Deep Habits and Exchange Rate Pass-through *

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Abstract

We propose a candidate solution to the imperfect exchange rate pass-through puzzle: habit persistence at the level of individual goods varieties. Deep habits generate a dynamic import demand function that leads to import price markup adjustments, independently of nominal pricing frictions. Augmenting a standard two-country model with deep habits, we obtain low exchange rate pass-through to import prices even when prices are relatively flexible. We match the model dynamics to those triggered by an identified shock to the US dollar exchange rate in a VAR. In the absence of deep habits, the model requires implausibly high degrees of price stickiness to match the inertial response of US import prices.

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1 Introduction

The coexistence of highly volatile exchange rates with import prices that are quite stable in local currency, has intrigued international macroeconomists for long.\footnote{See Burstein and Gopinath (2014) for a comprehensive review of the literature.} Imperfect exchange rate pass-through to the prices of internationally traded goods and the ensuing deviations from the law of one price have important implications for consumer welfare and the design of monetary policy (Monacelli, 2005). The workhorse open-economy dynamic stochastic general equilibrium (DSGE) model has mainly appealed to nominal price rigidities in local currency to replicate the imperfect exchange rate pass-through observed in the data (see e.g. Jacob and Peersman, 2013, Adolfson et al., 2007, Choudhri et al., 2005 and Devereux and Engel, 2002). However, econometric evidence presented in Gopinath, Itskhoki, and Rigobon (2010) suggests that exchange rate pass-through to local currency import prices is low even conditional on a price change by the importing firm. In other words, firms do not appear to fully pass through the change in their import costs induced by the fluctuation in the exchange rate, to the consumer even they can change prices. An implication of this finding is that nominal price stickiness, while being a convenient shortcut, may be less compelling as an explanation of the empirical observation.

We advance a theoretical framework to understand imperfect exchange rate pass-through even in environments where the firm can potentially adjust nominal prices fairly easily to respond to the change in the exchange rate, \textit{i.e.} pricing frictions are negligible. To this end, we augment a standard New Keynesian two-country economy with habit persistence at the level of individual goods varieties. Deep habits, originally modelled in Ravn, Schmitt-Grohé, and Uribe (2006), considers the possibility that consumers form habits separately over more narrowly defined categories of goods and not at the aggregate level, over final consumption expenditures. A direct consequence of this type of habit persistence is that the demand for the individual good is influenced by a predetermined habitual component so that the firm’s profit-maximization program becomes intertemporal, irrespective of the presence of price rigidities. In an economy with deep habits, a unit sale generates profits not only in the current period but also into the future due to the strength of habit persistence, and the firm can optimally smooth demand and profits over time. Importantly, in this environment, a change in price has strong effects on the
entire expected trajectory of future demand. In the context of the open economy, the importer realizes that passing through a depreciation of the exchange rate to the consumer by raising prices, may result in a loss of market share stretching far into the future. For this reason, the importing firm has an incentive to absorb the exchange rate movement into its price markup. In sum, in our model, sticky quantities - as opposed to sticky prices - can generate markup adjustments and deliver inertial pass-through of nominal exchange rate fluctuations into import prices.

We demonstrate that deep habits are able to generate imperfect pass-through even when nominal pricing frictions, modelled using standard convex adjustment costs à la Rotemberg (1982), are very weak. In a suite of simulation experiments, we find that low pass-through can be obtained both by strengthening habits at low degrees of price stickiness, and - as in the conventional case - by abstracting from habits and merely increasing price adjustment costs. Used in conjunction, deep habits and sticky prices complement each other to dampen import price movements easily, since both frictions enhance the absorption of the exchange rate fluctuation into the import price markup. We then empirically validate the deep habits model by matching the dynamics of the model triggered by an exchange rate shock to those induced by an identified shock to the US nominal effective exchange rate in a vector autoregression (VAR). Again, we find that deep habits and sticky prices complement each other in helping the model generate the dynamics observed in the VAR. In contrast, when we deactivate the deep habits channel, the model requires implausibly high values for the price adjustment cost parameter, to replicate the VAR evidence.

We build on the work of Ravn, Schmitt-Grohé, and Uribe (2012) and Ravn, Schmitt-Grohé, and Uribe (2007) who demonstrate that under deep habits, firms face more elastic demand functions in markets where current demand is high relative to habitual demand, creating an incentive to price discriminate. They focus on the role of country-specific demand shocks that change the price-elasticities across markets, to generate variable markups and deviations from the law of one price. In contrast, we emphasize another dimension of markup adjustment in the deep habits economy. While our environment preserves the price elasticity effect of deep habits, it highlights the implication that firms facing dynamic demand functions, have an incentive to smooth sales over time by adjusting price markups in response to shocks to nominal marginal cost. For the purpose of studying imperfect exchange rate
pass-through, we do not use demand shocks but instead rely on a random deviation from strict uncovered interest parity so that there is a more direct stimulus to the nominal cost structure of the exporting firm. Our choice of the exogenous trigger of the business cycle is along the lines of Choudhri, Faruqee, and Hakura (2005) and Devereux and Engel, 2002 who study exchange rate pass-through in conventional New Keynesian open-economy models without deep habits. Finally, we also follow these two papers in introducing price rigidities into our framework. For this reason, unlike the deep habits models of Ravn, Schmitt-Grohé, and Uribe (2012) and Ravn, Schmitt-Grohé, and Uribe (2007), we are able to provide a unified treatment of the potential interaction between frictions on the real and nominal sides in determining the rate of exchange rate pass-through.

Since a shock to the exchange rate is basically a shock to the effective nominal marginal cost of the firm that produces internationally traded goods, this paper is also related to Ravn, Schmitt-Grohé, and Uribe (2010a) who demonstrate the ability of deep habits to generate incomplete pass-through of idiosyncratic cost shocks to the firm’s price level. Hence, at its heart, the treatment of exchange rate pass-through presented here is a generalization of the partial-equilibrium, closed-economy analysis of Ravn et al. (2010a).

In the choice of the source of business cycle fluctuations and on the emphasis on the potential interaction between nominal and real rigidities in general equilibrium, we also depart from alternative models of real rigidities used to generate deviations in the law of one price. These papers have typically abstracted from nominal rigidities and have employed technology or monetary shocks as the source of cyclical movements. In Atkeson and Burstein (2008), quantity competition à la Cournot among firms implies that they do not fully pass through changes in their marginal costs to their prices because their optimal markup depends on their market share. In Corsetti and Dedola (2005), the price elasticity of demand for the intermediate goods producers vary due to the presence of local distribution costs and this creates an incentives for these firms to optimally charge different prices to domestic and foreign dealers. In Gust, Leduc, and Vigfusson (2010), the price elasticity of demand for the individual good is increasing in the price of the good relative to the competitors’ prices. As a result, a foreign exporter finds it optimal to vary its markup in response to shocks, insulating import prices from exchange rate movements. The real rigidities in all three of the above papers are in essence, static in nature. In
contrast, the deep habits model is in spirit akin to the dynamic ‘customers as capital’ framework of Drozd and Nosal (2012), in which firms need to explicitly build market shares by matching with their customers, and this process is costly and time consuming. Consequent market segmentation yields markup adjustment and departures from the law of one price. The dynamic acquisition of customers is latent in the formulation of deep habits. However, in our model, the firm can only attract consumers by lowering its price level and has no access to a marketing technology as in Drozd and Nosal (2012).

2 A Two-Country Model with Deep Habits

2.1 Preliminaries

We modify the open-economy deep habits environment of Ravn, Schmitt-Grohé, and Uribe (2012) in two dimensions. Firstly, we depart from their flexible price framework and introduce nominal rigidities in price and wage setting. Prices are rigid in the currency of the market of the goods’ destination. Secondly, we abstract from government spending. We follow Ravn, Schmitt-Grohé, and Uribe (2012) closely in the exposition of the model and notation that we use. The comprehensive derivation of the model is available in Jacob and Uusküla (2016).

The model involves two symmetric countries populated by representative households and firms. Only the home country’s problem is described here. Each country specializes in the production of a set of differentiated goods. We denote by $a \ (b)$ the set of goods produced by the home (foreign) country. We only consider goods that are internationally traded. Typically, a variable $z$ in the non-stochastic steady-state is presented as $\bar{z}$. A logarithmic deviation of the variable relative to its steady-state in period $t$ is represented as $\hat{z}_t \equiv \frac{\partial z_t}{\bar{z}} = \log \frac{z_t}{\bar{z}}$. In the interests of notational brevity, we avoid using the period $t$ subscript when we describe variables and functional forms in the main text, unless we refer to a dynamic relationship. $\mathbb{E}$ represents the conditional expectations operator while $\Delta$ indicates the temporal difference operator.
2.2 Households

The domestic economy is populated by a large number of identical households indexed by $j$, with preferences described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(\chi^j_t, n^j_t\right), \beta \in (0, 1)$$

(1)

where

$$\chi_t = \left[\omega x_{a,t}^{\xi-1} + (1 - \omega) x_{b,t}^{\xi-1}\right]^\frac{\xi}{\xi-1}, \omega \in [0, 1], \xi > 0$$

(2)

$$U(\chi_t, n_t) = \frac{\chi_t^\phi (1 - n_t)^{(1 - \phi)} 1 - \sigma_c}{(1 - \sigma_c)}, \phi \in [0, 1], \sigma_c > 0$$

(3)

$\chi$ is an aggregated final good that combines a home goods aggregate $x_a$ and an imported aggregate $x_b$ from the foreign country. The preferences defined over the consumption aggregate and hours worked $n$ are given a standard CES form.

2.2.1 Deep Habits

As in Ravn, Schmitt-Grohé, and Uribe (2006), the household forms habits at the level of the individual goods variety produced by the monopolistic firm, as opposed to the aggregated final good. This type of habit-formation is referred to as ‘deep’ or good-specific habits as it differs from the ‘superficial’ habits formed at the level of the aggregate good as in standard models (e.g. Smets and Wouters, 2007). Furthermore, habits are assumed to be external to the individual household, so that the level of average consumption in previous periods is the reference point for the household in their consumption decision. More formally, we can represent habit-adjusted consumption by

$$x_{a,t} = \left[\int_0^1 (c_{i,a,t} - h_a s_{i,a,t-1})^{1-1/\eta_c} d\bar{i}\right]^\frac{1}{1-1/\eta_c}, h_a \in [0, 1], \eta_c > 1$$

(4)

c_{i,a} denotes the consumption of variety $i$ of goods belonging to the set $a$ in each period. $h_a$ governs the degree of habit persistence and in the absence of habit-formation, i.e. $h_a = 0$, the parameter $\eta_c$ denotes the elasticity of substitution

\footnote{For expositional reasons, we will ignore the superscript $j$ for each household in the remainder of Section 2.2.1.}
between goods varieties. For \( h_a > 0 \), \( \eta_c \) represents the long-run price elasticity of habit-adjusted demand for the goods variety. \( s_{i,a} \) denotes the external habit stock of variety \( i \) of good \( a \) and evolves according to the law of motion

\[
s_{i,a,t} = \rho_a s_{i,a,t-1} + (1 - \rho_a) \tilde{c}_{i,a,t}, \quad \rho_a \in [0, 1)
\]

\( \tilde{c}_{i,a} \) is the per capita consumption of good \( i \) of good \( a \) in the home country. The parameter \( (1 - \rho_a) \) denotes the rate at which the habit stock decays over time.

The household distributes its expenditures over all the goods varieties and the demand for the individual variety is determined by the cost-minimization program

\[
\min_{c_{i,a,t}} \int_0^1 P_{i,a,t} c_{i,a,t} \, dt \quad \text{subject to \ (4)}
\]

The demand for good \( i \) of type \( a \) is given by

\[
c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_a} \right)^{-\eta_c} x_{a,t} + h_a s_{i,a,t-1}
\]

where \( P_a = \left( \int_0^1 P_{i,a}^{1-\eta_c} \, dt \right)^{1/(1-\eta_c)} \) indicates a price level for habit-adjusted demand for good \( a \). The demand for each variety is decreasing in its relative price \( P_{i,a}/P_a \) and increasing in \( x_a \) the level of habit-adjusted consumption of the composite good of type \( a \) as well as the habit stock \( s_{i,a,t-1} \). Total expenditure on goods of type \( a \) in period \( t \) can be expressed as

\[
\int_0^1 P_t c_{i,a} \, dt = P_a x_a + \omega_a \quad \text{such that} \quad \omega_a = h_a \int_0^1 P_{i,a,t} s_{i,a,t-1} \, dt.
\]

Imports of good \( b \) from the foreign country is similarly influenced by habit persistence, the demand for the individual imported variety mirrors that for the home variety

\[
c_{i,b,t} = \left( \frac{P_{i,b,t}}{P_{b,t}} \right)^{-\eta_c} x_{b,t} + h_b s_{i,b,t-1}
\]

Ravn, Schmitt-Grohé, and Uribe (2006) demonstrate that the lag structure of the demand functions for the individual varieties alters the firms’ price-setting behavior and induces price markup adjustment in response to structural shocks. In section 3.1, we highlight the role of the predetermined component of import demand in (7) in determining import price markup adjustment and the degree of exchange rate pass-through.

### 2.2.2 Budget Constraint and Optimality Conditions

In each period \( t \geq 0 \), each household \( j \) is assumed to have access to complete contingent claims markets. Let \( r_{t,t+k} \) denoted the nominal stochastic discount factor
such that $E_t r_{t,t+k} d_{t+k}$ is the period-$t$ price of a random payment of the numeraire good in period $t + k$. In addition, households are assumed to be entitled to the receipts of profits $\Pi$ from the ownership of firms. As in Erceg, Henderson, and Levin (2000), each household is a monopolistic supplier of specialised labour $n^j$. A large number of perfectly competitive ‘employment agencies’ aggregates the specialised labour-varieties from the households into a homogenous labour input $n$ using a CES technology and sells it to the representative firm. The employment agency returns to the household a labour-type specific nominal wage $W^j$. The demand function for the labour-type from the firm is given as $n^j = (W^j/W)^{-\eta_n} n$ with $\eta_n > 1$ representing the relative wage elasticity. We also introduce nominal wage rigidities by stipulating that it is costly à la Rotemberg (1982), to change wages. $\psi_w \geq 0$ governs the strength of the wage adjustment cost.

The domestic representative household’s period-by-period budget constraint can be written as

$$P_{a,t} x_{a,t}^j + \omega_{a,t}^j + P_{b,t} x_{b,t}^j + \omega_{b,t}^j + E_t r_{t,t+1} d_{t+1}^j = d_t^j + \left( W_t^j - \frac{\psi_w}{2} W_t \left( \frac{W_{t+1}^j}{\Delta n w W_{t-1}^j} - 1 \right)^2 \right) n_t^j + \Pi_t^j \tag{8}$$

In addition, households are assumed to be subject to a borrowing constraint of the form $\lim_{t \to \infty} E_t r_{t,t+z} d_{t+z} \geq 0$ which prevents them from engaging in Ponzi Games. The household’s optimization problem consists in choosing processes $x_{a,t}$, $x_{b,t}$, $W_t^j$ and $d_{t+1}^j$ to maximize the lifetime utility function (1) subject to (2), (8), labour demand and the No-ponzi-game constraints, taking as given the processes for $\omega_{a,t}$, $\omega_{b,t}$ and $\Pi_t$ and the initial asset holding $d_0$. We describe the optimality conditions in a symmetric equilibrium. The marginal rate of substitution between home and foreign good aggregates equals the ratio of their respective prices.

$$\frac{X_{x_{a,t}}}{X_{x_{b,t}}} = \frac{P_{a,t}}{P_{b,t}} \tag{9}$$

The standard asset pricing relation equates the price of contingent claims to the intertemporal marginal rate of substitution.

$$U_{x,t} x_{x,t}^r_{t,t+1} = \beta E_t \frac{U_{x,t+1} x_{x,t+1}^r}{\pi_{a,t+1}} \tag{10}$$

where gross inflation $\pi_{a,t+1} = P_{a,t+1}/P_{a,t}$. Finally, optimal wage-setting implies that costly wage adjustment drives a wedge between the marginal rate of substitution
between consumption and labour, and the domestic composite good-based real wage \( w_a = W/P_a \). \( \pi^{nw} \) indicates the gross rate of nominal wage inflation.

\[
\mathbb{E}_t \beta \sum_{x_{a,t+1}} \frac{x_{a,t+1}}{x_{a,t}} \frac{n_{t+1}}{n_t} \pi_{t+1}^{nw} \left( \frac{\pi^{nw}_{t+1}}{\pi^{nw}_t} \psi_w \left( \frac{\pi^{nw}_{t+1}}{\pi^{nw}_t} - 1 \right) \right)
= \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} \psi_w \left( \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} - 1 \right) + \eta_t \left[ 1 - \frac{\psi_w}{2} \left( \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} - 1 \right)^2 \right] \frac{\sum_{x_{a,t}} x_{a,t+1} w_{a,t}}{\sum_{x_{a,t}} x_{a,t}} - 1
\]

(11)

\[\mathbb{E}_t \beta \sum_{x_{a,t+1}} \frac{x_{a,t+1}}{x_{a,t}} \frac{n_{t+1}}{n_t} \pi_{t+1}^{nw} \left( \frac{\pi^{nw}_{t+1}}{\pi^{nw}_t} \psi_w \left( \frac{\pi^{nw}_{t+1}}{\pi^{nw}_t} - 1 \right) \right)
= \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} \psi_w \left( \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} - 1 \right) + \eta_t \left[ 1 - \frac{\psi_w}{2} \left( \frac{\pi^{nw}_t}{\pi^{nw}_{t+1}} - 1 \right)^2 \right] \frac{\sum_{x_{a,t}} x_{a,t+1} w_{a,t}}{\sum_{x_{a,t}} x_{a,t}} - 1
\]

2.3 Firms

Each individual variety of good of type \( a \) is assumed to be produced by a monopolist. Each variety \( i \in [0, 1] \) is manufactured using labor as the sole input with a linear production technology.

\[ y_{i,a,t} = n_{i,a,t} \]

(12)

\( y_{i,a} \) is the production of variety \( i \) and \( n_{i,a} \) is the labor required to produce it. The producer of variety \( i \) faces demands from the private sector at home and abroad respectively

\[ c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x_{a,t} + h_a s_{i,a,t-1} \]

(13)

\[ c^*_{i,a,t} = \left( \frac{P^*_{i,a,t}}{P^*_{a,t}} \right)^{-\eta_c} x^*_{a,t} + h^*_a s^*_{i,a,t-1} \]

(14)

The consumer’s optimal choices in (9), (10) and (11) in the deep habits economy are indistinguishable from those that would prevail in an economy of habit persistence at the level of the aggregated good. However, from the perspective of the firm, deep habits alters profit-maximization in fundamental ways. Observe that the first component of each demand function, \( (P_t/P)^{-\eta_c} x \), is price-elastic while the second component \( h s_{i,t-1} \) is purely predetermined. The habitual term makes the firm’s program comparable to a situation where procurement relationships are formed between buyers and sellers, the buyer favoring the seller that supplied the good in the past. Consequently, predetermined sales quantities affect pricing behavior.

It can be shown (see Jacob, 2015) that the effective price elasticity of demand, in its log-linear form, is a function of the degree of habit persistence as well as changes in aggregate demand, \( \text{e.g.} \ \hat{c}_t = \frac{h}{1-h} (\hat{c}_t - \hat{s}_{t-1}) \). If demand conditions differ across regions in the two country environment, the price elasticities vary and hence the
firm can use different price markups between home and foreign markets. This leads to endogenous deviations in the law of one price.

**Price-Setting Problem** The firm $i$ chooses labour input $\{n_{i,a,t}\}_{t=0}^{\infty}$, quantities $\{c_{i,a,t}, s_{i,a,t}, c_{i,a,t}^*, s_{i,a,t}^*\}_{t=0}^{\infty}$ and prices $\{P_{i,a,t}, P_{i,a,t}^*\}_{t=0}^{\infty}$ to maximize the expected value from profits taking as given $r_{0,t}, W_t, P_{a,t}, P_{a,t}^*, x_{a,t}, x_{a,t}^*$ and the initial conditions. The constraints that it faces are the goods market clearing condition, demand functions at home and abroad and flow of habit stocks. Unlike Ravn, Schmitt-Grohé, and Uribe (2012), we introduce nominal rigidities in price-setting. The firm incurs Rotemberg-type quadratic costs $\Psi_{a,t}$ and $\Psi_{a,t}^*$ in adjusting nominal prices for domestic and export sales respectively. The firm sets the export price $P_{i,a}^*$ in foreign currency, a model feature known in the literature as local currency pricing (see Burstein and Gopinath, 2014).\(^3\)

Revenue from export sales is converted to home currency, by using the nominal exchange rate $ner_t$, a rise in which indicates a depreciation of the home currency. The optimisation program that faces the firm is formally given as

$$\max_{\{n_{i,a,t}, c_{i,a,t}^*, s_{i,a,t}^*, P_{i,a,t}, P_{i,a,t}^*\}} \mathbb{E}_0 \sum_{t=0}^{\infty} r_{0,t} \left[ P_{i,a,t} c_{i,a,t} + ner_t P_{i,a,t}^* c_{i,a,t}^* - W_t n_{i,a,t} - \Psi_{a,t} - ner_t \Psi_{a,t}^* \right]$$

\(^3\)Alternatively, if export sales were priced in home currency (‘producer currency pricing’), the price at which the foreign country procures the exports of the home country, would be simply be the foreign-currency equivalent of the price that the home country sets. Hence, the pass-through of exchange rate fluctuations would be high, irrespective of the presence of deep habits.
subject to

\[ y_{i,a,t} = c_{i,a,t} + c^*_{i,a,t} \quad \text{where} \quad y_{i,a,t} = n_{i,a,t} \tag{15} \]

\[ c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x_{a,t} + h_{a} s_{i,a,t-1} \tag{16} \]

\[ c^*_{i,a,t} = \left( \frac{P^*_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x^*_{a,t} + h^*_a s^*_{i,a,t-1} \tag{17} \]

\[ s_{i,a,t} = \rho_a s_{i,a,t-1} + (1 - \rho_a) c_{i,a,t} \tag{18} \]

\[ s^*_{i,a,t} = \rho^* a s^*_{i,a,t-1} + (1 - \rho^*_a) c^*_{i,a,t} \tag{19} \]

\[ \Psi_{a,t} = c_{a,t} P_{a,t} \frac{\psi_a}{2} \left( \frac{P_{i,a,t}}{\bar{\pi}_a P_{i,a,t-1}} - 1 \right)^2, \quad \psi_a \geq 0 \tag{20} \]

\[ \Psi^*_{a,t} = c^*_{a,t} P^*_{a,t} \frac{\psi^*_a}{2} \left( \frac{P^*_{i,a,t}}{\bar{\pi}^*_a P^*_{i,a,t-1}} - 1 \right)^2, \quad \psi^*_a \geq 0 \tag{21} \]

with the nominal Lagrange multipliers \( nmc \), \( V_{i,a} \equiv P_a \nu_{i,a}, \quad \Lambda_{i,a} \equiv P_a \lambda_{i,a}, \quad V^*_{i,a} \equiv \text{NER} P^* a \nu^*_{i,a} \) and \( \Lambda^*_{i,a} \equiv \text{NER} P^* a \lambda^*_{i,a} \) attached to the constraints (15), (16), (17), (18), and (19) respectively. The multiplier \( nmc \) associated with the goods market clearing condition is the nominal marginal cost. The real multipliers \( \nu_{i,a} \) and \( \nu^*_{i,a} \) attached to the demand function constraints indicate the incremental profit (in real terms) that the firm gains when it sells a unit of the goods variety at home and abroad respectively. Similarly, the real multipliers \( \lambda_{i,a} \) and \( \lambda^*_{i,a} \) attached to the laws of the motion of the habit stocks, measure the marginal profits gained from changes in the habit stocks. We will consider the optimality conditions in a symmetric equilibrium. The first order condition for labor equates the marginal cost to the wage, both in nominal terms, \( \text{i.e. } nmc_t = W_t \). The optimal choice of domestic sales \( c_a \) of good \( a \) provides a law of motion for the real marginal profit \( \nu_a \) of selling a unit of the good.

\[ \nu_{a,t} = 1 - \frac{nmc_t}{P_{a,t}} + \lambda_{a,t} (1 - \rho_a) \tag{22} \]

The real marginal profit equals the difference between the real marginal cost \( nmc/P_a \) and the real marginal revenue which in turn, has two components. The first component is the unit real revenue \( P_a/P_a \) in the current period. In addition, due to habit persistence, selling a unit of the good in the current period also generates a stream of sales in the future and \( \lambda_a \) represents the present value of the future marginal profits generated. The present value \( \lambda_a \) is in turn determined by the optimal choice
of the habit stock $s_a$.

$$\lambda_{a,t} = \mathbb{E}_t r_{t+1} \pi_{a,t+1} (h_a \nu_{a,t+1} + \rho_a \lambda_{a,t+1})$$  \hspace{1cm} (23)

An increment in the habit stock in the current period generates sales of $h_a$ units in the ensuing period and expected marginal profits $\mathbb{E}_t \nu_{a,t+1}$ associated with that sale. The rate of decay, $\rho_a$, of the habit stock determines the strength of the effects of next period’s expectation of marginal profits from future sales, on the present value of marginal profits.

The first order conditions for export sales $c^*_a$ and export habit stock $s^*_a$ are almost isomorphic to those for domestic sales. However, since the firm prices the exports $P^*_a$ in the foreign currency, the nominal exchange rate enters the equilibrium conditions. The real marginal cost of the exporter is given by $nmc = \pi_a P^*_a$ and the relevant price markup is simply its inverse:

$$\nu^*_{a,t} = 1 - \frac{nmc_t}{\pi^*_a P^*_a,t} + \lambda^*_{a,t} (1 - \rho^*_a)$$  \hspace{1cm} (24)

Observe also that the expected depreciation of the home currency, indicated by $\pi^*_t = \pi^*_t \pi^*_a$, alters the effective discount factor used by the exporter to evaluate marginal profits from future foreign sales. This is because $\nu^*_a$ and $\lambda^*_a$ are, by definition, ‘real’ in terms of the home currency equivalent of the export price.

The optimal pricing for home and foreign sales imply

$$\mathbb{E}_t r_{t+1} \frac{c^*_{a,t+1}}{c^*_{a,t}} \left( \frac{\pi^*_{a,t+1} \pi^*_a}{\pi^*_a} - 1 \right) = \frac{\pi^*_{a,t}}{\pi^*_a} \psi^*_a \left( \frac{\pi^*_a}{\pi^*_a} - 1 \right) + \eta_c x^*_{a,t} \nu^*_{a,t} - 1$$  \hspace{1cm} (26)

$$\mathbb{E}_t r_{t+1} \frac{c^*_{a,t+1}}{c^*_{a,t}} \left( \frac{\pi^*_{a,t+1}}{\pi^*_a} \pi^*_a \pi^*_a - 1 \right) = \frac{\pi^*_{a,t}}{\pi^*_a} \psi^*_a \left( \frac{\pi^*_a}{\pi^*_a} - 1 \right) + \eta_c x^*_{a,t} \nu^*_{a,t} - 1$$  \hspace{1cm} (27)

In the vein of optimal pricing equations in standard sticky price models, these first order conditions pin down the expected evolution of inflation to the real marginal cost or equivalently the price markup. However in the presence of deep habits, the relation of inflation to the marginal cost is indirect, through the marginal profits $\nu^*_a$ and $\nu^*_{a,t}$ presented in (22) and (24). These price-setting equations, particularly the one for foreign sales in (27), are crucial for the purpose of this paper. We defer the discussion of optimal pricing to section 3 when we focus on exchange rate pass-through and the open-economy Phillips curve.
2.4 Risk-sharing and Monetary Policy

Since international financial markets are assumed to be complete, the home and foreign households face the same contingent-claim prices $r_{t,t+1}$. If we additionally assume that the two countries are equally wealthy, we obtain the international risk-sharing condition, where the good $a$-based real exchange rate ($rer_a = nerP_a^*/P_a$) is tied down by the ratio of the marginal utilities of the two countries.

$$\frac{\pi^*_x x^*_{x,a,t}}{\pi^*_x x_{x,a,t}} = rer_a$$

(28)

Finally, we close the model by assuming that the monetary authority sets the nominal interest rate $R$ according to a Taylor-type rule augmented by interest-rate smoothing.\(^4\)

$$R_t = \left( \frac{R_{t-1}}{R} \right)^{r_R} \left( \frac{\pi_{a,t}}{\pi_a} \right)^{(1-r_R)r_{*}} \left( \frac{y_t}{y} \right)^{(1-r_R)r_y}$$

(29)

3 Price Markups and Exchange Rate Fluctuations

Here we focus on the transmission of exchange rate fluctuations into the foreign economy’s export prices. In the empirics that will follow in section 4, the US will be positioned as the home country in the model and the discussion centres on the dynamics of the US import price following an exchange rate disturbance. In the context of the model developed here, the US import price is simply the foreign economy’s export price. We begin by analyzing the form on the foreign exporter’s Phillips curve and how the exchange rate affects the price markup in section 3.1. We then describe the source of the exchange rate fluctuation we generate, the disturbance to the uncovered interest rate parity condition, in section 3.2. To clarify the intuition underlying the mechanism, the optimality conditions in this section have been log-linearized around a non-stochastic steady-state and we additionally assume that there is no inflation and exchange rate depreciation in steady-state. Finally in section 3.3, we use a numerical experiment to illustrate how deep habits can dampen exchange rate passthrough even when nominal prices are quite flexible.

\(^4\)In equilibrium, the interest rate $R$ is the reciprocal of the expected value of the contingent-claim prices $r_{t,t+1}$.
3.1 The Foreign Exporter’s Phillips Curve

We now present the analogs of (24), (25), and (27), the optimal choice of sales quantity, habit stock and price for the foreign exporter. The foreign exporter’s optimal choice of export sales $c_b$ implies that the real marginal profit $\nu_b$ covaries positively with the export price markup $\mu_b$ and $\lambda_b$ the present value of marginal profits from future sales. If the foreign exporter’s price markup is defined as the ratio of export sales price $P_b$ to the foreign nominal marginal cost $nmc^*$ expressed in the same currency, i.e. $\mu_b = (P_b/ner)/nmc^*$, the real marginal profit flows as

$$\hat{\nu}_{b,t} = \frac{1}{\nu_b \mu_b} \hat{\mu}_{b,t} + (1 - \rho_b) \frac{\beta h_b}{1 - \beta \rho_b} \hat{\lambda}_{b,t} \tag{30}$$

The present value of future marginal profits from the optimal choice of habit stock $s_b$ evolves as

$$\hat{\lambda}_{b,t} = (1 - \beta \rho_b) E_t \hat{\nu}_{b,t+1} + \beta \rho_b E_t \hat{\lambda}_{b,t+1} - \left[ \hat{R}^*_{t} - E_t (\hat{\pi}_{b,t+1} - \hat{\pi}^{ner}_{t+1}) \right] \tag{31}$$

Observe the effect of the expected changes in the exchange rate on the effective real interest rate faced by the foreign exporter. A change in the value of the currency alters the present value of future profits. In particular, if the home currency is expected to depreciate, i.e. $E_t \hat{\pi}^{ner}_{t+1} > 0$, the effective real interest rate increases which depresses the present value of profits. Finally the foreign exporter’s optimal price $p_b$ is set as

$$\hat{\pi}_{b,t} = \beta E_t \hat{\pi}_{b,t+1} - \frac{1}{\psi_b} (\hat{\nu}_{b,t} + \hat{\lambda}_{b,t} - \hat{\rho}_{b,t}) \tag{32}$$

We will now establish the direct link between foreign export price inflation and the foreign export price markup which subsumes the nominal exchange rate. To distill the intuition, as a first step, it is useful to abstract from persistence in the habit stock, i.e. set $\rho_b = 0$. The steady-state export markup can now be expressed as

$$\mu'_b = \frac{\eta_c (1 - h_b)}{\eta_c (1 - h_b) - (1 - \beta h_b)} \tag{33}$$

Substitute the following into (32) : the steady-state real marginal profit $1/\hat{\nu}_b = \eta_c (1 - h_b)$, the dynamics of the real marginal profit in (30), the steady-state markup in (33), and the definition of aggregate habit-adjusted demand, $\hat{\rho}_{b,t} = (\hat{c}_{b,t} - h_b \hat{c}_{b,t-1}) / (1 - h_b)$.

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5The latter two have been modified to account for the fact that we have set $\rho_b = 0$ in this section.
The consolidated form of the exporter’s Phillips curve is given by

$$\hat{\pi}_{b,t} = \beta \mathbb{E}_t \hat{\pi}_{b,t+1} - \eta_c (1 - h_b) - (1 - \beta h_b) \frac{1}{\psi_b} \left( \beta h_b \hat{\lambda}_{b,t} + \frac{h_b}{1 - h_b} \Delta \hat{\epsilon}_{b,t} \right)$$

Equivalently, we can write the above expression in terms of the dynamics of the export markup, i.e. the wedge between export price and the foreign marginal cost expressed in the same currency.

$$\hat{\mu}_{b,t} = \beta \psi_b \mathbb{E}_t \hat{\mu}_{b,t+1} - \psi_b \hat{\mu}_{b,t} - \left( \beta h_b \hat{\lambda}_{b,t} + \frac{h_b}{1 - h_b} \Delta \hat{\epsilon}_{b,t} \right)$$

Other things constant, consider an exogenous depreciation of the home currency, i.e. a rise in the exchange rate so that $\tilde{\text{net}}_t > 0$. This affects the exporter’s price markup in distinct ways. Firstly, the fall in the value of the currency in which the export is priced in, depresses the exporter’s price markup, i.e. $\hat{\mu}_{b,t} < 0$. This effect is due to the definition of the foreign export price markup and is relevant even in the absence of deep habits. However, the influence of the predetermined habit component implies that the reduction in the markup positively stimulates current export demand and through the strength of demand persistence, also increases profits generated into the future. When the home currency depreciates, the economy expects it to appreciate in the future so that $\mathbb{E}_t \tilde{\text{net}}_{t+1} < 0$. The expected appreciation raises the present value of future profits $\hat{\lambda}_{b,t}$, which provides the foreign exporter an incentive to keep the current markup low (see Equation 31). Finally, the reduction of the markup can be reinforced by a rise in current export demand, which increases the price elasticity of demand $\hat{\epsilon}_{b,t} = \frac{h_b}{1 - h_b} \Delta \hat{\epsilon}_{b,t}$. In sum, the stronger the degree of habit formation, the more the exporter suppresses the price markup. Thus deep habits dampen the ‘pass-through’ of the exchange rate fluctuation into the export price level.

Since we have additionally assumed that it is costly for the exporter to adjust prices, the response of the price level is even slower; the firm will only make small price movements to react to the movement in the markup. Note however that even if prices were flexible, export price adjustment would be slow due to the suppression of the deep habits markup. In particular,

$$h_b > 0, \psi_b = 0 : \hat{\mu}_{b,t} = - \frac{\beta h_b \hat{\lambda}_{b,t} + \frac{h_b}{1 - h_b} \Delta \hat{\epsilon}_{b,t}}{\eta_c (1 - h_b) - (1 - \beta h_b)}$$
Alternatively, in the absence of deep habits but with costly price adjustment, the change of the markup would reflect slowly in the price level, with the cost of price adjustment moderating the degree of pass-through.

\[ h_b = 0, \psi_b > 0 : \hat{\mu}_{b,t} = \beta \psi_b \mathbb{E}_t \hat{\pi}_{b,t+1} - \psi_b \hat{\pi}_{b,t} \]  

(37)

Finally, with neither deep habits nor costly price adjustment, the markup does not adjust, \( i.e. \hat{\mu}_{b,t} = 0 \), so that the change in the effective nominal marginal cost brought about by the exchange rate movement will be transmitted fully to the price level instantaneously. Formally

\[ h_b = \psi_b = 0 : \hat{p}_{b,t} = \hat{m}_c^* + \hat{ne}_t \]  

(38)

In a nutshell, in the deep habits model, stickiness in sales quantities delays the pass-through of exchange rate fluctuations into the price level. Crucially, if habits are highly persistent, the price markup is linked tightly to current and future demand. Hence, exporters may choose to absorb the exchange rate movement into the markup instead of passing it through to the price level. This is true even when the exporters potentially \textit{can} adjust prices freely, as indicated by zero or low nominal price adjustment costs.

### 3.2 The Source of the Exchange Rate Movement

We generate business cycle fluctuations in the economy by using a stochastic process \( \varepsilon^{uip} \) that perturbs the uncovered interest parity (UIP) condition in (39) which pins down the expected depreciation of the domestic currency to the differential in nominal interest rates.

\[ \mathbb{E}_t \hat{ne}_t = \hat{R}_t - \hat{R}_t^* + \varepsilon^{uip}_t \]  

(39)

where \( \varepsilon^{uip}_t = \rho_{uip} \varepsilon^{uip}_{t-1} + v_t, v_t \sim \mathbb{N}(0, \sigma_{uip}) \)  

(40)

Along the lines of Choudhri, Faruqee, and Hakura (2005), we empirically validate our model in section 4 by matching the dynamics of the model to those triggered by an identified exchange rate shock in a VAR. Consequently, our choice of the shock to interest parity as the forcing variable is also adapted from the earlier work. The UIP shock is frequently used in the set of cyclical disturbances employed in

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the estimation of open-economy DSGE models (e.g. Jacob and Peersman, 2013, Adolfson et al., 2007 and Bergin, 2006). Devereux and Engel (2002) attribute the random deviation from strict interest parity to misaligned expectations from foreign currency traders on the evolution of the currency’s value. Alternatively, in McCallum and Nelson (1999), this shock is interpreted as a time-varying risk premium which is omitted by linearization. On the empirical front, Farrant and Peersman (2006) present VAR evidence on the importance of ‘pure exchange rate’ shocks in driving OECD exchange rates. To the extent that the UIP disturbance represents a source of exchange rate disconnect from fundamentals, it is the theoretical analogue closest to a ‘pure exchange rate’ shock identified in the data. Hence, among the candidate shocks used in the literature, the deviation from interest rate parity best supports our objective of understanding the response of international prices to a shift in the exchange rate.

3.3 Exchange Rate Pass-through: Deep Habits versus Sticky Prices

We will now use a numerical experiment to illustrate the dampening influence of deep habits on the degree of exchange rate pass-through. Of particular interest is a contrast of the effect of deep habits, against that of the more conventional friction used to generate imperfect exchange rate pass-through in open-economy models: stickiness in prices as embodied by the Rotemberg adjustment cost. We will assume the same degree of habit persistence for domestic and foreign sales in both countries so that $h_a = h^*_a = h_b = h$ and also impose the same degree of price stickiness for all sales so that $\psi_a = \psi^*_a = \psi^*_b = \psi_b = \psi$. The US is positioned as the Home country and the rest of the world as the foreign country. The parameter values we pick for the baseline calibration of the model are in the ballpark of estimated values or calibrations available in the literature, e.g. Ravn, Schmitt-Grohé, and Uribe (2012), Ravn, Schmitt-Grohé, Uribe, and Uusküla (2010b) and Lubik and Schorfheide (2006). The parameter values are presented in Table 1.

The habit and price adjustment cost parameter are allowed to vary over fixed intervals. For each combination $\{h, \psi\}$, we simulate the model using a sequence of UIP shocks and compute the ordinary least squares coefficient of a static regression of foreign export price inflation $\hat{\pi}_b$ on nominal depreciation of the home currency
We will label the slope coefficient computed from simulated data as the ‘pass-through’ coefficient.

We proceed in two steps and present the results in Panels (a) and (b) in Figure 1. In the left half of Panel (a), we present the surface plot for the pass-through coefficient for the case in which consider only i.i.d. UIP shocks. For simplicity, as in section 3.1, we abstract from the decaying habit stocks by setting $\rho_a = \rho_a^* = \rho_b = \rho_b = 0$. Not surprisingly, low pass-through can be achieved when we abstract from deep habits ($h = 0$) and raise the Rotemberg cost, the sticky price mechanism that delivers price markup adjustment in conventional open-economy New Keynesian models. The more interesting scenario is when we keep prices very flexible by setting the Rotemberg cost low at $\psi = 1$, and increase the habit parameter. Observe how the pass-through coefficient falls at higher levels of habit persistence. The source of the declining degree of pass-through even prices are quite flexible can be traced to the strong markup adjustments associated with deep habits. In the right half of Panel (a), we present a surface plot of the impact response of the price markup of the foreign exporter (US importer) to a depreciation of the US dollar triggered by a positive UIP shock of 1 percent. Each point on the surface corresponds to the $\{h, \psi\}$ parametric combinations that yield the pass-through surface in the left half of Panel (a). As habit persistence increases, the firm resists passing through the rise in its effective marginal cost into the price level and simply decreases its markup to absorb the exchange rate fluctuation.

Next, in Panel (b), we consider a more complex scenario in which the economy is hit with persistent UIP shocks with an autoregressive coefficient of $\rho_{\text{uip}} = 0.75$. We reintroduce highly persistent habit stocks and set $\rho_a = \rho_a^* = \rho_b = \rho_b = 0$. The pass-through coefficient surface in the left half of Panel (b), remains qualitatively similar to the previous case, with both deep habits and sticky prices capable of delivering low exchange rate pass-through even when the competing friction is weak. Note however with more persistent UIP shocks, the model requires, in order to dampen the degree of exchange rate pass-through. The markup dynamics exhibited in the right half of Panel (b) are far stronger than those in Panel (a), due to the extreme persistence in the habit stock.

The measurement of ‘pass-through’ in general equilibrium is non-trivial because prices respond contemporaneously to factors other than the fluctuation in the cur-
rency’s value, irrespective of the structural origin of the cyclical disturbance. A reduction in the simple least squares correlation that we have presented in this section is only one of the several possible ways of confirming imperfect exchange rate pass-through to international prices. In the next section, we will examine exchange rate pass-through through a different lens: we match the dynamic paths of the variables triggered by the exchange rate shock in the deep habits model to those generated by the empirical analogue of the shock in an identified VAR.

4 An Empirical Evaluation of the Deep Habits Model

5 Conclusion

A Further Estimation Details and Results
Figure 1: Deep Habits, Price Stickiness and Exchange Rate Pass-through

Panel (a): No persistent habit stocks, i.i.d UIP shocks

Panel (b): Persistent habit stocks, persistent UIP shocks

Note: For each parameter combination, we generate 100 samples, each of length 100 periods. The pass-through coefficient is measured by the slope of an OLS regression of import price inflation on nominal exchange rate depreciation and the average across samples is plotted for each parametric combination. The US import markup is simply the foreign exporter’s markup and we exhibit its impact response to a depreciation of the US dollar triggered by a 1% UIP shock.
Table 1: Calibrated Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ψₐ, ψₐ*, ψₐ*, ψₛ = ψ</td>
<td>Rotemberg price adjustment cost</td>
</tr>
<tr>
<td>hₐ, hₐ*, hₐ*, hₜ = h</td>
<td>Habit</td>
</tr>
<tr>
<td>ρₐ, ρₐ*, ρₐ*, ρₜ</td>
<td>Persistence of habit stock</td>
</tr>
<tr>
<td>ρₜ</td>
<td>Persistence of UIP shock</td>
</tr>
<tr>
<td>σₜ</td>
<td>Standard deviation of UIP shock</td>
</tr>
<tr>
<td>β</td>
<td>Subjective discount factor (quarterly)</td>
</tr>
<tr>
<td>1/σₑ</td>
<td>Intertemporal discount factor</td>
</tr>
<tr>
<td>1/σₑ = (1 – ⌠) / ⌠</td>
<td>Frisch elasticity of labor supply</td>
</tr>
<tr>
<td>ω</td>
<td>Home-bias in consumption</td>
</tr>
<tr>
<td>ξ</td>
<td>Elasticity of substitution between home and foreign goods</td>
</tr>
<tr>
<td>ηₑ = ηₑ</td>
<td>Elasticity of substitution between goods/labor varieties</td>
</tr>
<tr>
<td>rₑ</td>
<td>Interest rate smoothing</td>
</tr>
<tr>
<td>rₑ</td>
<td>Interest rate reaction to domestic inflation</td>
</tr>
<tr>
<td>rₑ</td>
<td>Interest rate reaction to output</td>
</tr>
<tr>
<td>ψₜ</td>
<td>Rotemberg wage adjustment cost</td>
</tr>
</tbody>
</table>

Note: Columns (a) and (b) list the parameter values used to generate the surface plots presented in Panel (a) and Panel (b) of Figure 1 respectively. Other steady-state parameters are derived from the restrictions of the model available in Jacob and Uusküla (2016). The home-bias parameter ω is set to achieve an import-intensity of 0.0375 in consumption, as observed in Table 4 of Section 4 of the National Income and Product Accounts tables published by the Bureau of Economic Analysis. The sample period we consider is 1983.I-2015.II.

References

Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2007), Bayesian Estimation


