitatively, GI2011's estimates of pass-through of the TWI are smaller, in part because they estimate pass-through conditional on a price change, rather than over the life of the good.

[14] Without materials prices, competitors' RERs are still significant at the 1% level, though with materials prices the p-value on competitors' RERs increases to 5.4%. Foreign competitors' prices are significant at the 10% level, though to some extent this reflects over-fitting with materials prices (which also are significant at the 10% level).

the firm responds to its own bilateral exchange rate and the exchange rates of its competitors. A version of this equation is estimated on simulated data. A detailed description of the model is in the online appendix.

Relative to AB, the key changes are (i) an increase in the number of countries to $\bar{C} = 11$ (US + 10) countries or $\bar{C} = 3$ symmetric countries in order to study multi-country competition, (ii) a slight change in the parametrization to reflect new estimates in the literature and the multi-country pass-through application, and (iii) a focus on a partial equilibrium (PE) case in the body of the paper with exogenous (but correlated) movements in real exchange rates. In an extension in the online appendix, I calculate pass-through in a three-country symmetric general equilibrium (GE) version of the model. As foreshadowed by AB in their conclusion, the partial equilibrium results are almost identical to the general equilibrium results.

AB show that a nested CES structure, quantity competition and a small number of firms per sector means the elasticity of demand faced by each firm is conceptually similar to a weighted average of the low inter-sector elasticity η and the higher intra-sector elasticity $\rho > \eta$, where the elasticity faced is decreasing in the firm's sector share (s_{jk}) (Equation 10).

$$\sigma(s_{ijk}) = \left[\frac{1}{\rho}(1 - s_{ijk}) + \frac{1}{\eta}s_{ijk}\right]^{-1} \tag{10}$$

In the model, the price of a good produced by firm k in sector j in country i (sold in the US) is a markup over marginal cost, given by Equation 11. Country-level unit labor costs (wages relative to TFP W_i/A_i) move to generate variation in unit labor cost based RERs, which affect firm sector shares s_{ijk} and prices p_{ijk}. However, the sector-specific iceberg trade cost D_{ij} and the firm-level productivity z_{ijk} are constant away from steady state. I also assume that the imported intermediate share is zero ($\phi = 0$), but relax this assumption in Appendix C.

$$p_{ijk} = \frac{\sigma(s_{ijk})}{\sigma(s_{ijk}) - 1}\left[\frac{W_i}{A_i}\right]\left[\frac{D_{ij}}{z_{ijk}}\right] \tag{11}$$

I log linearize Equation 11, which after some rearrangement yields Equation 12, where movements in firm k's optimal price are a weighted average of movements in *competitors' prices* $\sum_{k' \neq k} \frac{s_{ijk'}}{(1-s_{ijk})}\hat{p}_{ijk'}$ (because this affects the firm's market share) and its own marginal cost ($\hat{w}_i - \hat{a}_i$). Note this is the same form as in the simple model, but here Γ' will be a function of the firm's market share and model primitives.[15]

$$\hat{p}_{ijk} = \frac{\Gamma'}{1+\Gamma'}\sum_{k' \neq k}\frac{s_{ijk'}}{[1 - s_{ijk}]}\hat{p}_{ijk'} + \frac{1}{1+\Gamma'}b_{ijk}[\hat{w}_i - \hat{a}_i] \tag{12}$$

Solving Equation 12 for the set of prices in each sector and subtracting US unit labor costs $\hat{ulc}_{US} = [\hat{w}_{US} - \hat{a}_{US}]$ from both sides yields the structural pass-through Equation 13 for each importer in the sector. The equation for US firms is similar (Equation 14). The structural β-coefficients β_{ijk} and β^{PPI}_{ijk} are a non-linear function of the firm's market share, the distribution of market and import shares in the sector, as well as model primitives such as elasticities η and ρ.

$$\hat{p}^{IMP}_{ijk} - \hat{ulc}_{US} = \beta_{ijk}\left[(\hat{w}_i - \hat{a}_i) - \hat{ulc}_{US}\right] + \sum_{i' \neq US, i}\beta_{i'jk}\left[(\hat{w}_{i'} - \hat{a}_{i'}) - \hat{ulc}_{US}\right] \tag{13}$$

$$\hat{p}^{PPI}_{USjk} - \hat{ulc}_{US} = \sum_{i \neq US}\beta^{PPI}_{ijk}\left[(\hat{w}_i - \hat{a}_i) - \hat{ulc}_{US}\right] \tag{14}$$

On the left hand sides of Equation 13 and Equation 14 are import and US producer prices (respectively, at the firm level) relative to US ULCs. On the right hand sides are unit labor cost-based real exchange rates — which is just the cost of a productivity-adjusted unit of labor in the foreign country (relative to the US), measured in a common currency. An appreciation of the RER of the foreign country *increases* the price of foreign labor relative to that in the US, and so increases $(\hat{w}_i - \hat{a}_i) - \hat{ulc}_{US}$. The first term in brackets on the right of Equation 13 is the bilateral ULC-based real exchange rate between the producing country and

[15]Here $\Gamma' = \Gamma_{AB}(s_{ijk}) \times [\rho - 1][1 - s_{ijk}]$ where $\Gamma_{AB}(s_{ijk}) = s_{ijk}(\eta^{-1} - \rho^{-1})/(1 - \rho^{-1}(1 - s_{ijk}) - \eta^{-1}s_{ijk})$

the US. The other terms on the right hand side are the "competitors' exchange rates" which appear very naturally in the model. In Equation 14 (producer prices) there is no bilateral exchange rate, so all of the exchange rates are those of foreign competitors.[16]

With many countries, the specification in Equations 13 and 14 will have a large number of estimated coefficients — and so each coefficient is likely to be estimated imprecisely. Instead, I use a *summary measure* to capture the effects of competitors' RERs. Let $\tilde{\beta}_C = \sum_{i' \neq US,i} \beta_{i'jk}$ (equivalently $\tilde{\beta}_C^{PPI} = \sum_{i \neq US} \beta_{ijk}^{PPI}$ for producer prices). It turns out that the relative size each competitors' structural β -coefficient is almost identical to the country's sectoral import share, i.e $\beta_{i'jk}^{PPI} / \sum_{i \neq US} \beta_{ijk}^{PPI} \approx S_{i'j}^{C,PPI}$. In the three-country model for PPI for example, $\beta_{i'jk}^{PPI} / \sum_{i \neq US} \beta_{ijk}^{PPI}$ and $S_{i'j}^{C,PPI}$ line up almost exactly along the 45-degree line with a correlation of over 98% (the analogous figure for import prices is similar). As such, I can replace $\beta_{i'jk}$with $\tilde{\beta}_C S_{i'j}^C$ and $\beta_{i'jk}^{PPI}$ with $\tilde{\beta}_C^{PPI} S_{i'j}^{C,PPI}$ which yields Equations 15 and 16, which can be taken to the data. The final term in each of these equations is the *import-weight exchange rate for the sector*, which excludes the bilateral RER for the import price Equation 15 (with weights rescaled so they add to one). This is a measure that I construct in each sector in the model and in every 6 digit NAICS manufacturing sector in the data (see Appendix B).

$$\hat{p}_{ijk}^{IMP} - \hat{ulc}_{US} = \beta_{BI} \left[(\hat{w}_i - \hat{a}_i) - \hat{ulc}_{US} \right] + \tilde{\beta}_C \sum_{i' \neq i} S_{i'j}^C \left[(\hat{w}_{i'} - \hat{a}_{i'}) - \hat{ulc}_{US} \right] \tag{15}$$

$$\hat{p}_{USjk}^{PPI} - \hat{ulc}_{US} = \tilde{\beta}_C^{PPI} \sum_{i} S_{ij}^C \left[\hat{w}_i - \hat{a}_i - \hat{ulc}_{US} \right] \tag{16}$$

To generate estimates of pass-through of competitors' exchange rates in the model (to compare to the data) I first solve the full model in steady state and calculate the set of structural β coefficients. Then I draw a sample of exchange rates, use Equation 13 and 14 to generate a vector of firm-level prices, and then estimate variants of Equations 15 and 16 on the simulated data (sampling in proportion to size) — see the online appendix for further details.[17]

4.1. **Calibration.** The calibration of the model is challenging due to the absence of microdata on quantities (and hence sector shares) in the BLS data on the demand side, as well as the lack of firm-specific information in the many producing countries on the supply side (for example the share of intermediates in costs, and their source). Moreover, there is also the challenge of defining a "sector" — which will determine the number of firms as well as elasticities of demand — both of which are important determinants of the firms' pricing behavior. In all reasonable calibrations the model has difficulty matching the extreme degree of incomplete pass-through estimated in the data. However, these are common problems in the literature and my parameters are reasonably standard, though these challenges should be noted as a caveat.

There are two calibrations of the model used in the paper (parameters are listed in Table 2). The first is the baseline asymmetric calibration with 11 countries (US+10), which is the closest to the estimated data. In each sector, I keep the number of US firms the same as AB ($K_{US} = 20$), but set $K = 3$ firms per foreign

[16]One can also derive a related structural pass-through equation with firm market shares on the LHS. I don't have data on firm-level market shares to test this relationship, but it is an interesting area for future research. A previous draft of this paper also investigated the relation between changes in country shares and exchange rates, with mixed results. As mentioned in the introduction, this model belongs to a class of model that has difficulty in matching both short-run and long-run responses of quantities to exchange rates.

[17]Amiti et al (2016) argue that OLS estimation of the response to competitors' prices in structural equations like Equations 2 or 12 will be biased due to the correlation between unobserved idiosyncratic demand shocks (in the error term) and competitors' prices via the price setting game. They provide several instruments for competitors' prices, one of which is foreign exchange rates, which they argue will be uncorrelated with local demand shocks. This suggests that estimated pass-through of competitors' exchange rates in Equations 15 and 16 will also be unbiased, because exchange rates are plausibly exogenous to firm/sector level demand shocks. While estimates of pass-through competitors' prices such as those in Equation 8 might be biased in theory, the IV and OLS estimates of the coefficient on Δp_{-it} in Amiti et al (2016) are fairly close, which suggests that in practice the size of the bias is reasonably small.

Table 2. Calibration

A. Universal Parameters				**Target/Source**
$\rho = 10.5$ (Within Sector Elasticity)				EMX(2015) based on Taiwanese Manf. Data.
$\eta = 1.24$ (Between Sector Elasticity)				
$\theta = 0.385$ (Firm prod. log-normal SD)				AB(2008)
$D_j \in \{1, 1.5, 2\}$ $w.p$ 1/3 (Sectoral Iceberg trade cost)				Distrib. import shares (Feenstra & NBER Manf Data)
B. Parameter/Equilibrium Object	**US+10C Model**	**3C Model**	**Data/Target**	**Source**
K_{US} (US firms/Sector)	20	15	-	Average size of trade partners GDP relative to US
K (Foreign Firms per Country per sector)	3	15	-	
Sales-weighted ave markup	31%	32%	30%	AB (2008), value used in literature
Import share	28%	34%	28%	Feenstra & NBER Manf Data
Import-weighted ave import share	55%	58%	48%	
Median Herfindahl	0.165	0.17	0.1-0.18; 0.26	DoJ "Moderately Concentrated" (AB); EMX#
Sales-weighted demand elasticity	5.3	5.2	≈5	Gopinath & Itskhoki (2010)/Broda & Weinstein (2006)
Mean share of largest dom. firm in sector	0.27	0.27	0.12-0.45	Amiti et al (2016) - EMX (2015)
# calc from median inverse Herf				

country, since the average of the top 10 US trade partners' GDP is approximately 3/20th that of the US.[18] The second calibration is a three-country symmetric model which can be simulated in general equilibrium, and is used to study the correlation of exchange rates. In the body of the paper the three-country model is simulated in PE (GE in the online appendix).

I set $K = K_{US} = 15$ in the three-country model to keep the number of firms per sector close to the number considered in AB (45 here, 40 in AB). The standard deviation (and distribution) of firm productivity is taken from AB (where $log(z_{jk}) \sim N(0, \theta^2)$ and $\theta = 0.385$). I set the iceberg cost of exporting to be $D = 1$, 1.5 or 2 per sector (with equal probability) in order to match the aggregate import share in the US manufacturing data of 0.28, and also (approximately) the distribution of import shares, as measured by the average import-weighted import share of around 0.5.[19] The fact that the import-weighted average import share is higher than the total import share suggests that imports are concentrated in particular sectors, which is important for the mechanism in the model.[20]

I calibrate the process of simulated RERs to match those in the data (in the GE model in the online appendix RERs are driven by TFP shocks). For the US+10 country calibration, I estimate the variance-covariance matrix of the RERs of the same top 10 trade partners as in the empirical work. For the symmetric three-country model, I calibrate the RER process to match the correlation of the bilateral RER and competitors' RERs of ≈ 0.4 (with equal RER variances) in the sample of countries and time period in the empirical component.[21]

Elasticities Two of the most important parameters to calibrate in the AB model are the within-sector (ρ) and between-sector (η) elasticities, because the *gap* between η and ρ determines the strength of the variable markup mechanism (in trade models with fixed markups $\eta = \rho$). I discipline the size of this gap based on evidence from Edmond, Midrigan and Xu (2015; henceforth EMX), who note that Equation 10 and Equation 11 imply a *linear* relationship between the inverse markup μ_{ijk}^{-1} and market share s_{ijk}, such that $\mu_{ijk}^{-1} = b_0 + b_1 s$ where $b_0 = (\rho - 1)/\rho$ and $b_1 = -\left(\eta^{-1} - \rho^{-1}\right)$. EMX estimate b_0 and b_1 using Taiwanese manufacturing data and use the ratio $\hat{b}_1/\hat{b}_0 = -0.78$ which pins down a tight relationship of $\eta = [\rho^{-1} + 0.78(\rho - 1)/\rho]^{-1}$. I take a

[18]The average of nominal GDP of Canada, China, Mexico, Japan, Germany, United Kingdom, Republic of Korea, France, Hong Kong SAR China, and Brazil in 2010 USD at market exchange rates (from IMF, World Economic Outlook Database, April 2011). The average is 3.6/20 of that of the US, but I round down to 3 firms per country per sector to keep the aggregate number of firms as close to AB who have 40 firms per sector.

[19]These two statistics are calculated using 2005 import and export data from Feenstra's trade database and 2005 manufacturing production from the NBER manufacturing database for 371 matched NAICS 6d sectors which had import, export and US production data.

[20]In contrast, AB set $D = 1.45$ to match the average of import and export shares over 1987-2003 of 16.5%. The discrepancy between my figure and that of AB can be explained by (i) manufactured imports greater than exports, and (ii) the share of manufactured imports trending up over time.

[21]For the US+10 country sample, I calculate changes in RERs over overlapping three year periods, as this is halfway between the average life-length of goods in the IPP and PPI samples. The resulting correlation in the US+10 country model between bilateral and competitors' RERs is 0.3, which is slightly lower than the empirical sample (and results in a smaller bias of univariate bilateral PT). Depending on weights of different countries in the sample, this correlation is between 1/4-1/2. As the competitors' RER averages across multiple RERs, it usually has a SD 1/2-2/3 as large as the typical bilateral RER SD.

value of $\rho = 10.5$ from EMX, which implies $\eta = 1.24$ (similar to the values of $\rho = 10$ and $\eta = 1.01$ from AB). My model also does well in matching the sales-weighted demand elasticity of around 5 (targeted by Gopinath and Itskhoki (2010), based on Broda and Weinstein (2006)). The GE version of the model produces a trade elasticity in the range estimated in the literature (see the online appendix).

Concentration The value of ρ, combined with other parameters, yields a median sectoral Herfindahl index of around 0.165, in the "moderately concentrated" range of 0.1-0.18 according to the Department of Justice (as reported in AB). A much higher (lower) value of ρ leads to much higher (lower) concentration statistics, outside the DoJ's moderate range. The level of concentration depends on the size of the sector one seeks to represent. In the empirical work I calibrate to 6 digit industries, so I would expect concentration statistics in between those of 4 digit industries of Amiti et al (2016) and 7 digit industries of EMX. The only concentration statistic reported by both papers is the mean share of the top domestic firm, which is around 0.45 in EMX and 0.12 in Amiti et al. In my calibration, the mean share of the top US firm is 0.27, which is almost exactly in the middle of EMX and Amiti et al's estimates. My Herfindahl index is also lower than the 0.26 reported in EMX. As higher levels of concentration are associated with more variable markups, my calibration can be considered conservative.

5. Simulation Results (and comparison to data)

5.1. **PT of competitors' RERs to simulated import and producer prices.**

Estimates of exchange rate pass-through on *simulated* data are shown in Table 3. Using the preferred US+10 country model (Panel A), one can see that a 1% appreciation of the bilateral exchange rate raises import prices by 0.65% in the bivariate specification.[22] Note that bilateral pass-through is well above that estimated in the data, which is a well-known puzzle in the literature.

A 1% appreciation of competitors' exchange rates in the model increases import prices by around 0.15% in the US+10 country specification (Table 3 column 2), showing that Testable Prediction 1 holds in the quantitative model. While this is a good deal lower than the estimate in the data of 0.35, (i) the estimates in the data might include some effect of imported intermediates, which are absent from the baseline model and (ii) estimates here are much larger than pass-through of competitors' RERs in standard models (which is zero). As in the data, the addition of competitors' exchange rates *reduces* bilateral pass-through, suggesting that measured pass-through is biased upwards (Testable Prediction 2). Quantitatively, the bias is 0.025 — a good deal smaller than in the data — mostly because pass-through of competitors' RERs in the model is also smaller than in the data.

For US producer prices, a 1% increase in competitors' RERs implies a 0.09% increase in simulated US producer prices (Table 3, column 4). These coefficients are very similar to those estimated in data, where a 1% increase in competitors' exchange rates lead to a 0.11% increase in US producer prices.

In the model, pass-through of competitors' RERs works through pass-through of foreign competitors' *prices.* In the US+10 country model, a 1% increase in foreign competitors' prices leads to a 0.19% increase in simulated import prices and a 0.11% increase in simulated producer prices (Table 3, columns 3 and 5 respectively). The estimates in the model are a good deal smaller than those in the data, which might reflect (i) a lower general responsiveness to competitors' prices in the model ($\Gamma/(1+\Gamma)$ is too small) and/or (ii) the absence of sector specific-shocks in the model (for example, sector-specific technology shocks) which would be reflected in competitors' prices, but not competitors' RERs. The addition of these shocks would be an interesting area for future work.[23]

Relative to the US+10 country calibration, the three-country symmetric model has (i) a larger own country import share (for importers), (ii) a smaller foreign competitors' share (for importers) and (iii) a larger total import share. Panel B of Table 3 shows estimates in the three-country symmetric model that are generally similar to the US+10 country calibration, but differences (i)-(iii) respectively imply (i) slightly higher bilateral pass-through for importers, (ii) slightly lower pass-through of competitors' RERs for importers, and (iii) slightly higher pass-through of competitors' RERs for US producer prices.

The estimated rates of pass-through in Table 3 are very similar to the relevant structural β-coefficients averaged across individual firms. Figure 2 plots the structural β_{BI} (LHS, bilateral PT) and $\tilde{\beta}_C$ (RHS, competitors' PT) for each *sampled* importing firm using the three-country model (vs the firm's sector share).

[22] Standard errors are usually tiny (and arbitrary), so I don't report them.

[23] As exchange rates are the only driver of prices in the model, competitors' prices and competitors' exchange rates are highly co-linear and I get over-fitting when trying to include both in the regression (not reported).

Table 3. Pass-through of competitors' RERs (model)

	A. US+10 Foreign Country PE					B. 3 Country Symmetric PE				
Dependent Variable:	Import Prices			US Producer Pr		Import Prices			US Producer Pr	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Bilateral RER	0.65	0.63	0.62			0.75	0.71	0.70		
Competitors' RER		0.15		0.09			0.11		0.13	
Foreign Comp. Prices			0.19		0.11			0.14		0.15

Note: coefficients from regressions of simulated producer/import prices on simulated RERs.

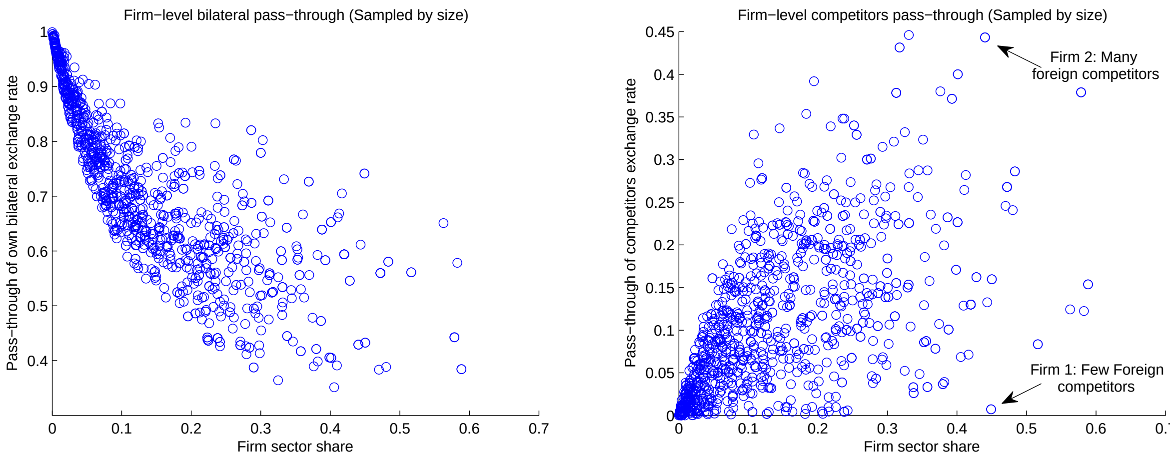

Figure 2. Bilateral β_{BI} (LHS) and competitors' PT β_C (RHS) by firm size (3 country model)

The "average" bilateral pass-through coefficient β_{BI} is around 0.7 and the average competitors' PT coefficient $\tilde{\beta}_C$ is around 0.1, almost identical to the corresponding estimates in Column (7) of Table 3.

From Figure 2, one can see that all small firms have high bilateral pass-through and low competitors' ER pass-through. On average, large firms tend to have lower bilateral pass-through, and higher pass-through of competitors' exchange rates, though there is substantial variation in both β_{BI} and β_c, depending on whether firms face competitors from foreign competitor countries vs from compatriots/US firms. Consider two firms with sector share ≈ 0.45 in the RHS of Figure 2. Firm 1 happens to have very little competition from firms in the foreign country in the same sector and so $\tilde{\beta}_C \approx 0$. In contrast, firm 2 has a large share of foreign competitors and so is very sensitive to competitors' exchange rates ($\tilde{\beta}_c \approx 0.44$).

5.2. **The bias in measured bilateral PT and the correlation of RERs.** How important is the correlation of exchange rates for bilateral pass-through? As shown in Equation 5, there will be omitted variable bias if competitors' exchange rates are excluded from the estimated equation in the data. The effect of omitted variable bias depends on the correlation between competitors' RERs and the bilateral exchange rate. Due to the presence of common shocks in the US (for example, a US TFP shock), bilateral and competitors' exchange rates will generally be positively correlated. This suggests that measured univariate bilateral pass-through will generally be upward biased, as in Testable Prediction 2.

Figure 3 shows how the omitted variable bias from excluding competitors' RERs varies with the correlation of the two RERs (US-Foreign Country 1 and US-Foreign Country 2) in the three-country model. The black solid line is *measured* bilateral pass-through from a univariate regression of simulated import prices on the bilateral RER, as is common in the literature. The red dashed line represents "true" bilateral pass-through

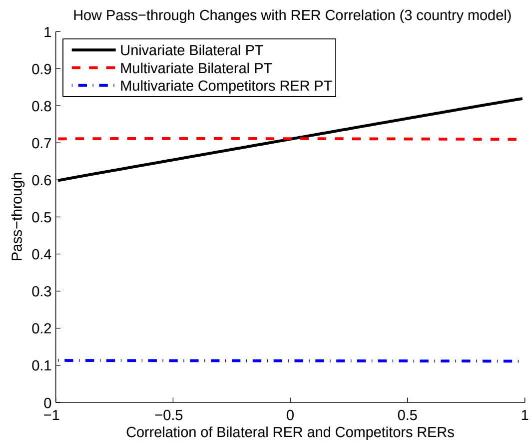

Figure 3. Correlation of bilateral ER and competitors' RER (3 country model)

after controlling for competitors' RERs in a multivariate regression. The gap between red (dashed) and black (solid) lines is a measure of bias. Quantitatively, $\beta_C \approx 0.1$ in the three-country model and $corr(rer_1, rer_2) = 0.4$, so if we assume equal RER SD we should expect an upward bias of about $0.4 \times 0.1 \times 1 = 0.04$, which is close to the estimate in Table 3 (the calculation is much more complicated with additional controls, as in the data). The bias ranges from around $-\beta_C = -0.1$ when the two exchange rates are almost perfectly negatively correlated, to around $\beta_C = 0.1$ when they are almost perfectly positively correlated.

When the model is correctly specified, the estimates of β_{BI}, β_C and β_C^{PPI} are not very sensitive to the correlation of exchange rates. In Figure 3, estimates of β_C and β_{BI} in the multivariate specification change by less than 0.01 as the correlation of RERs range from -0.95 to 0.95. Correlation *among* competitors' RERs also doesn't make much difference. Simulating the three-country model with the correlation of RERs from -0.95 to 0.95, leads to estimates of β_C^{PPI} which change by less than 0.03; and from -0.5 to 0.95 (which is more empirically relevant), estimates change by less than 0.015. Simulations (not reported) using a four country model suggest similar results for pass-through to import prices.[24]

5.3. **Extension: Imported intermediates.** An alternative explanation of high empirical pass-through of competitors' RERs is that producers use intermediate goods that are imported from third countries, which naturally make the prices of final goods sensitive to third country exchange rates. In Appendix C, I recalibrate the quantitative model with a 32% imported intermediate share based on a cross-country average (see Appendix C for detailed results). A combination of variable markups (as in the rest of this section) and imported intermediates can match the rates of pass-through of competitors' RERs to import prices estimated empirically in Section 3 of 0.35 — around 20ppts above the main results in Table 3 — *but* only if the imported inputs are generally sourced from countries that are also competitors. If intermediates are sourced equally from all countries (who may or may not be competitors in the same sector), pass-through of competitors' RERs is around 0.25 — around 10ppts above the main results in Table 3. In the extreme case that all intermediates are sourced from the US, there is no increase in pass-through of competitors' RERs — even though the total imported intermediate share is high (full results in Table 5). As such, one needs detailed information on the full international production network to accurately calibrate the model, which is beyond the scope of this paper.[25]

Note that the presence of imported intermediates always reduces bilateral pass-through — regardless of the the source of those intermediates — which is welcome given the poor empirical fit of the model in this regard. Quantitatively, pass-through of bilateral RER is around 0.47 with a 32% imported intermediate share — around 15ppts below that in the main results in Table 3 — though this is still substantially above bilateral pass-through estimates of around 0.2 in the data.

[24]As argued above, the reason is that the estimated pass-through equation is a very good approximation of the true data generating process.

[25]Results in Appendix C also suggest variable markups are needed to match the pass-through rates observed in the data.

6. Extension: PT of other competitors' prices to import prices

While pass-through of *foreign* competitors' exchange rates (and prices) are the focus of this paper, the simple model (Section 2) and the full model (Section 4) also suggest that import prices will respond to other components of the sectoral price: (i) to the US producer price index (β_{PPI}) and (ii) to other compatriots' prices (β_{OCP}). In this section, I add measures of these two prices to the standard import price pass-through regression (Equation 8). GI2011 competitors' price index is a combination of foreign competitors' prices and other compatriots' prices.

The first two columns of Table 4 show that a 1% increase in other compatriots' prices (other firms from the same exporting country) is associated with an increase in US import prices of around 0.5% (significant at the 1% level). Controlling for compatriots' prices also reduces pass-through of the bilateral RER ($0.23 \rightarrow 0.17$) in column 1. However, once competitors' RERs are included as a control, the addition of compatriots' prices only has a small effect on estimates of bilateral pass-through, suggesting modest rates of "indirect" bilateral pass-through (Section 2).

Columns 3-4 of Table 4 show that pass-through of sectoral US producer prices to US import prices is extremely large: a 1% increase in US producer prices in the same sector raises US import prices by 0.9% (significant at the 1% level). The coefficient is much larger than pass-through of foreign competitors' prices or GI2011's measure of import competitors' prices (both around 0.6). Controlling for the sectoral PPI substantially reduces pass-through of the bilateral RER (from $0.23 \rightarrow 0.16$) and also reduces PT of competitors' RERs ($0.35 \rightarrow 0.10$), which becomes insignificant.

Table 4. Pass-through of alternative measures of competitors' prices to US import prices

	Dependent Vble: Real US Import Prices (Δp over life of good)					
	(1)	(2)	(3)	(4)	(5)	(6)
Bilateral RER (β_{BI})	0.17***	0.13***	0.16***	0.14**	0.16**	0.15**
	[4.0]	[3.0]	[2.6]	[2.1]	[2.5]	[2.2]
Competitors' RERs		0.20***		0.10		0.06
(β_C)		[3.0]		[1.4]		[0.8]
Foreign Comp. Prices					0.23***	0.22**
(β_{FPP})					[2.6]	[2.5]
Sectoral PPI			0.92***	0.90***	0.48***	0.48***
(β_{PPI})			[7.3]	[7.1]	[3.5]	[3.5]
Other Compatriot's	0.50***	0.48***			0.25***	0.25***
Prices (β_{OCP})	[6.7]	[6.7]			[2.8]	[2.9]
Observations	4030	4028	3231	3228	2491	2489

Notes: Robust t-statistics are in brackets. ***,**,* indicate significance at the 1, 5 and 10 per cent levels. 1% outliers dropped. All specification include BLS primary lower stratum × country fixed effects, with standard errors clustered at this level. Regressions include controls for US GDP growth, date and life-length.

As the different measures of competitors' prices are correlated, including only one measure will bias upward the estimated coefficient. Columns 5-6 includes all three measures of competitors' prices in the regression, which approximately halves the estimated coefficients β_{FCP}, β_{OCP} and β_{PPI} relative to regressions with only one of these variables. It also makes β_C small and insignificant, which is consistent with competitors' RERs working through competitors' prices.

How does this relate to the model's predictions? In the quantitative model (Section 5), changes in exchange rates are the only shocks, which lead to overfitting when similar measures of competitors' prices and exchange rates are included concurrently in the model.[26] When a measure of the sectoral PPI is added to a standard

[26] In order to separately identify the role of competitors' prices and competitors' exchange rates, the model likely needs sector-specific cost or demand shocks, which is an interesting area for future research. The model is not able to separately identify the effects of the bilateral exchange rate and compatriots' prices due to overfitting.

bilateral PT regression (similar to Table 4, Column 3), the coefficient on the sectoral PPI is around 0.6 (not reported). While this is smaller than the comparable estimates in the data, the model does correctly predict much larger pass-through of the sectoral PPI than foreign competitors' prices.

7. Conclusions

In this paper, I show that a multi-country extension of a general class of models with variable markups (and possibly imported intermediates) predicts that movements in competitors' exchange rates should affect US import and producer prices. Because bilateral and competitors' RERs are generally positively correlated, excluding competitors' RERs will bias upward measures of bilateral pass-through in the univariate pass-through regressions common in the literature. The model's mechanism suggests that competitors' RERs affect foreign competitors' prices as an intermediate step. I find evidence in favor of these predictions using BLS microdata at the product level.

Using a specific form of the model based on AB, I run similar regressions on simulated data. Quantitatively, the model is able to explain around half of pass-through of competitors' RERs to import prices and almost all of pass-through to US producers prices. While the presence of imported intermediates can boost pass-through of competitors' RERs to import prices, the size of the effects depend on the exact structure of international production.

An online appendix is available at:
https://sites.google.com/site/stevenpennings/PenningsCompPTAppendixFinalWeb.pdf

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Appendix A. Summary of Data Sources

- US import prices and US producer prices (dependent variables in regressions): confidential BLS microdata (see www.bls.gov/bls/blsresda.htm).
- Import and export values (for import shares): Feenstra Trade Database (http://cid.econ.ucdavis.edu/).
- Nominal bilateral exchange rates, country CPI, US CPI: Gopinath and Rigobon (2008) (http://www.aeaweb.org/articles.php?doi=10.1257/aer.100.1.304). Chinese CPI: IMF IFS.
- US Real Trade Weighted Exchange Rate (TWI), US GDP: Federal Reserve of St Louis Economic Database (FRED).
- Manf. output data and materials prices (series: PIMAT) from NBER-CES Manf. Ind. Database (http://www.nber.org/nberces/).
- NAICS6 measure of producer prices: bls.gov.
- Construction of Figure 1 (Aggregate Data). Manufacturing import prices index from Canada and Europe and all imports from Japan downloaded from bls.gov/mxp/. Annual average indices deflated by annual US CPI from FRED. Bilateral ER data and foreign CPI from FRED, annual averages. Competitors' RERs data: Broad Real US TWI from FRED. Country trade weights for removing the bilateral rate and rescaling the TWI: Federal Reserve H.10 release.

Appendix B. Data Construction

B.1. **Import price data.** The import price variable is constructed as the change in the log of the price of each individual good over its life in the sample (mean of around 2 years) in USD, from the first reported price to the last new price, which is essentially a pooled cross-section regression. The models in Sections 2 and 4 suggest I should deflate by unit labor costs (ULC). However, they are not available (or are poorly measured) for many of the countries in the sample, so I deflate all import prices with the CPI instead to remove the effects of inflation. I calculate the change in the log of each independent variable (such as the bilateral exchange rate and competitors' exchange rate) over the life of the good. I also restrict the sample to USD priced goods. Restricting the sample to USD is common in the literature (e.g. GI2011), it only reduces the sample size by 10% and does not have much effect on the results. My model also deals with transactions between parties and so I remove intra-firm transactions. As in Gopinath and Rigobon (2008) and GI2011, I add country × BLS lower primary stratum fixed effects, and cluster standard errors at this level for import prices. I remove the 1% tails. I estimate the empirical model for goods from 10 countries/regions. I select the largest trading partners of the US in 2010, which together account for about two-thirds of US imports.[27] As the top 10 countries often compete against firms from countries outside the top 10, I construct the competitors' exchange rate variable using data from all countries.

B.2. **Producer price data.** The construction of the producer price variable is similar to that for import prices, though more prices and firms are sampled as part of the PPI and so the sample size is larger. The PPI sample period is also slightly shorter, running from 1994-2006, and the life of goods is longer, with a mean life of around 4 years. As with the import data, non-market transactions are excluded. I drop all prices specifically for export. There are no fixed effects or clustering of standard errors by country (as all goods are produced by a single country). As a robustness test, in the online appendix I consider a specification with fixed effects and clustered standard errors at the NAICS3d level. The materials cost variables are also deflated by the CPI and reflect total materials costs (to which imported materials costs contribute).

B.3. **Measuring competitors' exchange rates.** The primary measure of competitors' exchange rates is the import-weighted average of the change in the log of exchange rates within the NAICS 6 digit sector. This is the measure suggested by the multi-country AB model in Section 4, and in a three-country model (for import prices) is equal to the third-country RER in Section 2. For import prices, I first remove the bilateral exchange rate of the country who manufactured the good (with weights rescaled so they add to 1),[28] though for US producer prices this is clearly not necessary. Ideally, I would measure competition at a lower level — AB argue their model is best applied at the "more disaggregated than ten-digit NAICS" level — but

[27] The countries/regions are: China, Canada, Mexico, Japan, Germany, France, United Kingdom, Republic of Korea, Brazil and Hong Kong SAR China. I replace Taiwan, China with Hong Kong SAR, China due to a lack of available data from Taiwan, China, and because many Chinese exports pass through Hong Kong SAR, China.

[28] That is, they are multiplied by $1/(1 - s^{BI}_{IM})$.The import shares used to calculate competitors' exchange rates are those at the start of the life of the good in the BLS data.

unfortunately data on sector shares for US manufacturing are unavailable below the 6 digit level, and the number of prices in each industry is small (important for calculating competitors' prices).

The competitors' RER variable has a correlation with the Federal Reserve's Broad Trade Weighted Index of about 0.8 (calculated over the life of the good for either import or producer price samples), which might be considered an alternative measure of competitors' RER (and was used in GI2011). See the online appendix for a discussion.

B.4. **Construction of competitors' prices.** In the main specification, I construct an index of *foreign* competitors' prices using import price microdata from the same NAICS 6 sector. For regressions where the dependent variable is an import price, the set of foreign competitors will change depending on the country producing the good, resulting in a different price index for each country × sector. That is, the foreign competitors' price index for a German firm includes the prices of imports from all *other* countries selling in the US in the same sector (excluding all other German firms). For regressions where the dependent variable is a US producer price, the foreign price index includes the prices of all foreign producers in the same sector.

The index is constructed using a similar method as that in GI2011: I take the average growth rate of competitors' prices in the same sector in the month, and cumulate growth rates to get an index. As the BLS samples according to size, no weighting adjustment is needed. Alternative methods produce similar results.[29]

As an extension in Section 6, I consider pass-through of the prices of two other types of competitors in the same NAICS 6d sector: (i) other firms from the same country (compatriots), and (ii) US firms. Other compatriots' prices are constructed from BLS microdata in a similar manner to foreign competitors' prices and aggregate US producer price indices by NAICS 6d sector are taken from the BLS website.

Appendix C. Intermediate inputs in the quantitative model.

In a model with imported intermediate inputs, Equation 11 is replaced by Equation 17, where V_c is the price of imported intermediates from country c, and $\phi_{i,c}$ is the input weight in the production function of inputs from country c used in production in country i and $\phi_{i,i} = 1 - \sum_{c\neq i} \phi_{i,c}$ is the weight on domestic costs. In the model in the main text $\phi_{i,c} = 0 \,\forall_{i\neq c}$.

$$p_{ijk} = \frac{\sigma(s_{ijk})}{\sigma(s_{ijk}) - 1} \left[\frac{D_i \kappa}{z_{jk}}\right] \left[\frac{W_i}{A_i}\right]^{\phi_{i,i}} \prod_{c\neq i} V_c{}^{\phi_{i,c}} \tag{17}$$

I assume that imported intermediates are produced in competitive markets only with labor, such that $V_c = W_c/A_c$ (κ is a normalizing constant). Log-linearizing and rearranging, with $a_{ijk} = \Gamma_{AB}(s_{ijk})[\rho - 1]/\left[1 + \Gamma_{AB}(s_{ijk})[1 - s_{ijk}][\rho - 1]\right]$ and $b_{ijk} = \left[1 + \Gamma_{AB}(s_{ijk})[1 - s_{ijk}][\rho - 1]\right]^{-1}$ as in the main text:

$$\hat{p}_{ijk} = a_{ijk}[1 - s_{ijk}] \sum_{k'\neq k} \frac{s_{ijk'}}{[1 - s_{ijk}]} \hat{p}_{ijk'} + b_{ijk}(\phi_{i,i}[\hat{w}_i - \hat{a}_i] + \sum_{c\neq i} \phi_{i,c}[\hat{w}_c - \hat{a}_c]) \tag{18}$$

One can then solve of the system of prices as in the model without imported intermediates (in the main text and online appendix), where now the "structural β-coefficients" will be a combination of effects through competitors' prices, and effects through imported intermediates.

C.1. **Calibration.** Across major US trade partners, OECD data suggests the average imported intermediate share is 0.32 for manufacturing exports (Figure 4), though there is substantial variation across countries. In general, larger or more closed countries/regions have a lower intermediate share, with the US, EU, Brazil and Japan all having manufacturing intermediate shares around half the cross-country average. Table 5

[29]As a robustness test, I also constructed an index which uses the average of index values for each good $I^{sector}_{j,c,t} = \left(\sum_{c'\neq c} I^{good}_{i,j,c',t} / \sum_{c'\neq c} I^{good}_{i,j,c',t-1}\right) I^{sector}_{j,c,t-1}$ which is closer to the BLS's pre-1997 methodology and produces almost identical results. Another issue is that around 40% of product-month prices are missing in the import price program (Nakamura and Steinsson 2012). I follow the BLS methodology (and that of Nakamura and Steinsson 2012) by pulling forward missing prices (replacing missing price $p_{i,t}$ with $p_{i,t-1}$ for each good i). Nakamura and Steinsson (2012) argue that neither pulling prices, nor reweighing indices (as the BLS has done since 1997), substantially affects long-run pass-through.

presents simulation results in the 10 country model with a 32% imported intermediate share.[30] In the main calibration, I assume that $\phi_{i,c}$ does not vary across firms or sectors, and is constant across pairs of non-US countries, the simplest assumption given the available data. In alternative specifications, I allow a positive correlation between share of intermediates from a country in a sector and the sector share of firms from that country.[31]

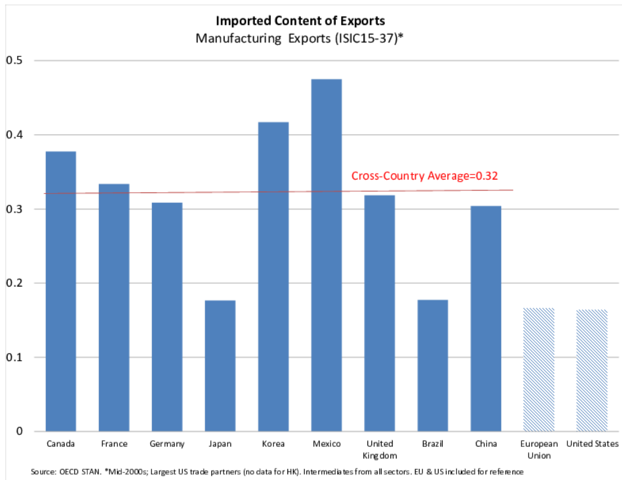

FIGURE 4. Imported Intermediate Shares in the Data

C.2. **Results.** Quantitatively, one can explain rates of pass-through of competitors' RERs estimated in the data with a combination of variable markups (as in the rest of the paper) and imported intermediates, conditional on imported intermediates being sourced from countries that are also competitors in the same sector. Table 5 (Panel B) shows that in the 10 country model with a 32% imported intermediate share and a 90% rank correlation between intermediate source and sectoral competitor countries, the model produces pass-through of competitors' RER to import prices of 0.34, which is almost identical to empirical estimates in Table 1 (Column 2).[32]

Pass-through of competitors' RERs will be higher with imported intermediates because when third country exchange rates appreciate (relative to the US), this will increase costs for all producers using intermediates sourced from the third country. These producers will then increase their prices in the US, resulting in positive pass-through of competitors' RERs — even if markups are fixed.

Quantitatively, the presence of imported intermediates *by themselves* can not explain the degree of pass-through of competitors' RERs that we see in the data. In a model where markups are fixed, pass-through of competitors' RERs is around 0.20 (Table 5 Panel A) in the baseline where intermediates are sourced equally across countries. This is above the estimates presented in the body of the paper (Table 3 without imported intermediates), but below estimates in the data (Table 1). Interestingly, even though markups are fixed,

[30]For Belgium, Amiti et al (2014) report the export-weighted non-EU median imported intermediate share of total variable costs is about 13% (including imports from the US). This is similar to the aggregate share in countries like Brazil, but less than a third of Mexico or Korea, and less than Belgium's own intermediate share including countries from the EU (54% from OECD-STAN). Moreover, as pointed out by Amiti et al (2014), exporters in Belgium use more imported intermediates than non-exporters, so weighting imported intermediate use by production value (as in I-O tables, like the World Input-Output Database) rather than by export value might mis-measure the share of imported intermediates. As production chains are likely to be location-specific due to differences in transport costs, language barriers etc, I calibrate to a cross-country average rather than to data for a specific country.

[31]To generate variations this correlation while ensuring intermediate shares are non-negative and cost shares sum to one, I form the intermediate shares for each sector as a (scaled) rearrangement of the sectoral country shares, with Kendal's τ correlation coefficient ρ_τ generated by a Gumbel copula capturing the rank correlation between country intermediate shares and country sector shares. This is not an issue in the three-country model.

[32]For US producer prices, the equivalent number (with 90% rank correlation) is 0.36, which matches empirical estimates almost exactly (Table 1 Column 6, without materials costs).

TABLE 5. PT to import prices in the 10 country model with 32% imported intermediates

32% imp. int. share	A. Symmetric ($\phi_{i,c} = 3.2\%$)				B. Correlated with Sector shares*				C. Only from US ($\phi_{i,us} = 32\%$)			
Markups	Fixed		Variable		Fixed		Variable		Fixed		Variable	
Bilateral RER	0.72	0.69	0.50	0.46	0.73	0.68	0.53	0.47	0.68	0.68	0.46	0.44
Competitors' RER		0.20		0.24		0.28		0.34		0		0.13

Note: coefficients from regressions of simulated import prices. *Rank Correl($\phi_{i,c}$,$S^C_{i,c}$)=0.9

pass-through of the bilateral exchange rate is biased upwards in univariate regressions, which is corrected when competitors' RER are added as an additional control. Relaxing the equal allocation assumption can either increase (Panel B) or decrease (Panel C) pass-through of competitors' exchange rates, but even in the former case pass-through of competitors' RERs fall short of those estimated in the data.

Are imported intermediates sourced from competitor countries?

In a multi-country world, pass-through of competitors' RERs is sensitive to the source of imported intermediates, rather than just the total intermediate share as in two-country models of bilateral pass-through. Given the data on this source distribution is not available, it is hard to be precise on the quantitative effects of imported intermediates on pass-through of competitors' RERs, which I leave for future research. Instead I show how pass-through changes using several different calibrations of intermediate source countries.

To see the importance of source country, take the most extreme case: intermediates are sourced from the US rather than from other foreign countries (Table 5 Panel C). In this case, pass-through of competitors' RERs to US import prices is zero with fixed markups, or in the case of variable markups, *lower* than it would be with no imported intermediates (discussed further below).

Even when intermediates are sourced equally from all countries (as in Table 5 Panel A), pass-through of competitors' RERs in a fixed markup model (20%) is somewhat lower than what we might expect based on the 29% share of foreign (non-US) costs in the production function. The reason is that the competitors' RER variable weights on each country ($S^C_{i,c}$) likely differ from the share of intermediates sourced from that country, and so the competitors' RER variable will not fully reflect changes in the cost of intermediate inputs. To see this, I replaced the symmetric and non-stochastic distribution of imported intermediate shares in Panel A of Table 5 with one where the imported intermediate share is stochastic but correlated with the country share in the sector (keeping the total imported intermediate share unchanged). If the imported intermediates shares are highly correlated with competitors' sector shares (0.9 rank correlation, Panel B of Table 5), pass-through of competitors' RER is around 8-10ppts higher than the symmetric (uncorrelated) case.

Variable markups and imported intermediates Imported inputs have less effect on pass-through of competitors' RERs in the variable markup model than one might expect given the combination of pass-through rates without import intermediates in the main text, and effect of imported intermediates in the fixed markup model. That is, pass-through of competitors' RERs to import prices of 0.24 with variable markups in Panel A in Table 5 is well below the sum of pass-through in the fixed mark-up model (0.20) and pass-through in the body of the paper (0.15). In the three-country model (which removes the complication of correlations between $S^C_{i,c}$ and $\phi_{i,c}$ above) an increase in the share of costs from the third country by 10 ppts increases pass-through of competitors' RER by 10ppts in the fixed markup model, but only by about 6ppt in the variable markup model.[33] There are two reasons. First, the variable markup mechanism always makes large firms less sensitive to their own costs — regardless of whether the costs are local or imported. Second, with higher imported intermediate use by competitors, a shock to third country RERs generates a smaller increase in competitors' costs and hence prices, reducing the need for other importers to increase prices to maintain their market share.

[33]In the baseline 3C model in the main text, pass-through of competitors' RER is about 0.1 without intermediates. With a 100% intermediate share from the 3rd country, PT competitors' RER equals 0.7 (bilateral PT in baseline model), a 0.6 increase.