Pricing-to-Market in Business Cycle Models*

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Abstract

This paper evaluates the performance of leading micro-founded pricing-to-market frictions vis-a-vis a set of robust stylized facts about international prices. In order to make that evaluation meaningful, we embed each friction into a unified IRBC framework and parameterize the models in a uniform way. Our goal is to evaluate the broad-based applicability of these frictions for policy-oriented DSGE modeling by documenting their strengths and weaknesses. We make three points: (i) the mechanisms generating pricing to market are not always neutral to business cycle dynamics of quantities, (ii) some mechanisms require producer markups at least 50% to account for the full range of estimates of the empirical exchange rate pass-through to export prices of 35%-50%, (iii) some frictions crucially depend on a particular driver of uncertainty in the underlying model.

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1 Introduction

It is a well known fact that frictionless international macro models, while successful in accounting for business cycle dynamics of quantities, fail to account for international prices. In particular, they are inconsistent with a vast empirical literature documenting international deviations from the law of one price and incompleteness of exchange rate pass-through. Not surprisingly, reconciling the predictions of business cycle models for international prices with the data has been on the forefront of research in international economics. Thus far, the literature has stressed the importance of two potential sources of the price behavior in the data: sticky prices and broadly defined real rigidities. In many ways, these are complementary. In fact, our reading of the empirical evidence and theoretical results is that it suggests a significant role for real rigidities in accounting for the behavior of prices, even after controlling for potential nominal rigidities (Gopinath and Itskhoki (2011)).[1]

Which set of real frictions is best suited to address the shortcomings of models with purely nominal frictions? The literature has proposed several micro-founded real frictions generating pricing to market behavior (PTM hereafter). In various contexts, they have been demonstrated to be capable of improving upon their respective frictionless benchmarks. However, since the definition of the frictionless benchmark as well as the set of analyzed data moments typically vary across papers, it is hard to compare the performance of these mechanisms against each other, and thus evaluate their potential for policy-oriented work.

In an attempt to fill this gap, this paper performs a consistent comparison of several leading frictions in the literature that can generate PTM. To this end, as a point of departure and baseline, we start from the same the same frictionless business cycle model that is relevant from an applied perspective, and embed each of the frictions into this common framework. We then focus on the following three key features which, in our view, are likely to determine the broad-based applicability of these frictions to policy-oriented business-cycle work: (i) dependence of the mechanism generating PTM on the source of economic fluctuations in the model, (ii) implications of the mechanism generating PTM for the dynamic behavior of quantities, and finally, (iii) the degree of deviations from the law of one price generated by the friction.

Clearly, given the uncertainty about the actual shocks that drive the enormous exchange rate

[1] Johri and Lahiri (2008) argue that sticky prices alone cannot account for the persistence of the deviations from the law of one price. Gopinath and Itskhoki (2011) discuss evidence of strong real rigidities at the wholesale level. For an overview of theory and evidence, see also Burstein and Gopinath (2014).

volatility in the data, the first feature determines to what extent a given friction can be employed in models featuring different types of shocks. The second feature is important because accounting for dynamics of prices should not be achieved by sacrificing the quantitative fit of the model in other dimensions. Finally, the third feature determines how well a given friction accomplishes its primary goal of bringing the models' predictions for prices closer to the data.

Our formal analysis focuses on four state-of-the-art frictions that lead to imperfect competition and pricing to market: (*i*) *Industry Aggregation* friction, based on a quantitative trade/macro model due to Atkeson and Burstein (2008); (*ii*) *Consumer Search* friction developed by Alessandria (2009); (*iii*) *Deep Habits*, developed in Ravn, Schmitt-Grohe, and Uribe (2007); and (*iv*) *Costly Distribution* friction, proposed by Corsetti and Dedola (2005). All selected frictions are potentially amenable to quantitative analysis within large-scale DSGE models, are widely cited in the literature, and all are micro-founded.

The nature of our exercise is as follows. We embed each friction into a standard business cycle model a la Backus, Kehoe, and Kydland (1995), and parameterize each model using a common set of data targets that are also standard in the literature. Whenever this is not possible, our preferred approach is to use the methodology or parameters from the original papers that introduced the frictions. To focus on the ability of each friction to generate deviations from the law of one price, we first perform *qualitative* analysis within each model, deriving the predicted theoretical pass-through of exchange rates to export prices. This allows us to pin down parameter restrictions required by each of the frictions in order to match the empirical pass-through range. These parameter restrictions then impact measurable predictions of the model, such as markups or market shares, which we contrast with the available evidence. Next, we study the *quantitative* predictions of each of the frictions, focusing on a set of moments pertaining to export prices.First, we compare the model vis-a-vis the consensus range of pass-through estimates to export prices[2] of 35%-50%. By focusing on the pass-through coefficient implied by the theory, our analysis is largely independent from the exact mechanism generating real exchange rate movements.[3] Then, we evaluate each PTM mechanism comprehensively by analyzing a set of price and quantity statistics, and assess the importance of the exact specification of the forcing process.

Even though we often refer to each friction by citing the paper that introduced it, it is important to stress that our exercise modifies the original models, and also takes a selective look at the

[2]Pass-through to import prices is approximately 100% *minus* the pass-through to export prices.

[3]This is important, since the baseline for our quantitative analysis is a complete markets setup, which typically fails to match the volatility and correlation of the real exchange rate.

implications of the theory. Thus, our results should not be interpreted as a criticism of these original contributions. Instead, they are intended to inform about the differences between these mechanisms when modeled within a unified environment.

In our quantitative exercises, we provide a comprehensive analysis of the pricing and quantity predictions of the theories. We provide three sets of results, summarized below.

In the first set of results, we show that not all frictions generating PTM are neutral to business cycle dynamics of quantities, i.e., preserve the performance of the competitive baseline model. Moreover, some of the counterfactual implications are directly implied by the very mechanism generating PTM. Specifically, we find that the *Costly Distribution* and *Deep Habits* frictions are neutral to the predictions for quantities. However, the remaining two: *Industry Aggregation* and *Consumer Search* frictions significantly affect the fit of the model for quantities.

First, the *Industry Aggregation* friction, which was designed to work in a low-frequency-oriented trade model, requires a high elasticity between home and imported goods for the PTM mechanism to work (consistent with the trade literature), which hurts the implications of the model for quantities on business-cycle frequencies. In particular, the high elasticity resurrects some of the problems of the early Backus, Kehoe, and Kydland (1992) setup with one homogeneous good, like excess comovement of TFP over output or excess comovement of consumption over output. Furthermore, the *Industry Aggregation* friction delivers PTM through movements of importer's market shares which pin down the demand elasticity perceived by exporters. Consequently, in order to deliver deviations from LOP that are in line with the data, the model requires that the aggregate import shares be volatile. Our back-of-the-envelope calculation suggests that, for a plausible range of parameter values, they will be more volatile in the model than in the data and also too tightly correlated.

Second, the *Consumer Search* friction alters the predictions for quantities when modeled as in Alessandria (2009) (we denote this formulation as *Consumer Search**). This original specification, featuring a quasi-linear utility function in labor and an exogenous labor-wedge shock, results in excess volatility of employment and output. With CRRA utility and only productivity shocks, similar problems arise.[4] That is why in our baseline specification of the friction, we propose a modification of the original model by making search a market activity. This restores a good fit for quantities, while still delivering statistics for prices, but also alters the economic interpretation of

[4]Specifically, the model predicts employment that is negatively correlated internationally, and too little comovement of output.

the friction.

In the second set of findings, we show that the equilibrium level of markups significantly affects the performance of the models for pricing. The *Consumer Search* and *Costly Distribution* frictions require high equilibrium markups in order to be consistent with the theoretical target for the pass-through coefficient of exchange rates to export prices. For example, in our benchmark comparison, we set markups equal to 30%, which turns out to be grossly insufficient. In particular, the *Consumer Search* friction, and especially *Costly Distribution* friction[5] deliver a subset of moments for prices at our targeted level of 30% markups, but in order to be consistent with empirical estimates of 35-50% of exchange rate pass-through to export prices, the model requires markups of at least 50%. On the other hand, the *Industry Aggregation* friction does well for the benchmark setting of markups, but quantity statistics deteriorate rapidly when markups are lowered significantly below this benchmark level (while still matching statistics on prices). In particular, when markups are set to 15%, as suggested by Basu and Fernald (1997), the import shares need to be much more volatile in the model to deliver meaningful amounts of PTM.

What is the appropriate target for markups? There is a lot of varied evidence about the level of markups in manufacturing. Industry studies[6] point to numbers around 20-30% (as used by Atkeson and Burstein (2008) and Alessandria (2009)), while on the other end, there are aggregate estimates by Basu and Fernald (1997) pointing to markups as low as 10-15%. While high markups can be rationalized in the context of PTM models by a fixed or sunk cost of production, such features may critically affect business cycle implications of the models, especially in the case of quantities. For this reason, we do not explore such considerations here and leave it for future research.

Finally, the third finding is that not all models' predictions are independent from the specifics of the forcing process. Specifically, we find that the *Deep Habits* model with productivity shocks[7] delivers deviations from LOP in the opposite direction to the data. Specifically, export markups fall relative to home markups when the real exchange rate depreciates, and theoretical exchange rate pass-through to export prices is negative. This makes the model perform worse vis-a-vis our frictionless baseline model in which LOP holds.[8]

[5] In *Costly Distribution* friction only part of the markup is in the foreign unit, whereas in *Consumer Search* model the whole markup is. Thus, it is easier to get more PTM in *Consumer Search* model than in *Costly Distribution* model for the same level of markups.

[6] Martins, Scarpetta, and Pilat (1996), Christopoulou and Vermeulen (2012) and Oliveira Martins and Scarpetta (1999) in cross-country and -industry studies, all find markups generally falling below 30%.

[7] This is also true for standard demand shocks modeled as shocks to the marginal utility of consumption: results are available upon request.

[8] It should be noted, however, that when demand shocks are modeled as stochastic government purchases that are additionally subject to deep habit formation, they can give rise to PTM in the right direction—as demonstrated by

The rest of the paper is organized as follows. Section 2 presents the frictionless framework in which we embed the frictions. Section 3 introduces the frictions. Section 4 provides analytical results and qualitative analysis of the sources of PTM in each friction. Sections 5 and 6 present the parameterization and quantitative results. Section 7 concludes.

2 Baseline Frictionless Model

In this section, we set up the baseline frictionless framework for our analysis, into which we then incorporate all the frictions. It includes the elements common across all the models we consider in Section 3.

The overall structure of the model follows closely Backus, Kehoe, and Kydland (1995). Time is discrete, $t = 0, 1, 2, ...$, and there are two ex-ante symmetric countries labeled *domestic* and *foreign*. Each country is populated by identical and infinitely lived households which supply labor and physical capital, consume goods, trade assets, and accumulate physical capital. Tradable intermediate goods are country-specific: d is produced in the domestic country, and f in the foreign country. The source of uncertainty are country-specific productivity shocks.

There are two levels of aggregation: *intermediate* and *final*. At the intermediate level, producers of goods (d at home and f abroad) sell their respective good to the *final good producers* from each country. International trade takes place at this stage. On the final good level, local final good producers combine d and f into a final consumption/investment good and resell them to the local households in a perfectly competitive market.

In terms of notation, we distinguish foreign country-related variables from the domestic ones using an asterisk. The history of shocks up to and including period t is denoted by $s^t = (s_0, s_1, ..., s_t)$, where the initial realization s_0, as well as the time invariant probability measure μ over the compact shock space S are assumed given. In the presentation of the model, whenever possible, we exploit symmetry of the two countries and present the model from the domestic country's perspective.

2.1 Uncertainty and Production

Each country has access to a constant returns to scale production function $zF(k, l)$ that uses country-specific capital k and labor l, and is subject to a country-specific stochastic technology

Ravn, Schmitt-Grohe, and Uribe (2007). For such shocks, the model implies that following a government spending shock, the real exchange rate appreciates, rather than depreciates as in the frictionless model. According to some VAR-evidence, such correlation of the real exchange rate may be consistent with the data for some countries, including US and Japan (see Corsetti, Dedola, and Leduc (2006)). We do not consider shocks of this kind here.

shock $\hat{z} \equiv \log(z)$, following an exogenous AR(1) process

$$\hat{z}(s^t) = \hat{\psi}\hat{z}(s^{t-1}) + \varepsilon_t, \quad \hat{z}^*(s^t) = \hat{\psi}\hat{z}^*(s^{t-1}) + \varepsilon_t^*, \tag{1}$$

where $0 < \hat{\psi} < 1$ is a common persistence parameter, and $s_t \equiv (\varepsilon_t, \varepsilon_t^*) \in S$ is an i.i.d. normally distributed random variable with zero mean.

Since the production function is assumed to be constant returns to scale, and our focus will be on prices, we find it convenient to summarize the production process by an economy-wide marginal cost v. Given domestic factor prices w, r and domestic shock z, the marginal cost, equal to per unit cost, is given by:

$$v\left(s^t\right) \equiv \min_{k,l}\left\{w\left(s^t\right)l + r\left(s^t\right)k \;\text{ subject to }\; z\left(s^t\right)F\left(k,l\right) = 1\right\}. \tag{2}$$

2.2 Households

Each country is populated by a unit measure of identical and infinitely lived households. Households supply production factors to domestic producers, accumulate physical capital, and consume goods. After each history s^t, the stand-in household chooses the allocation, which consists of the level of consumption c, investment in physical capital i, labor supply l, and purchases of a set of one-period s_{t+1}-contingent bonds $b\left(s_{t+1}|s^t\right)$ to maximize the expected discounted lifetime utility

$$\sum_{t=0}^{\infty}\beta^t\int_{S^t}u\left(c\left(s^t\right), l\left(s^t\right)\right)\mu\left(ds^t\right). \tag{3}$$

Asset markets are complete, and the budget constraint of the domestic household is given by

$$P\left(s^t\right)\left(c(s^t) + i(s^t)\right) + \int_S Q(s_{t+1}|s^t)b(s_{t+1}|s^t)\mu(ds_{t+1}) = b(s^t) + w\left(s^t\right)l\left(s^t\right) + r\left(s^t\right)k\left(s^{t-1}\right) + \Pi\left(s^t\right),$$
$$k\left(t+1\right) = \left(1-\delta\right)k\left(s^t\right) + i\left(s^t\right) \text{ all } s^t.$$

In the above budget constraint, we assume that the composite consumption good in each country is the numéraire. We do so by normalizing the level of prices $P\left(s^t\right)$ in each country to one so that the resulting ideal CPI price indexes in each country are equal to unity.

The expenditure side of the budget constraint consist of purchases of the consumption and investment goods and purchases of one-period-forward s_{t+1}-state contingent bonds. The income side consists of income from maturing bonds purchased at history s^{t-1}, labor income, rental income from physical capital, and the dividends paid out by local firms. The foreign budget constraint, due to a different numéraire unit, additionally involves a price $x(s^t)$ that translates the foreign numéraire to the domestic numéraire in the bond purchases term. By definition of the numéraire in each country, this price is the real exchange rate,[9] which integrates the domestic and foreign asset markets.The model implies that the real exchange rate is governed by the perfect risk sharing condition

$$x\left(s^t\right) = \frac{u_c^*\left(s^t\right)}{u_c\left(s^t\right)}, \tag{4}$$

which says that households fully share risk internationally, and equalize MRS from consumption with the relative price of the final consumption good across countries x.[10]

2.3 Final Good Producers

In each country, there is a unit measure of final good producers, who buy goods d and f from the intermediate good producers at home and abroad, and then aggregate them into the final consumption/investment good. Intermediate goods are aggregated according to a CES function given by

$$G(d,f) = \left(\omega d^{\frac{\gamma-1}{\gamma}} + (1-\omega) f^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \tag{5}$$

where γ is the elasticity of substitution (Armington elasticity) and ω is parameterizing home bias.

Given the aggregation technology above, the instantaneous profit of a final goods producer is

$$P\left(s^t\right) G\left(d,f\right) - P_d\left(s^t\right) d\left(s^t\right) - P_f\left(s^t\right) f\left(s^t\right).$$

The market for producing the final good is perfectly competitive, and hence the optimality conditions for the final good producers' problem are given by $P_d\left(s^t\right) = G_d\left(s^t\right) P\left(s^t\right)$, $P_f\left(s^t\right) = G_f\left(s^t\right) P\left(s^t\right)$, while the aggregation constraint is given by (5).

[9] In the data real exchange rate is measured using fixed-weight CPI rather than ideal CPI indices. Quantitatively, this distinction turns out not to matter in this particular class of models.

[10] Since we evaluate pricing implications of the models *relative to* the underlying movements of the real exchange rate, the fact that the model implies partly counterfactual properties of the real exchange rates has no bearing on our main results.

2.4 Intermediate Good Producers

Tradable intermediate goods, d, and f, are country-specific and are produced by a unit measure of atomless competitive producers residing in each country. Producers employ local capital and labor to produce these goods using the technology specific to their country of residence. Their unit production cost is given by (2).

The instantaneous profit function of the producer is determined by the profits from selling in each market and is given by

$$\Pi\left(s^t\right) = \left(p_d\left(s^t\right) - v\left(s^t\right)\right) d\left(s^t\right) + \left(x\left(s^t\right) p_d^*\left(s^t\right) - v\left(s^t\right)\right) d^*\left(s^t\right) \quad \forall s^t.$$

Since market for intermediate goods is perfectly competitive, zero profit condition implies that the producer markups are zero and the law of one price holds, i.e., $p_d\left(s^t\right) = v\left(s^t\right)$ and $x\left(s^t\right) p_d^*\left(s^t\right) = v\left(s^t\right)$. Additionally, equilibrium must satisfy the usual market clearing and feasibility conditions, which are omitted. The definition of equilibrium is straightforward.

3 Sources of Real Rigidities

We now introduce the key frictions into the baseline setup outlined above. These frictions depart from the frictionless competitive paradigm, and give rise to imperfect competition that leads to pricing to market. Below, we only discuss how introducing each particular friction modifies the baseline setup described above.

3.1 Consumer Search

In this section, we lay out the *Consumer Search* friction along the lines of Alessandria (2009). Compared to the original paper, we modify the setup so that search occurs on the final good producer's level rather than on the consumer level. This modification changes the interpretation of the original model, and should be interpreted as business-to-business search friction rather than a consumer search friction. We introduce this modification to improve the performance of the model on the quantity side without sacrificing prices. Later, we also present a version of the model that follows closely the original paper.

The production function and the household's problem are identical to the one in the frictionless baseline in Sections 2.1 and 2.2. The modified final and intermediate goods producers' problems are presented below.

Final Good Producers The final good producer aggregates goods d and f using the CES aggregator given by (5). Goods d and f, which enter final aggregation, are assumed to be acquired through the process of search by atomless representatives of the final good firm—employed at the economy-wide marginal cost v. Specifically, it is assumed that in every period, the firm (headquarters thereafter) sends measures s_d and s_f of reps to purchase $1/\theta$ units of good d and f, respectively. The total cost of this activity for the firm is $(s_d + s_f)v(s^t)$.

With probability q, each atomless rep obtains one price quote of the good that it was directed to search for (d or f), and with probability $1 - q$ it manages to obtain two competing quotes. After observing the prices, each rep purchases $1/\theta$ of their respective good at the lowest price—conditional on the price not exceeding the reservation prices $r_d(s^t)$ and $r_f(s^t)$ set a priori by the headquarters. Since in equilibrium no posted price will ever exceed this reservation price, we can assume without loss of generality that the rep always makes a purchase, i.e., all posted prices are lower than the reservation price. Given measures of the searching reps, the total amount of goods purchased by the firm is given by $d = \frac{s_d(s^t)}{\theta}$ and $f = \frac{s_f(s^t)}{\theta}$.

The distribution of prices at which goods are purchased depends on the distribution of prices posted by firms $F(p; s^t)$, and is given by (distribution of the lowest of the two draws from F):

$$H_d(p; s^t) = qF_d(p; s^t) + (1 - q)\left[1 - (1 - F_d(p; s^t))^2\right],$$

The average price paid by the searching reps (for commodity d) can then be obtained by integrating over H

$$p_d(s^t) = \int_{P_l}^{P_h} p\frac{dH_d(p; s^t)}{dp}dp,$$

where the bounds of the integration will be defined later. The price of good f is derived analogously.

Intermediate Good Producers Intermediate good producers sell their respective goods (d or f) to the final good producers from the home and foreign country. The production cost is equal to the marginal cost v as in the baseline frictionless setup.

The intermediate good producer, when making the price offer to a searching rep, does not know how many quotes a given rep will observe. This feature, as first demonstrated by Butters (1977) and Burdett and Judd (1982), is sufficient to give rise to a unique equilibrium featuring an endogenous price dispersion of physically identical goods. Moreover, the support of distribution the prices posted by all firms selling in a given market is compact and connected, and thus can be represented by a closed interval $[P_h, P_l]$. Moreover, the optimal probability distribution $F(\cdot)$ is uniquely pinned down by the condition that, given other producers also draw from $F(\cdot)$, the intermediate good producer must be indifferent between all the prices from the support of $F(\cdot)$, after taking into account endogenous probability of making a sale. Formally, for any $p \in [P_l(s^t), P_h(s^t)]$, the condition requires that the probability $F(p; s^t)$ must satisfy:

$$(p - v(s^t))(q + 2(1-q)(1 - F(p; s^t))) = (P_h(s^t) - v(s^t))q. \tag{6}$$

The above condition says that the expected profits from posting price p, factoring in the endogenous probability of making sales, $(q + 2(1-q)(1 - F(p; s^t)))$, as implied by the strategy F played by other firms, must be the same as the profits from posting the highest price P_h (equal to reservation price). At this highest price, by definition, the intermediate producer is making sales if and only if the representative has only one price quote (which happens with probability q), which makes it easy to calculate this price.

Clearly, given bounds of the support, $P_h, P_l,$, equation (6) defines the function F. These bounds can then be derived as follows. The upper bound of the distribution P_h is determined by the condition that the final good producer must be indifferent between buying the good for P_h and instructing representatives who have a draw $P_h(s^t)$ to abort the purchase and instead direct more reps to purchase the same good at the average price p_d, i.e., $\theta v(s^t) = P_h(s^t) - p_d(s^t)$. The lowest bound can be found by plugging in P_l for p to (6).

The full characterization of equilibrium prices in the model is as follows:

$$\begin{aligned}
P_h(s^t) &= v(s^t) + \frac{\theta}{1-q} v(s^t), \\
P_l(s^t) &= \frac{P_h(s^t)q + 2(1-q)v(s^t)}{2-q} = v(s^t) + \frac{q\theta}{2 - 3q + q^2} v(s^t), \\
F(p) &= 1 - \frac{1}{2}\frac{q}{1-q}\frac{P_h(s^t) - p}{p - v(s^t)},
\end{aligned}$$

and the expected price paid by a representative looking for good d is:

$$p_d(s^t) = v(s^t) + \frac{\theta q}{1-\theta} v(s^t).$$

Feasibility At every date and state, the feasibility condition for intermediate goods additionally includes the cost of search: $d + d^* + \theta(d + f) = zk^{\alpha} n^{1-\alpha}$. The remaining feasibility conditions are identical as in the frictionless benchmark.

3.1.1 Consumer Search*

For comparison, we also include results from a version of the model that follows closely the original formulation. In this version, following Alessandria (2009), we introduce search into the household's problem, and hence there are no final good producers in this formulation. The intermediate good producers' problem is identical to the one above. Below, we only highlight the key differences relative to the setup presented above.

Key Differences The search friction requires that households need to search in order to purchase goods d and f. Specifically, the household sends measures n_d and n_f of searchers who can purchase $\bar{z}$ units of good d and f, respectively. These measures are counted against the total time endowment of the household, and so the total amount of labor entering the utility function is given by

$$l(s^t) = n\left(s^t\right) + \theta(d\left(s^t\right)/\bar{z} - f\left(s^t\right)/\bar{z}),$$

where n is the time devoted to work in production of goods, θ is the disutility from shopping, and $\bar{z}$ is the number of units purchased by each searcher (implying $d = n_d * \bar{z}$).

Following the original paper, we use quasi-linear utility,

$$u(c, l) = \frac{c^{1-\sigma}}{1-\sigma} - \kappa l,$$

and introduce shocks to κ (labor-wedge shock).

3.2 Costly Distribution

In this section, we lay out a version of monopolistic competition on the intermediate good level along the lines of Corsetti and Dedola (2005). The friction here is that each producer is a monopolist over an atomless country-specific variety of good as in the Dixit-Stiglitz model, but for each good, a local distribution cost has to be incurred before the good is delivered to the final consumer. The existence of a distribution sector, governed by a Leontief production function, makes the demand for each variety of good depend not only on the price of that good charged by intermediate good producers, but also on the local cost of distribution — in effect delivering what is perceived by intermediate good producers as time-varying price elasticity of demand.[11]

We first setup the version of the model closest to the baseline, and then extend it to introduce an explicit non-tradable sector, following more closely the original specification of the model. The production function for each variety of the good and the household's problem are identical to the one in the frictionless mode.

In order to accommodate the *Costly Distribution* friction, we model intermediate good producers as monopolistically competitive producers of a continuum of varieties indexed by i and incorporate a middle (*sectoral*) level of production and aggregation. Sectoral producers trade internationally with intermediate good producers, pay the local distribution costs and aggregate and resell the goods to final good producers. The final good producers aggregate the domestic and foreign composite goods into a final consumption/investment good, just as in Section 2.3. We provide the details below.

Sectoral Good Producers The sectoral good producers aggregate a variety of differentiated intermediate goods purchased from measure one of intermediate good producers from each country. In addition to paying the purchase price for the tradable good to the intermediate good producer, each sectoral producer has to incur a distribution cost ξ, denominated in the local good (fixed per unit of the good).[12] Sectoral producers then aggregate different varieties of goods into composite goods d and f, according to a CES aggregator with elasticity parameter θ:

$$d\left(s^t\right) = (\int_0^1 d(i,s^t)^{\frac{\theta-1}{\theta}} di)^{\frac{\theta}{\theta-1}}.$$

Aggregation of the foreign goods (in the domestic country) is analogous. The instantaneous profit function of the sectoral producers is given by

$$P_d\left(s^t\right) d\left(s^t\right) + P_f\left(s^t\right) f\left(s^t\right) - \int_0^1 \left[p_d\left(i,s^t\right) + \xi v\left(s^t\right)\right] d(i,s^t)di - \int_0^1 \left[p_f\left(i,s^t\right) + \xi v\left(s^t\right)\right] f(i,s^t)di.$$

[11]Leontief specification of distribution is a critical assumption. If, for example, the production function in the distribution sector is Cobb-Douglas, as for example in Eaton and Kortum (2002), there is no pricing to market in the model. If elasticity is higher than unity, pass-through coefficient would be counterfactually negative.

[12]We can think of the sectoral good producers as just employing capital and labor to produce distribution services according to the economy-wide technology.

Markets for composite goods d and f are competitive, and hence the prices of composite goods charged by sectoral good producers are given by

$$P_j(s^t) = \left[\int_0^1 \left(p_j(i, s^t) + \xi v\left(s^t\right) \right)^{1-\theta} di \right]^{\frac{1}{1-\theta}},$$

where $j = d, f$.

The demand function for good $d(i)$ is then (analogously for good $f(i)$)

$$d(i, s^t) \quad = \quad \left(\frac{p_d(i, s^t) + \xi v\left(s^t\right)}{P_d(s^t)} \right)^{-\theta} d(s^t). \tag{7}$$

The above equation captures the key implications of the model for prices. As we can see, unlike in the standard Dixit-Stiglitz model, here, demand for each variety of good not only depends on the price charged by each intermediate good producer ($p_d\left(i, s^t\right)$ and $p_f\left(i, s^t\right)$), but also on the local marginal distribution cost v. Hence, changing prices changes the elasticity of demand perceived by each of the monopolistic intermediate good producers. This leads to variable markups and pricing to market.

Intermediate Good Producers In each country, there is a measure of imperfectly competitive intermediate good producers, indexed on a unit interval by i. Their unit production costs are given by (2).

A producer of variety $i \in [0, 1]$ chooses home wholesale price $p_d(i, s^t)$ and dock export price $p_d^*(i, s^t)$ to maximize profit

$$(p_d(i, s^t) - v\left(s^t\right))d(i, s^t) + (x(s^t)p_d^*(i, s^t) - v\left(s^t\right))d^*(i, s^t),$$

subject to demand equations at the sectoral level (given by (7), and analogous ones for the export market).

The wholesale prices solve the problem stated above, and are given by

$$\begin{aligned} p_d(i, s^t) &= \frac{\theta}{\theta - 1} v(s^t) + \frac{\xi}{\theta - 1} v(s^t), \\ p_x(s^t) &\equiv x(s^t) p_d^*(i, s^t) = \frac{\theta}{\theta - 1} v(s^t) + \frac{\xi}{\theta - 1} x(s^t) v^*(s^t). \end{aligned} \tag{8}$$

Feasibility Feasibility in this setup includes the cost of distribution: $d+d^*+\xi(d+f) = zk^\alpha n^{1-\alpha}$. Definition of equilibrium and other feasibility conditions are standard.

3.2.1 Costly Distribution*

Here, we extend the friction outlined above to incorporate non-tradable goods. This specification follows closely the original paper. We include it for comparison purposes, and argue later that this departure qualitatively does not matter for our conclusions. For details, refer to the original paper, here, we only highlight the key differences with respect to the earlier setup.

Key Differences Now, the distribution cost is paid in non-tradables. Since now each country produces and consumes tradable and non-tradable goods, the pricing formulas additionally include the relative price of non-tradable goods P^N:

$$\begin{aligned} p_d(i,s^t) &= \frac{\theta}{\theta-1}v^T(s^t) + \frac{\xi}{\theta-1}P^N(s^t), \\ p_x(i,s^t) &\equiv x(s^t)p_d^*(i,s^t) = \frac{\theta}{\theta-1}v^T(s^t) + \frac{\xi}{\theta-1}x(s^t)P^{N*}(s^t). \end{aligned}$$

3.3 Industry Aggregation

This section studies the friction developed by Atkeson and Burstein (2008). It features a two-stage CES demand structure, and Cournot competition between firms at the lowest level of aggregation. As for the *Costly Distribution* friction, we will keep the middle, sectoral level of production and aggregation here as well. The key prediction is that the price elasticity of demand perceived by each Cournot firm is a weighted average of the demand elasticity on both firm and sectoral level of aggregation, with the weight depending on a firm's market share in its sector. These elasticities differ, and so variation of market shares endogenously gives rise to variation in markups.

The production function at the lowest level of aggregation and the household's problem are identical to the baseline frictionless setup, and will be omitted. To incorporate the nested CES structure into a tractable business cycle model, in contrast to the original paper, here we exogenously fix the number of firms in the economy, and make them all identical within their respective category: exporters or non-exporters. There are also no non-tradable goods.

Production in the economy is divided into sectors and individual goods feature three levels of production and aggregation. First, at the lowest level of aggregation, *a finite number* of imperfectly competitive intermediate good producers (Cournot competitors) in sector j in each country produce a variety of their respective goods k ($d(k,j)$ and $f(k,j)$) and then sell their goods to *sectoral good producers*, who aggregate $d(k,j)$ and $f(k,j)$ into composite sectoral goods $y(j)$ and sell them to final good producers. Final good producers aggregate the composite sectoral goods into a final consumption/investment good. The critical assumption of the model is that the elasticity between sectoral goods $y(j)$ is low relative to the elasticity within sector at the intermediate good level. We describe formally all three levels of production/aggregation below. As before, international trade takes place between intermediate and sectoral producers.

Final Good Producers Final consumption $c(s^t)$ and investment goods $i(s^t)$ in the home country are produced by a competitive final good producer, using as input commodities produced by a continuum of identical sectors (indexed by j), with elasticity of substitution γ:

$$c(s^t) + i(s^t) = \left[\int_0^1 \left(y(j, s^t) \right)^{1-\frac{1}{\gamma}} dj \right]^{\frac{\gamma}{\gamma-1}}. \tag{9}$$

Given prices of each sectoral good, $P(j, s^t)$, the inverse demand for $y(j, s^t)$ is

$$\frac{P(j, s^t)}{P(s^t)} = \left(\frac{y(j, s^t)}{c(s^t) + i(s^t)} \right)^{\frac{-1}{\gamma}},$$

where $P\left(s^t\right)$ is the price index of the consumption/investment good, given by

$$P(s^t) = \left(\int_0^1 \left(P(j, s^t) \right)^{1-\gamma} dj \right)^{1/(1-\gamma)},$$

and normalized to 1, to serve as the numéraire.

Sectoral Good Producers There is a unit mass of perfectly competitive sectoral good producers in each sector in each country. They purchase goods from intermediate good producers within the sector and aggregate them into sectoral output. We assume that in each sector j, there are n home intermediate good producers, of which n_X are exporters. The aggregation of individual goods into sectoral output is subject to a CES aggregator:

$$y(j, s^t) = \left[\sum_{k=1}^{n} \left(d(k, j, s^t) \right)^{\frac{\rho-1}{\rho}} + \sum_{k=1}^{n_X} \left(f(k, j, s^t) \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}},$$

where j denotes sector and k indexes intermediate good producers.

The instantaneous profit function of the sectoral producers is given by

$$P\left(j, s^t\right) y\left(j, s^t\right) - \sum_{k=1}^{n} P_d\left(k, j, s^t\right) d(k, j, s^t) - \sum_{k=1}^{n_X} P_f\left(k, j, s^t\right) f(k, j, s^t),$$

and the inverse demand for a domestic intermediate good k in sector j is

$$\frac{P_d(k, j, s^t)}{P(j, s^t)} = \left(\frac{d(k, j, s^t)}{y(j, s^t)}\right)^{\frac{-1}{\rho}}.$$

The sectoral price index $P\left(j, s^t\right)$ is taken by the producers as given, and it is given by

$$P(j, s^t) = \left[\sum_{k=1}^{n} \left(P_d(k, s^t)\right)^{1-\rho} + \sum_{k=1}^{n_X} \left(P_f(k, s^t)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}.$$

Since the firm's problem is effectively static, sectoral producers maximize the instantaneous profit function given prices, and subject to the aggregation constraint. Since all firms of the same type across all sectors within a country are identical, the subscripts j and k are redundant once we restrict attention to 'type-identical' allocations.

Intermediate Good Producers Within each country and sector, n producers sell at home, of which n_X sell in both markets. Producers employ local labor and capital to produce their respective variety of good. Their unit production costs are given by (2) and are the same across varieties within a country. They are Cournot competitors.

The problem of the domestic country producer k selling in sector j in the home country is given by choosing price p and quantity d to maximize profit (at all s^t):

$$\pi_d(j, s^t) = \left(p - v(s^t)\right) d$$

subject to demand equations implied by sectoral and final good producer demands

$$p = \left(\frac{d}{y(j, s^t)}\right)^{-\frac{1}{\rho}} \left(\frac{y(j, s^t)}{c(s^t) + i(s^t)}\right)^{-\frac{1}{\gamma}}.$$

The solution of the above maximization problem implies:

$$p = \frac{\varepsilon(j, s^t)}{\varepsilon(j, s^t) - 1} v(s^t),$$

where the elasticity $\varepsilon(j, s^t)$ is a function of the market share of intermediate good producer k and involves the choices of all other producers (Cournot competition):

$$\begin{aligned} \varepsilon(j, s^t) &= \left[\frac{1}{\rho}\left(1 - S(j, s^t)\right) + \frac{1}{\gamma} S(j, s^t)\right]^{-1} \\ S(j, s^t) &= P_d(k, j, s^t) d(k, j, s^t) \left[\sum_{\kappa=1}^{n} P_d(\kappa, j, s^t) d(\kappa, j, s^t) + \sum_{\kappa=1}^{n_X} P_f(\kappa, j, s^t) f(\kappa, j, s^t)\right]^{-1}. \end{aligned}$$

The maximization for other markets is defined in an analogous way. The only modification is that to produce for exports, a producer has to incur an exporting cost of τ units of own production per unit exported.

Feasibility Representativeness implies that subscripts k and j are redundant, and all variables indexed by these subscripts must take the same value. Given this assumption, production feasibility is $nd(s^t) + n_X d^*(s^t)(1 + \tau) = z(s^t)k(s^t)^{\alpha} l(s^t)^{1-\alpha}$, with analogous conditions applying in the foreign country. Other feasibility and market clearing conditions, as well as the formal statement of equilibrium are omitted.

3.4 Deep Habits

In this section, we introduce 'relative deep habits', as first proposed by Ravn, Schmitt-Grohe, and Uribe (2007). Just like in the standard Dixit-Stiglitz model, the setup involves a measure of atomless intermediate good producers who are monopolists over their country-specific variety of good. Unlike in the Dixit-Stiglitz model, here, consumers develop an *external habit* for each good they consume.[13]

The production function for each variety of the country-specific good, and the household's problem are identical to the one in the frictionless benchmark. As for the *Costly Distribution* friction, we have three levels of aggregation. At the lowest level of aggregation, imperfectly competitive intermediate good producers in each country produce a continuum of varieties of their respective

[13] Evolution of habits is driven by average purchases of each variety and not purchases of any individual household. For simplicity, here we model habit as being formed at the level of producers, which is isomorphic to the setup in which it is directly incorporated into the consumer problem.

goods ($d(i)$ and $f(i)$) and then sell these goods to the sectoral good producers in each country, who aggregate these goods into a composite domestic and imported goods, d and f, respectively, and then resell them to the final good producers. Final good producers aggregate the composite goods into a final consumption/investment good. Their problem is identical to the frictionless model's and is described in Section 2.3. The sectoral and intermediate good producers' problems are described below.

Sectoral Good Producers Sectoral good producers are perfectly competitive and produce the composite goods d and f by aggregating all the varieties of *habit-adjusted* quantities $d^h(j)$ and $f^h(j)$ according to a CES aggregator with elasticity φ:

$$d(s^t) = \left[\int_0^1 d^h\left(j, s^t\right)^{\frac{\varphi-1}{\varphi}} dj\right]^{\frac{\varphi}{\varphi-1}} \text{ and } f(s^t) = \left[\int_0^1 f^h\left(j, s^t\right)^{\frac{\varphi-1}{\varphi}} dj\right]^{\frac{\varphi}{\varphi-1}}.$$

For each good $j \in [0,1]$, the habit-adjusted quantity $d^h(j)$ is determined by the level of habit from last period, $h_d\left(j, s^{t-1}\right)$, and the purchases of the good this period, $D\left(j, s^t\right)$, according to the formula:

$$d^h\left(j, s^t\right) = \frac{D\left(j, s^t\right)}{h_d\left(j, s^{t-1}\right)^{\theta}},$$

where θ parameterizes the strength of the habit (θ assumed to be less than zero, following the convention introduced by Ravn, Schmitt-Grohe, and Uribe (2006)). Habit evolves according to:

$$h_d\left(j, s^t\right) = \rho h_d\left(j, s^{t-1}\right) + (1-\rho)\, \bar{d}^c\left(j, s^t\right), \tag{10}$$

where $\bar{d}^c$ is the *average* level of purchases of good j in the economy—introduced here so that the households do not internalize the effect of their purchases on their own level of habit (catching up with the Joneses specification of habit). Analogous equations hold for good f.

The instantaneous profit function of the sectoral producers is given by

$$P_d\left(s^t\right) d\left(s^t\right) + P_f\left(s^t\right) f\left(s^t\right) - \int_0^1 p_d\left(i, s^t\right) D(i, s^t) di - \int_0^1 p_f\left(i, s^t\right) F(i, s^t) di,$$

where $p_d\left(i, s^t\right)$ and $p_f\left(i, s^t\right)$ are prices charged by the monopolistically competitive intermediate good producers.

The sectoral good producer's problem can be simplified by solving a intra-temporal decision of allocating purchases across the j goods. For any amount of the aggregate goods desired, d, given prices, $p_d(j)$, there is a unique expenditure-minimizing allocation of $D(i, s^t)$, given by

$$D\left(i, s^t\right) = \left(\frac{p_d\left(i, s^t\right)}{P_d\left(s^t\right)}\right)^{-\varphi} h_d\left(i, s^{t-1}\right)^{\theta(1-\varphi)} d(s^t), \tag{11}$$

where the aggregate price index is

$$P_d\left(s^t\right) \equiv \left[\int h_d\left(j, s^{t-1}\right)^{\theta(1-\varphi)} p_d\left(j, s^t\right)^{1-\varphi} dj\right]^{\frac{1}{1-\varphi}}.$$

Equations for quantities and prices of good f can be expressed analogously.[14]

Intermediate Good Producers In each country, there is a measure of goods produced by monopolistic intermediate good producers, indexed on a unit interval by i. Their unit production cost is given by (2). Producers take the demand relations (11) as given, as well as the prices charged by other producers. Since intermediate producers are monopolists over their variety, they internalize the effect of making sales on the formation of habit. Specifically, they take into account the law of motion for habit as laid out in (10), but with $\bar{d}^c$ replaced by the chosen production for each market: D at home, and D^* abroad, respectively. Their instantaneous profit function is given by

$$\left(p_d\left(i, s^t\right) - v\left(s^t\right)\right) D\left(i, s^t\right) + \left(x\left(s^t\right) p_d^*\left(i, s^t\right) - v\left(s^t\right)\right) D^*\left(i, s^t\right).$$

The optimization problem of each intermediate good producer is to maximize the present discounted stream of profits, where the discount factor is implied by the consumer's stochastic discount factor. Optimization is subject to demand equations and the internalized law of motion for habit, as explained above. As we can see, this problem is inherently dynamic, as habit h is a state variable from the producer's perspective.

Feasibility The usual feasibility conditions apply. The key assumption is that capital and labor can freely flow between different producers, and so on the aggregate level the economy satisfies analogous conditions to the frictionless model, only here they are integrated over a measure of producers.

[14] To save on notation, the setup here is a simplified version of the setup that we use in the quantitative analysis section. There, we exclude investment i from the habit formation process, as it seemed more natural for us to think of investment as being denominated in physical units rather than habit adjusted units. Habit is only imposed on consumption goods. We have verified that this distinction would not make any significant difference for any of the result reported throughout the paper.

4 Discussion of the Mechanisms Generating PTM

Below, we present a qualitative analysis of pricing-to-market mechanism of each model. Specifically, we focus on the predictions of each of the frictions for the theoretically-implied pass through of exchange rate to export prices. We also assess the quantitative potential of the different frictions for accounting for the empirical range of pass-through coefficients.

4.1 Consumer Search

Formulas for prices in the *Consumer Search* model depend on the local search cost. Specifically, the export and home price of the domestic good in the model are given by

$$p_x(s^t) = v(s^t) + \frac{\theta q}{1-q} x(s^t) v^*(s^t) \text{ and } p_d(s^t) = v(s^t) + \frac{\theta q}{1-q} v(s^t).$$

By dividing these two prices, we can link the the deviations from the law of one price in the model to the cost-based real exchange rate $x(s^t)v^*(s^t)/v(s^t)$ by

$$p_d^x(s^t) \equiv \frac{p_x(s^t)}{p_d(s^t)} = \frac{1 + \frac{\theta q}{1-q} \frac{x(s^t)v^*(s^t)}{v(s^t)}}{1 + \frac{\theta q}{1-q}}.$$

The above equation implies that the magnitude of pricing to market generated by the model crucially depends on the level of producer markups, here given by $\frac{\theta q}{1-q}$. Below, we discuss the implication of this feature of the model for different levels of (steady-state) markups.

Quantitative Potential of the Consumer Search Model As noted in the previous section, the model can generate pricing-to-market and incomplete pass-through of exchange rates due to costly search denominated in local units. Here we asses the size of these effects by deriving the theoretical pass-through coefficient implied by the model. We do so by evaluating the elasticity of the real export price with respect to the real exchange rate, which is given by:

$$PT \equiv \frac{\partial \log(p_x)}{\partial \log(x)} = \frac{\frac{\theta q}{1-q} \frac{v^*(s^t)x(s^t)}{v(s^t)}}{1 + \frac{\theta q}{1-q} \frac{x(s^t)v^*(s^t)}{v(s^t)}}|_{ss} = \frac{\frac{\theta q}{1-q}}{1 + \frac{\theta q}{1-q}}.$$

By definition, this number tells us by how much in percentage terms the real export price moves in response to a 1% change of the real exchange rate x.

As we can see, the theoretical pass-through in the model crucially depends on the level of producer markups, captured by the ratio $\frac{\theta q}{1-q}$. In particular, for markups equal to 30%, we find that the PT coefficient generated by the model is 24%, for the level of markups equal to 50%, it is 33%, and for the level of markups as high as 100%, it is 50%.

The evidence on the degree of pass-through varies widely in the literature, but most studies, while controlling for costs and other factors, estimate the empirical pass-through coefficient to be in the interval[15] 35%-50%. We refer to this range as the 'consensus view'. The calculation above suggests that for the model to be consistent with the consensus range, it requires markups of at least 50% – a high value relative to the empirical estimates. While possible to rationalize using large fixed costs of production, it is not clear to what extent such features would then affect the model's performance in terms of business cycle statistics. We interpret this finding that the model restricts the applicability of to environments that allow such high markups.

4.2 Costly Distribution

As we can see from (8), the formulas for prices in the case of the *Costly Distribution* model are similar to the ones implied by the *Consumer Search* model. However, one crucial difference is that in the case of *Costly Distribution*, as opposed to *Consumer Search*, only part of the markup is denominated in the local numéraire units, reducing pricing-to-market implied by the model. This conclusion follows immediately from a derivation of the theoretical exchange rate pass-through to export prices, which in this case is given by

$$PT \equiv \frac{\partial \log(p_x)}{\partial \log(x)} = \frac{\frac{\xi}{\theta-1}\frac{x(s^t)v^*(s^t)}{v(s^t)}}{1+\frac{\xi}{\theta-1}\frac{x(s^t)v^*(s^t)}{v(s^t)}}|_{ss} = \frac{\frac{\xi}{\theta-1}}{1+\frac{\xi}{\theta-1}},$$

and is determined by a term that is lower than the total producer markup[16] given here by $\frac{\theta}{\theta-1}+\frac{\xi}{\theta-1}$. Hence, compared to the *Consumer Search* model, the *Costly Distribution* model requires *higher* steady state markups to hit the same pass-through coefficient, and the discussion in the previous section applies here as well.

[15]Most estimates are centered around 60% for import prices, which would imply 40% to export prices (=100%-60%). For example, Goldberg and Campa (2005) find pass-through to import prices in OECD to be around 46%. Goldberg and Knetter (1997) report number closer to .6 for import prices and thus .4 for export prices.

[16]In the original paper by Corsetti and Dedola (2005) the non-tradable sector is assumed less productive than the tradable sector—requiring a lower setting of ξ. This assumption, however, does not resolve the issue. In the quantitative model, the share of distribution cost in the final retail price is disciplined by the available estimates by Burstein, Neves, and Rebelo (2003) and effectively it does not matter whether it comes from a parameter, or a 'productivity inflated price' of the non-tradable input.

4.3 Industry Aggregation

The key implication of this setup is the perceived demand elasticity by the monopolistic intermediate good producers depends on market shares, which varies the markup. Specifically, the export price of the home good is given by

$$p_x(s^t) \equiv x(s^t)P_d^*(s^t) = \frac{\varepsilon_d^*(s^t)}{\varepsilon_d^*(s^t)-1}\,(1+\tau)\,v(s^t)$$

where

$$\begin{aligned}
\varepsilon(s^t) &= \left[\frac{1}{\rho}(1-S_d^*(s^t)) + \frac{1}{\gamma}S_d^*(s^t)\right]^{-1} \\
S_d^*(s^t) &= \frac{P_d^*(s^t)d^*(s^t)}{nP_f^*(s^t)f^*(s^t) + n_X P_d^*(s^t)d^*(s^t)}
\end{aligned}$$

while the home price of the same good is given by

$$p_d(s^t) \equiv P_d(s^t) = \frac{\varepsilon_d(s^t)}{\varepsilon_d(s^t)-1}v(s^t)$$

where (τ stands for the iceberg cost of exporting)

$$\begin{aligned}
\varepsilon(s^t) &= \left[\frac{1}{\rho}(1-S_d(s^t)) + \frac{1}{\gamma}S_d(s^t)\right]^{-1} \\
S_d(s^t) &= \frac{P_d(s^t)d(s^t)}{nP_d(s^t)d(s^t) + n_X P_f(s^t)f(s^t)}.
\end{aligned}$$

As we can see from the above formulas, markup in each market is crucially influenced by the perceived endogenous elasticity of demand $\frac{\varepsilon^*}{\varepsilon^*-1}$ in the export market and $\frac{\varepsilon}{\varepsilon-1}$ in the domestic market. Any variation in markups in the model will hence work through the variation in these elasticities. Formally, elasticities vary with the term $\frac{1}{\rho}\left(1-S_d^*\right)+\frac{1}{\gamma}S_d^*$. How large this variation is crucially depends on the difference between elasticities γ and ρ (for a given change in S_d), and the variability of the market shares over the business cycle.

To illustrate this point, following Atkeson and Burstein (2008), we explicitly derive the elasticity of exporter's markup with respect the market share:

$$\frac{d\log(\frac{p_x}{v})}{d\log(S_d^*)} = \frac{S_d^*\left(\frac{1}{\gamma}-\frac{1}{\rho}\right)}{1-\frac{1}{\rho}\left(1-S_d^*\right)-\frac{1}{\gamma}S_d^*}.$$

As is clear from the formula, the size of the firm matters the most, as the elasticity of the markup with respect to the market share turns out strictly increasing in market share S_d^*. This implies that having large firms in the model makes markups sensitive to changes in their market share, amplifying pricing-to-market implications of this framework. Atkeson and Burstein (2008) quantitatively meet the above requirement for PTM by matching the size distribution of firms in the data. In our quantitative analysis, since all firms are identical, we satisfy the 'large exporting firm' requirement by assuming the most extreme possibility of just one exporting firm ($n_X = 1$). This approach is consistent with the idea of finding the upper bound of PTM this model is capable of delivering.

The intuition behind PTM in the *Industry Aggregation* model is then as follows. After a positive productivity shock in the domestic country, the market shares of domestic firms at home and abroad typically go up, which decreases the elasticity of demand in both markets, and raises markups in both markets. However, because initially there is aggregate home bias in consumption (by assumption), consumption of good d abroad goes up by more in percentage terms than consumption of good d at home. As a result, the perceived demand elasticity in the export market goes down by more than the elasticity in the domestic market, and so export markups rise relative to the domestic markups on the same good. Quantitatively, this increase is accompanied by a real exchange rate depreciation, and the export markup increase is large enough to actually raise the export price, implying a positive correlation of the export prices with the real exchange rate (despite falling marginal cost), consistent with the data.[17]

We next investigate its quantitative potential to deliver a plausible range of pricing to market coefficients.

Quantitative Potential of the Industry Aggregation Model As noted above, market share movement in response to exchange rates is critical for pricing to market to arise in this model. Below, we ask how large these market share movements need to be for the model to be consistent with the estimates of the empirical pass-through of exchange rates into export prices of at least 35%, given the business cycle frequency volatility of the real exchange rate of 3.97% (US quarterly data, 1984-2009).

To answer this question, we assume that only market shares co-vary with the real exchange rates—an assumption justified by the fact that other components of the prices are typically con-

[17] Our setup, as opposed to the original, does not have an explicit link between entry and size generated by firm level heterogeneity and fixed cost of entry. This could potentially generate additional effects. However, the analysis in Atkeson and Burstein (2008) suggests that this is not a critical feature for any of the results.

trolled for in the empirical estimates of exchange rate pass-through. The theoretical pass-through coefficient implied by the model (at the steady state) is

$$PT \equiv \frac{d\log p_x}{d\log x} = \left.\frac{S_d^*\left(\frac{1}{\gamma}-\frac{1}{\rho}\right)}{1-\frac{1}{\rho}\left(1-S_d^*\right)-\frac{1}{\gamma}S_d^*}\right|_{ss}\frac{d\log \hat{S}_d^*}{d\log x},$$

By plugging in the required value of pass-through ($PT = 0.35$), we obtain the lower bound for the elasticity of market shares with respect to exchange rates

$$\frac{d\log \hat{S}_d^*}{d\log x} \geq 0.35 \times \left.\frac{1-\frac{1}{\rho}\left(1-S_d^*\right)-\frac{1}{\gamma}S_d^*}{S_d^*\left(\frac{1}{\gamma}-\frac{1}{\rho}\right)}\right|_{ss}.$$

The right-hand side of the above formula tells us how much the foreign market shares must move (in percentage terms) in response to a 1% change of the real exchange rate change to deliver exchange rate pass-through of 35% to export prices.

The derived lower bound depends only on the elasticity parameters and steady state market shares. Hence, we can evaluate it using the values of calibrated parameters and the targeted aggregate import shares. Since higher S_d^* helps the model to generate more PTM, in order to give it the best chance, we follow our parameterization by assuming $n_X = 1$—implying that the market share of an average exporting firm is equal to an aggregate import share of a country. Furthermore, we choose sectoral import share S_d^* of 16.5% based on the numbers reported by Atkeson and Burstein (2008)[18], as well as their elasticity parameters.[19]

Given the aforementioned values of all the parameters, our evaluation implies that the market shares in the model must be at least 1.8 more volatile than the real exchange rate. As mentioned above, we view this as the most favorable calculation of the model, as the same calculation using our calibrated parameter values is as high as 4.4 ($S_d^* = .12, \rho = 8.7, \gamma = 1.52$). Comparing to the data, 1.8 is still a bit too high. In the US data, the relative volatility of the (aggregate) import share relative to the real exchange rate is about 1.20.[20]

Our conclusion is that this friction can deliver high levels of exchange rate pass-through to

[18] Average of exports and imports of manufacturing goods in the US divided by gross manufacturing output.

[19] In Atkeson and Burstein (2008), these elasticities have been chosen to align the quantitative model with the producer markups of 30% and an equal expenditure share across industries. In our specification, we target the same level of markups and predicted theoretical pass-through of 40%.

[20] To calculate this number we have rescaled nominal series for GDP by a constant equal to the share of non-service sectors in GDP (for year 2000). Then, we have subtracted exports of goods to obtain the domestic absorption as measure of domestic sectoral output. For imports we have used series for imports of goods to the US. The time period is 1984:2009. Volatility of the real exchange rate for this period is 3.97% (IMF IFS), and it has been used to relate it.

export prices for a reasonable range of producer markups, but on the business cycle frequency, this will most likely generate excessively volatile market shares.

4.4 Deep Habits

The formulas for prices in the *Deep Habits* model depend on the target market-specific shadow value of habit ψ. Specifically, the real export and home prices of good d are given by

$$p_x(s^t) = v(s^t) + \Delta_d^*(s^t) - (1-\rho)\,\psi_d^*(s^t) \text{ and } p_d\left(s^t\right) = v(s^t) + \Delta_d(s^t) - (1-\rho)\,\psi_d(s^t),$$

where

$$\Delta_d(s^t) = \frac{p_d(s^t)}{\phi} \text{ and } \Delta_d^*(s^t) = \frac{x(s^t)p_d^*(s^t)}{\phi}, \tag{12}$$

and

$$\psi_d\left(s^t\right) = \sum_{s_{t+1}} Q\left(s_{t+1}, s^t\right)\mu\left(s^{t+1}|s^t\right)\left[\rho\psi_d\left(s^{t+1}\right) + \Delta_d\left(s^{t+1}\right)\frac{\theta\,(1-\varphi)\,d^c\left(j, s^{t+1}\right)}{h_d\left(j, s^t\right)}\right], \tag{13}$$

$$\psi_d^*\left(s^t\right) = \sum_{s_{t+1}} Q\left(s_{t+1}, s^t\right)\mu\left(s^{t+1}|s^t\right)\left[\rho\psi_d^*\left(s^{t+1}\right) + \Delta_d^*\left(s^{t+1}\right)\frac{\theta\,(1-\varphi)\,d^{c*}\left(j, s^{t+1}\right)}{h_d^*\left(i, s^t\right)}\right]. \tag{14}$$

In the above expressions, Δ represents the shadow cost of selling an additional unit of output today, and it is implied by the loss of markups on existing sales due to an underlying fall in the price. ψ represents the shadow value of habit, and is given by a recursive asset pricing equation involving an exogenous depreciation of habit determined by $1-\rho$, and a per unit 'dividend payment' equal to the reduced future cost of sales by an additional unit of habit.[21]

The formulas for prices reveal that pricing to market in this model crucially depends on the dynamics of the shadow value of habit. In fact, after substituting Δ into the expressions above, we can see that in the absence of ψ, the export price is proportional to the marginal cost, just like in the Dixit-Stiglitz model:

$$x(s^t)p_d\left(s^t\right) = \frac{\phi}{\phi-1}\left[v(s^t) - (1-\rho)\psi_d^*\right].$$

What determines the value of habit? Qualitatively, multiple factors, including the discount factor

[21] Note that the expression $\theta\,(1-\varphi)\,d^c\left(j, s^{t+1}\right)/h_d\,(j,t)$ that appears in the formula for ψ is equal to the derivative of the demand function faced by the monopolist w.r.t. h_d.

and future evolution of prices. Quantitatively, we find the following effect as the most important in driving the response of prices to a positive productivity shock: When marginal cost v falls persistently in the model due to a shock, due to persistently lower cost and prices (even if markups were constant), home producers are likely selling more today and in the future. As a result, due to the higher expected future sales by them, habit today becomes more valuable (term $\theta(1-\varphi)\, d^c\left(j, s^{t+1}\right)/h_d\left(j, s^t\right)$ goes up). Consequently, in order to build up habit, producers slash markups below the Dixit-Stiglitz benchmark and price to market.

Quantitative Potential of the Habit Model With productivity shocks, the model generates a *negative* pass-through of exchange rates to export prices. More precisely, after a persistent positive productivity shock in the home country, home firms expect to sell more abroad in the future, which makes habit abroad more valuable today, and thus results in lower markups on exported goods. Moveover, the markups abroad fall more than markups at home, as under home-bias, in this class of models the increase in demand abroad is larger than the increase at home (in percentage terms).[22]

Based on this analysis, we conclude that the model requires a particular correlation between real exchange rate movements and the value of habit. This property will not in general hold for all kind of shocks/model environments, even though there are shocks which do imply such correlation, as demonstrated by Ravn et al. (2007).[23]

5 Parameterization

All models are parameterized in a uniform way (whenever possible). The common targets we use are: (*i*) imports/GDP ratio of 12% (US data), (*ii*) 30% producer markups, (*iii*) 30% work hours relative to time endowment, and (*iv*) short-run elasticity of trade flows of 0.7, as measured by volatility ratio (see Appendix C for details), except for the *Industry Aggregation* friction, discussed below.

The parameters $\beta, \sigma, \delta, \alpha$, are parameterized in a standard way. Productivity shock process

[22] The same conclusion applies when the underlying shocks are standard demand shocks multiplying the utility function of a representative consumer – an exception is a particular specification of demand shocks proposed by Ravn et al. (2007). In that setup, additive demand shocks generate incomplete pass-through because they are combined with an additional habit formation imposed on the government consumption generating demand shocks. As a result, government expenditures creates an externality that lowers markups in the entire economy. This effect flips the correlation of the real exchange rate with the shock—which in this case depreciates following a positive demand shock at home rather than appreciates.

[23] We do not report here the results from the additive formulation of the *deep habits* model, but we have studied this variation as well, and the same conclusions apply.

Table 1: Parameter Values in the Models.

Parameter	Baseline	Variation (model w/ asterisk)
Common parameters		
σ	2.0	
β	0.99	
α	0.36	
δ	0.025	
Consumer Search, Consumer Search*		
η	0.325	n.a.
ω	0.643	0.7562
θ	1.73	11.193
$\bar{z}$	n.a.	5.46
γ	2.0	1.76
q	0.148	0.1051
ϕ	n.a.	8.5
κ	n.a.	0.033
Deep Habits		
θ	-0.1	
ρ	0.85	
γ	0.675	
$\bar{l}$	10	
φ	3.48	
Costly Distribution, Costly Distribution*		
ω	0.6680	n.a.
θ	8.7	8.0
ξ	1.33	0.8
γ	1.63	1
δ	as above	.1 (annualized)
β	as above	.96 (annualized)
$\bar{z}^N$ (rel. prod. of NT-sector)	n.a.	0.5
Industry Aggregation		
n	4	
n_X	1	
ρ	8.7	
γ	1.52	
τ	0.1525	

is common across all models, and symmetric across countries. The persistence parameter is .91, volatility of measured TFP residuals is 0.00608, and the correlation between measured TFP residuals is .28. In the case of Corsetti and Dedola (2005) the process has been taken directly from Corsetti, Dedola, and Leduc (2008) (See the Appendix B for more details).

We now turn to the description of the specifics of the calibration unique to each friction. The values of all parameters are summarized in Table 1.

Consumer Search We parameterize this friction by requiring that the following additional targets from the original paper are met: (*i*) shopping time relative to work time of 25%, as reported by Alessandria (2009), and (*ii*) coefficient of variation of the posted prices of 25%.

Because our main specification of the friction differs from the original paper, we no longer target the share of search in time endowment of households as Alessandria (2009) does. An analog of this share in our model is the fraction of GDP that is used in the distribution sector. In our setup, it is endogenously implied by the model, and accounts for 60% of the total value added produced in the economy. Since higher values help the model, and we are seeking an upper bound in terms of PTM implications, we adopt this number. Nevertheless, one should keep in mind that this number is large, for example, relative to the size of retail and distribution sectors as a whole (38% of total value added in non-service sector in the US data for year 2000).

Consumer Search* The parameterization of this setup follows closely the original paper. All targets of the original paper are met, but the exact values of the parameters are slightly different because the value of the common parameters are different.

Following the original paper, we use quasi-linear utility,

$$u(c,l) = \frac{c^{1-\sigma}}{1-\sigma} - \kappa l,$$

and introduce shocks to κ (labor-wedge shock).

In the calibration, the shock is backed out from the data on real wages and consumption, and labor-leisure choice first order condition implied the household's problem:

$$\kappa = \frac{w_t}{P_t} c^{-\sigma}.$$

Business cycle volatility of this object is about 4.5% in the US data, and it allows the model to match closely the volatility of the real exchange rate. Following the original setup, we also include a convex cost of capital adjustment (governed by parameter ϕ), which tames the otherwise too high volatility of investment.[24]

Costly Distribution We parameterize the friction by requiring that distribution costs constitute 50% share of 'non-tradable' inputs in retail prices (as implied by Burstein, Neves, and Rebelo (2003)).

Costly Distribution* The model has been parameterized similarly as in the original paper. The baseline period is one year, and all parameters have been adjusted to this frequency. The stochastic process has been taken from Corsetti, Dedola, and Leduc (2008). All targets of the original paper are met and all main parameters take the same value. However, unlike the original model, this version of the model does not include monetary shocks and sticky wages.

Industry Aggregation The most important parameters for pricing-to-market are: the number of firms chosen in the model, and the difference between the elasticities, γ and ρ. In terms of the number of firms, as pointed out by Atkeson and Burstein (2008), the presence of large firms is crucial for generating pricing to market. In the original paper, there is a large number firms (40), but firm size heterogeneity implies that only a few large ones really matter for (export) prices. In our specification of their friction, due to assumed representativeness, all firms need to be of equal size. Therefore, we set the total numbers of firms to a low number of firms ($n = 4$), and make an extreme assumption that only one firm exports ($n_X = 1$). The setting of the two parameters is consistent with the ratio ($\frac{n_X}{n}$) taken from Atkeson and Burstein (2008).

To calibrate the value of the elasticity parameters γ and ρ, we note that the difference between these elasticities maps onto the degree of pass-through generated by the model, and their weighted average determines the average level of producer markups. Consequently, we choose these numbers to match a coefficient of pass-through of exchange rates to export prices of 40% and producer markups of 30% (as in the original paper).

[24]This calibration of the model crucially differs from the baseline specification outlined before. Unlike in our version of the setup, here shopping time is counted as home production rather than market production. This imposes an additional restriction on the parameter values, requiring, for example, that search time is consistent with the American Time Use Survey (ATUS) number of about 25% of work time.

Deep Habits As for the habit parameters, θ and ρ, we adopt the values from Ravn, Schmitt-Grohe, and Uribe (2006) for their relative habit specification, which corresponds to our modeling of the habit.

6 Quantitative Analysis

6.1 Data

To set the quantitative goal for the theories, we compute moments characterizing the dynamics of export prices. We are motivated by the following decomposition of the export price movements:

$$p_x \equiv \frac{P_X}{P} = \underbrace{\frac{P_X}{P_D}}_{p_d^x} \times \underbrace{\frac{P_D}{P}}_{p_d}, \tag{15}$$

where P_X denotes the home currency based price of exported good (basket), P_D denotes a home currency based producer price of a comparable tradable good (basket) sold at home, and P is some measure of the overall price of aggregate consumption in the home country, measured by CPI.

This decomposition allows us to split the movements of the export prices into pure deviation from LOP p_d^x, and the residual relative price movements specific to the home market p_d. In most models, P_X and P_D will correspond to the price of the same commodity, and so p_d^x will be a good test of the model's capability to generate deviations from LOP. As we will see below, in the data p_d^x is highly volatile and highly positively correlated with the real exchange rate. The frictionless model implies that this term is constant, and all frictions considered here make it variable.

To document properties of prices in the aggregate data, we first use US data on producer export price index (EPI) from the BEA to measure export prices, and a comparable index for producer prices of finished products excluding food and energy (PPI) to measure home prices of comparable tradable basket.[25] We have excluded food and energy because these components are likely to be volatile for reasons unrelated to business cycle fluctuations. To measure the price of aggregate consumption, we use CPI that excludes food and energy for consistency (the findings do not depend on this). All our data is quarterly for the time period (1983-2010), and statistics are based on logged and HP filtered time series (smoothing 1600).

[25] The PPI data confounds both export prices and domestic prices, and is only an approximate measure of P_D. However, for our particular application this is sufficient, as it will only imply that our conclusions establish the lower bound for the underlying deviations from LOP implied by the aggregate data.

Table 2: Deviations from LOP in Aggregate Data.

Statistic	Value
A. Properties of Aggregate Real Export Price	
$\sigma(p_x)/\sigma(x)$	.52
$\rho(p_x, x)$	.47
B. Deviations from LOP	
$\sigma(p_d^x)/\sigma(x)$	.53
$\rho(p_d^x, x)$	.51
C. Residual	
$\sigma(p_d)/\sigma(x)$	.13
$\rho(p_d, x)$	-.18

σ denotes the standard deviation of logged and HP filtered data, ρ denotes the correlation coefficient.

Table 2 summarizes the results. Panel A shows that aggregate real export price in the US is relatively volatile, and also highly positively correlated with the real exchange rate. On the basis of our decomposition, and the statistics included in panel B, we conclude that most of the movements in the real export price are attributable to the deviations from LOP. In fact, the deviations from LOP captured by the relative price p_d^x are at least 4 times more volatile than the residual p_d , and are almost the sole driver of the observed positive correlation between the aggregate real export price and the real exchange rate. These findings are consistent with the idea of a positive but incomplete pass-through of exchange rates to export prices.

6.2 Predictions of the Leading PTM Models

Quantitative predictions of the parameterized models are reported in Tables 3 and 4. As we can see from Table 3, panel B, all models generate some degree of pricing-to-market, as expected. Overall, compared to US data, most statistics look well qualitatively, but the models fall short in generating enough incompleteness of pass-through. Furthermore, as pointed out before, the Ravn, Schmitt-Grohe, and Uribe (2006) model generates pricing to market that gives rise to generally counterfactual correlations of the aggregate price indices (Panel A of Table 3).

Below, we discuss each friction's quantitative predictions, and also include the Frictionless Model's predictions as a baseline.

Consumer Search, Consumer Search* Despite a low degree of theoretical pass-through predicted by the model, the friction implies large deviations from LOP as measured by the relative

Table 3: International Prices: Comovement and Relative Volatility[a]

		Predictions of the PTM Theories						
Statistic	Data[b]	Frictionless Model	Consumer Search	Consumer Search*	Costly Distribution	Costly Distribution*[d]	Industry Aggregation	Deep Habits
A. Correlations								
p_x, x	0.47	-1.00	1.00	0.82	1.00	0.52	0.98	-0.95
p_d^x, x	0.51	0.02	1.00	0.98	1.00	0.98	1.00	-0.83
p_d, x	-0.18	-1.00	-1.00	0.11	-1.00	0.27	-1.00	-0.97
B. Standard deviations								
x	3.97	0.45	0.55	3.67	0.54	1.86	0.31	0.51
relative to[c] x								
p_x	0.52	0.16	0.18	0.26	0.04	0.83	0.23	0.36
p_d^x	0.53	0.00	0.30	0.20	0.17	0.24	0.35	0.12
p_d	0.13	0.16	0.12	0.14	0.13	0.76	0.11	0.17
C. X-Rate Pass-through								
	35%-50%	0%	23%	18%	15%	20%	40%	n.a
D. Producer Markups								
	30%	0%	30%	22%	30%	40%	30%	30%

[a] All reported statistics are based on logged and Hodrick-Prescott filtered quarterly time series (with a smoothing parameter $\lambda = 1600$).
[b] Data for the US, 1984:1-2009:4.
[c] Ratio of corresponding standard deviation to the standard deviation of the real exchange rate x.
[d] The model has been calibrated to annual frequency and the statistics generated are not readily comparable to the ones listed in data column.

Table 4: Quantities - Comovement and Relative Volatility[a]

Statistic	Data[b]	Predictions of the PTM Theories: Frictionless Model	Consumer Search	Consumer Search*	Costly Distribution	Costly Distribution*[d]	Industry Aggregation	Deep Habits
A. Correlations								
domestic with foreign								
Measured TFP[c]	0.30	0.30	0.34	0.44	0.33	0.54	0.31	0.30
GDP	0.40	0.36	0.40	0.50	0.38	0.56	0.17	0.37
Consumption	0.25	0.33	0.30	0.61	0.32	0.54	0.73	0.40
Employment	0.21	0.49	0.52	0.43	0.50	0.55	0.05	0.55
Investment	0.23	0.19	0.24	0.56	0.23	0.31	0.32	0.26
GDP with								
Consumption	0.83	0.95	0.95	1.00	0.96	0.99	0.94	0.95
Employment	0.85	0.98	0.98	0.96	0.98	0.91	0.99	0.97
Investment	0.93	0.67	0.67	0.73	0.67	0.45	0.64	0.67
Net exports	-0.49	-0.57	-0.54	-0.49	-0.56	-0.87	0.58	-0.56
Terms of trade with								
Net exports	-0.17	-0.84	-0.86	-0.86	-0.86	-0.77	0.98	-0.93
B. Standard deviations								
GDP	1.33	1.13	1.18	2.45	1.15	2.05	1.55	1.08
relative to GDP[d]								
Measured TFP	0.60	0.70	0.67	0.32	0.69	0.89	0.51	0.74
Consumption	0.74	0.33	0.36	0.84	0.36	0.78	0.44	0.38
Investment	2.79	3.24	3.76	2.76	3.77	3.00	2.78	3.81
Employment	0.81	0.47	0.50	1.30	0.47	0.17	0.75	0.41
Net exports	0.30	0.14	0.13	0.04	0.13	0.11	0.21	0.13

[a] All reported statistics are based on logged and Hodrick-Prescott filtered quarterly time series (with a smoothing parameter $\lambda = 1600$).
[b] US data for the period 1980:1-2004:1.
[c] Calculated using the actual national accounting formulas; due to time varying markups measured TFP slightly differs from the TFP coefficient fed into the models.
[d] Ratio of corresponding standard deviation to the standard deviation of *GDP*.
[e] The model has been calibrated to annual frequency and the statistics generated are not readily comparable to the ones listed in data column.

price p_d^x. At the same time, the real export price p_x is not volatile enough relative to the volatility of the real exchange rate x. The reason for that is that the model implies a relatively volatile home marginal cost v relative the real exchange rate x. As we can see from column 4 of Table 3, the *Consumer Search** model improves on this by introducing an additional shock, and by matching the volatility of the real exchange rate. We conclude that this particular property is more of an artifact of too low volatility of the real exchange rate relative to marginal cost.

The *Consumer Search* model does well in accounting for the quantity-related statistics. However, part this success is can be attributed to our particular specification of the friction that effectively makes a large share of GDP to be a non-tradable distribution/search sector. In our baseline specification more than half of the GDP is accounted for by the value added generated in the final good sector (search). Such large share would help all models to come closer to the data in this respect. In contrast, the *Consumer Search** model, by treating shopping as home production and by adding an extra shock, is no longer neutral to quantities. The model results in excess output volatility, and excess employment volatility and international consumption correlation. Our conclusion is that the *Consumer Search* specification is not fully neutral to business cycle dynamics of quantities.

Costly Distribution, and Costly Distribution* The model results are similar to *Consumer Search* model, but due to a slightly different dependence of export prices on markups, the performance of the *Costly Distribution* model for prices is strictly worse. As discussed in Section 4, this is a robust feature of this friction and is due to the fact that in the case of *Consumer Search* the entire markup is denominated in the foreign unit, as opposed to only part of it in the case of *Costly Distribution*. Specifically, the *Costly Distribution* parameterization severely underpredicts the volatility of the export price relative to the real exchange rate and implies the smallest pass-through of all of the frictions save *Deep Habits*. On the other hand, the *Costly Distribution** parameterization, while improving the pricing predictions, deteriorates the quantity predictions, implying too much volatility of output and excess international correlation of consumption.

Industry Aggregation The *Industry Aggregation* friction performs well on prices, that is, it generates a high degree of exchange rate pass-through to export prices. However, quantity statistics look worse when compared the other frictions or the frictionless model. This should not surprise given a high setting of international elasticity between home and foreign goods needed for pricing to market to arise. Specifically, the model implies a too low international comovement of GDP relative to TFP, and an excess international comovement of consumption. In addition, despite capital accumulation being present, it implies a positive correlation of net exports and output, versus a negative one in the data and in the other models.[26]

Deep Habits For reasons discussed in Section 4, the *Deep Habits* friction implies counterfactual correlations of international prices (panel A of Table 3), and hence implies negative pass-through. On the quantities side, the model performs well, similar to other frictions.

7 Conclusions

In this paper, we provide the first unified study of several leading pricing to market frictions. We evaluate these frictions from the point of view of DSGE models that are required to be consistent with a broad range of statistics, and ask the question how useful are these friction to bring prices closer to the data without compromising model performance in other dimensions. We also identify key predictions of these model and requirements for PTM to arise. We view these findings as useful in guiding researchers in developing empirical strategies to discriminate between these theories.

References

Alessandria, George, 2009, Consumer Search, Price Dispersion and International Relative Price Volatility, *International Economic Review.*

Atkeson, Andrew, and Ariel T. Burstein, 2008, Pricing-to-Market, Trade Costs, and International Relative Prices, *American Economic Review.*

Backus, D.K., P.J. Kehoe, and F.E. Kydland, 1992, International Real Business Cycle, *Journal of Political Economy* 100, 174–1775.

Backus, D. K., P. J. Kehoe, and F. E. Kydland, 1995, International Business Cycles: Theory and Evidence, in T. Cooley, eds.: *Frontiers of Business Cycle Research* (Chapter 11, pp. 331-356, Princeton, NJ: Princeton University Press,).

Basu, S., and J. G. Fernald, 1997, Returns to Scale in U.S. Production: Estimates and Implications, *Journal of Political Economy* 105(2), 249–283.

Burdett, K., and K. L. Judd, 1982, Equilibrium Price Dispersion, *Econometrica* 51(4), 955–969.

Burstein, Ariel, and Gita Gopinath, 2014, International prices and exchange rates, in *Handbook of international economics* (Elsevier,).

[26]Note also that since pricing to market arises due to market share movements, once the model is required to match real exchange rate volatility from the data, it may be harder than in the case of other models to tame quantities by introducing additional features. To retain the same degree of PTM, for example, it would require market shares to more volatile by an order of magnitude.

Burstein, A. T., J. C. Neves, and S. Rebelo, 2003, Distribution Costs and Real Exchange Rate Dynamics, *Journal of Monetary Economics*.

Butters, Gerard R, 1977, Equilibrium Distributions of Sales and Advertising Prices, *The Review of Economic Studies* 44, 465–491.

Christopoulou, Rebekka, and Philip Vermeulen, 2012, Markups in the Euro area and the US over the period 1981–2004: a comparison of 50 sectors, *Empirical Economics* 42, 53–77.

Corsetti, G., and L. Dedola, 2005, Macroeconomics of International Price Discrimination, *Journal of International Economics* 67(1), pp, 129–156.

Corsetti, G., L. Dedola, and S. Leduc, 2006, Productivity, External Balance and Exchange Rates: Evidence on the Transmission Mechanism Among G7 Countries, *in Lucrezia Reichlin and Kenneth West (eds.) NBER International Seminar on Macroeconomics*.

Corsetti, G., L. Dedola, and S. Leduc, 2008, International Risk-Sharing and the Transmission of Productivity Shocks, *Review of Economic Studies* 75, 443–473.

Drozd, Lukasz A, and Jaromir B Nosal, 2012, Understanding international prices: Customers as capital, *American Economic Review* 102, 364–95.

Goldberg, L., and J. Campa, 2005, Exchange Rate Pass-Through into Import Prices, *Review of Economics and Statistics*.

Goldberg, P. K., and M. M. Knetter, 1997, Goods Prices and Exchange Rates: What Have We Learned?, *Journal of Economic Literature* 35, 1243–1272.

Gopinath, Gita, and Oleg Itskhoki, 2011, In search of real rigidities, *NBER Macroeconomics Annual* 25, 261–310.

Heathcote, J., and F. Perri, 2004, Financial Globalization and Real Regionalization, *Journal of Economic Theory* 119, 207–243.

Johri, Alok, and Amartya Lahiri, 2008, Persistent Real Exchange Rates, *Journal of International Economics* 76, 223–236.

Martins, Joaquim Oliveira, Stefano Scarpetta, and Dirk Pilat, 1996, Mark-up ratios in manufacturing industries: estimates for 14 OECD countries, .

Oliveira Martins, Joaquim, and Stefano Scarpetta, 1999, The levels and cyclical behaviour of mark-ups across countries and market structures, *Organisation for Economic Co-operation & Development, Economics Department Working Paper*.

Ravn, Morten, Stephanie Schmitt-Grohe, and Martin Uribe, 2006, Deep Habits, *Review of Economic Studies* 73, 195–218.

Ravn, Morten, Stephanie Schmitt-Grohe, and Martin Uribe, 2007, Pricing to Habits and the Law of One Price, *American Economic Review Papers and Proceedings* 97, 232–238.

A National Accounts in the Model

Real GDP is real GDP in constant prices (≡steady state prices). Since the price of consumption/investment good is normalized to one, consumption and investment in period zero prices are c and i. Employment index is measured by $l_{i,t}$.

In deflation of the prices and measurement of real exchange rate, we have used the ideal CPI. This does not make any difference except for Consumer Search friction. In the case of this model, the transacted prices differ from the posted price (CPI measurement should be based on posted prices). However, since in the data such distinction does not make any difference for any of the patterns we focus on[27] we have decided to use the ideal CPI to abstract from any implications of the model coming from this channel.

[27] I.e exactly analogous patterns can be documented by instead using PCE deflator or GDP deflator,

B Estimation of the Productivity Shock Process

To construct the TFP residuals z from the data we follow a similar procedure to Heathcote and Perri (2004), and include physical capital. Physical capital has been constructed from the gross-fixed capital formation series using perpetual inventory method with exogenously assumed depreciation rate of $\delta = 0.025$. For the US we have used total hours worked, and for the rest of the world civil employment index instead. Given the quarterly data-set from 1980.1 to 2004.3 for the aggregate of main 15 European countries, Japan, Canada, Switzerland, and Australia, we have constructed the series of z from the following equation

$$\log(z) = \log(y) - 0.36 \log(k) - 0.64 \log(n),$$

where y denotes GDP in constant prices, and the coefficient 0.64 denotes the assumed share of labor income in GDP - consistent with the parameterization of the model and the values estimated for the developed countries. We linearly detrend the series for $\log(z)$, and estimate the parameters of the underlying productivity process. In the case of Corsetti and Dedola (2005) the process has been taken directly from Corsetti, Dedola, and Leduc (2008)—which limits our analysis to annual frequency.

C Measurement of Short-run Price Elasticity of Trade

Short-run elasticity of trade flows measures how trade flows between countries respond to a relative price changes seen in the time-series. Here, we use the so called volatility ratio, introduced by Drozd and Nosal (2012), to assess the lower bound for this elasticity.
When the demand for domestic and foreign good is modeled by a CES aggregator of the form

$$G(d_t, f_t) = \left(\omega_t d_t^{\frac{\gamma-1}{\gamma}} + (1 - \omega_t) f_t^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}},$$

the import ratio $\frac{f_t}{d_t}$ is intimately related to the relative price of domestic and imported goods $\frac{p_{d,t}}{p_{f,t}}$:

$$\log \frac{f_t}{d_t} = \gamma \log \frac{p_{d,t}}{p_{f,t}} + \log \frac{\omega_t}{1 - \omega_t}. \quad (16)$$

Thus, in the case of time-varying weights ω, the above approach gives the upper bound value for the value of this parameter:

$$\gamma = \sigma(\log \frac{f_t}{d_t}) / \sigma(\log \frac{p_{d,t}}{p_{f,t}} + \frac{1}{\gamma} \log \frac{\omega_t}{1 - \omega_t}) \leq \sigma(\log \frac{f_t}{d_t}) / \sigma(\log \frac{p_{d,t}}{p_{f,t}}) = VR. \quad (17)$$

Based on the median value for OECD countries, we this way obtain the upper bound on elasticity γ to be .7 on quarterly frequency. In models with frictions, VR does not map onto γ, and so we instead construct the analogous object in the model, and set γ so that the model implied VR is .7.

D Data Sources

Export prices and PPI data comes from BEA. Real exchange rate data comes from International Monetary Fund, International Financial Statistics Database, 2010. Prices for Japan come from Bank of Japan and have been compiled by the authors from flat files available online. To construct TFP residuals used in the estimation of the stochastic process, we have used nominal GDP data from World Development Indicators, World Bank, Gross Fixed Capital Formation, GDP in constant prices and Civil Employment from Source OECD.org, Quarterly National Accounts, series for physical capital have been constructed using the perpetual inventory method with a constant depreciation of 2.5%, and aggregate GDP for blocks of countries has been computed from growth rates of GDP in constant prices (recent years, varies by country) weighted by the nominal GDP of each country in 2000 (we applied the growth rates backwards). Statistics pertaining to quantities that appear in the paper have been calculated from the same data.