

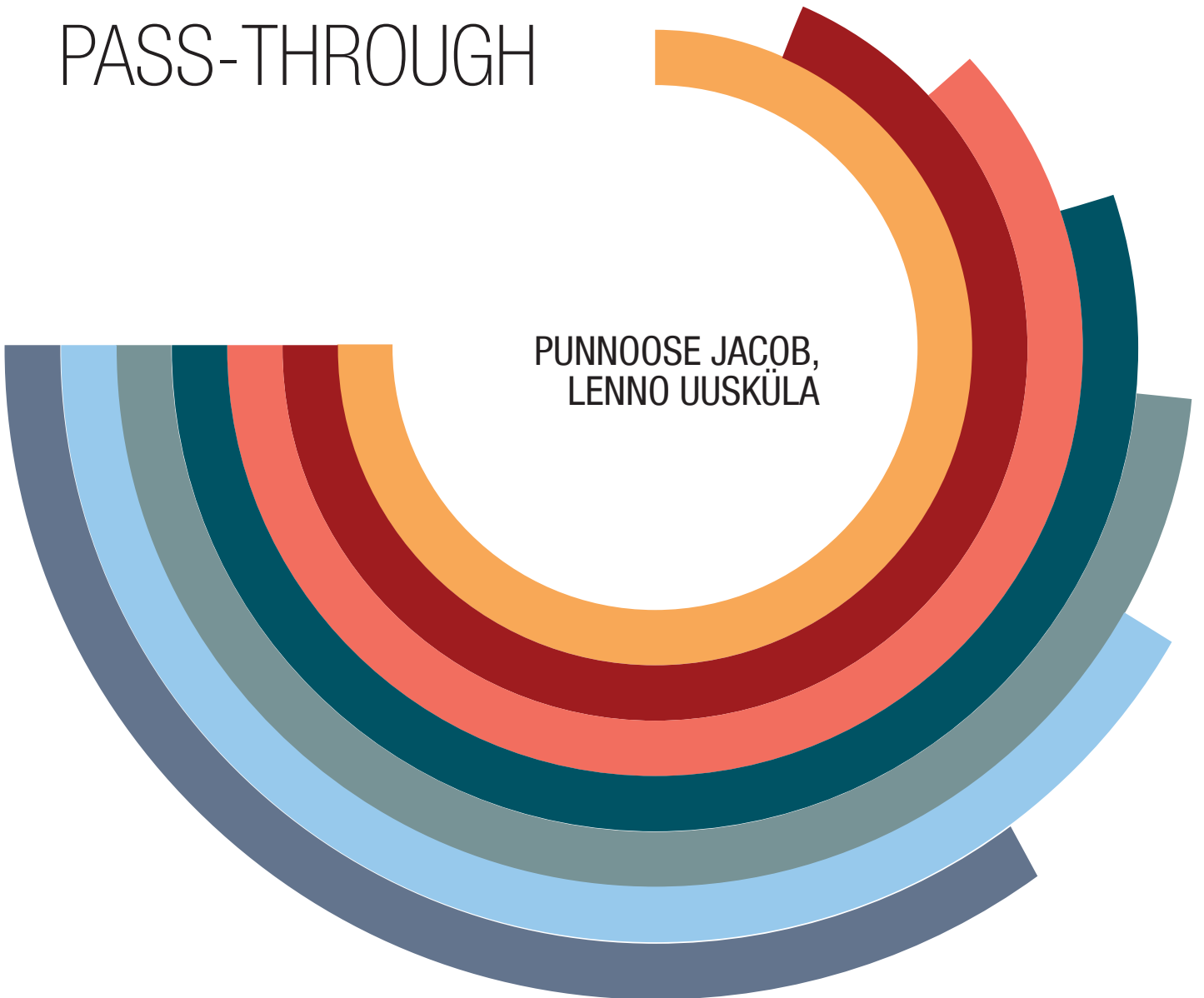


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# DEEP HABITS AND EXCHANGE RATE PASS-THROUGH

PUNNOOSE JACOB,  
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# Deep Habits and Exchange Rate Pass-through

Punnoose Jacob and Lenno Uusküla\*

## Abstract

Habit persistence at the level of individual goods varieties can explain incomplete exchange rate pass-through to international prices. Deep habits give rise to a dynamic import demand function that leads to import price markup adjustments, independently of nominal pricing frictions. Augmenting a standard New Keynesian two-country model with deep habits, we obtain low exchange rate pass-through to import prices even when local currency prices are relatively flexible. As prices become more rigid, the presence of deep habits further reduces the pass-through of exchange rate fluctuations. Without deep habits, the model requires implausibly high degrees of price stickiness to match the pass-through dynamics triggered by an exchange rate shock in a vector autoregression.

JEL classification: F41, E31

Keywords: Exchange Rate Pass-through, Deep Habits, Sticky Prices, Price Markups, Local Currency Pricing

The views expressed are those of the authors, and do not necessarily represent the official views of the Reserve Bank of New Zealand, the Bank of Estonia or the Eurosystem.

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# Non-Technical Summary

The coexistence of highly volatile exchange rates and import prices that are quite stable in local currency has long intrigued international macroeconomists. Incomplete 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. The workhorse open-economy dynamic stochastic general equilibrium (DSGE) model has mainly appealed to nominal price rigidities in local currency to replicate the incomplete exchange rate pass-through observed in the data.

This paper brings to the fore the importance of a real rigidity - deep or good-specific habit persistence, originally modelled in Ravn, Schmitt-Grohé, and Uribe (2006). It looks at the interplay between a real rigidity and nominal local currency price stickiness in weakening exchange rate pass-through in an otherwise standard New Keynesian two-country economy. Deep habits considers the possibility that consumers form habits separately over more narrowly defined categories of goods and not at the level of final consumption expenditures. Consumers form habits of consumption at the level of a good of certain brand, such as shoes from a particular firm, but do not internalize the effect of her current consumption on future habit. Consumption behaviour of households remains unchanged, but affects price setting behaviour of firms.

In an economy with deep habits, a unit sale generates profits not merely in the current period but also into the future due to the strength of habit persistence. The firm takes into account future demand in its profit maximization problem. Importantly, in this environment, a change in price has strong effects on the entire 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 strongly raising prices, may result in a loss of demand stretching far into the future. For this reason, the importing firm has an incentive to partially absorb the exchange rate movement into its price markup. In sum, in our model, sticky demand - 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 low pass-through can be obtained both by strengthening deep habits at low degrees of price stickiness modelled using standard convex adjustment costs à la Rotemberg (1982), and, as in the conventional case, by abstracting from habits and merely increasing price adjustment costs. Used in conjunction, deep habits and sticky prices 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 for it to replicate the VAR evidence.

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# 1 Introduction

The coexistence of highly volatile exchange rates and import prices that are quite stable in local currency has long intrigued international macroeconomists.<sup>1</sup> Incomplete 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 incomplete exchange rate pass-through observed in the data (see among others Jacob and Peersman, 2013, Rabanal and Tuesta, 2010 and Devereux and Yetman, 2010). However, econometric evidence presented in Gopinath et al. (2010) suggests that exchange rate pass-through to local currency import prices is low even conditional on a price change by the importing firm. The sources of incomplete exchange rate pass-through appear to lie beyond nominal pricing frictions.

This paper brings to the fore the interplay between a real rigidity – deep or good-specific habit persistence – and nominal local currency price stickiness in weakening exchange rate pass-through in an otherwise standard New Keynesian two-country economy. Crucially, deep habits can explain incomplete pass-through in conditions where nominal pricing frictions are weak, i.e. the firm can change prices fairly easily to adjust to the exchange rate movement. Naturally, as prices become more rigid, the presence of deep habits further diminishes the pass-through of exchange rate fluctuations to international prices.

Deep habits, originally modelled in Ravn et al. (2006), consider the possibility that consumers form habits separately over more narrowly defined categories of goods and not at the level of final consumption expenditures. A consequence of this type of habit persistence is that the demand for the individual good is influenced by a predetermined component so that the firm’s profit-maximization programme becomes intertemporal, whether or not there are price rigidities. In an economy with deep habits, a unit sale generates profits not merely in the current period but also into the future due to the strength of habit persistence. The firm takes future demand into account in its profit maximization problem. Importantly, in this environment, a change in price has strong effects on the entire 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 strongly may result in a loss of demand stretching far into the future. For this reason, the importing firm has an incentive partially to absorb the exchange rate movement into its price markup. In sum, in our model, sticky demand – 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 low pass-through can be obtained both by strengthening deep habits at low degrees of price stickiness modelled using standard convex adjustment costs *à la* Rotemberg (1982), and – as in the conventional case – by abstracting from habits and merely increasing price adjustment costs. Used in conjunction, deep habits and sticky prices 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

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<sup>1</sup>See Burstein and Gopinath (2014) for a comprehensive review of the literature.

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 to 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 parameters for it to replicate the VAR evidence.

We build on the work of Ravn et al. (2012, 2007) who demonstrate how the presence of deep habits can influence firms in pricing-to-market. In the deep habits economy, firms face more elastic demand functions in markets where current demand is high relative to habitual demand, creating an incentive for them to price discriminate across markets. In contrast to Ravn et al. (2012, 2007), we delve deeper into incomplete exchange rate pass-through, which is a consequence of pricing-to-market and markup adjustment by firms. While the economy we consider preserves the price elasticity effect of deep habits detailed by Ravn et al. (2012, 2007), we additionally emphasize the intertemporal sales smoothing incentive for firms facing dynamic demand functions.

Departing from the flexible price framework of Ravn et al. (2012, 2007), we adopt the New Keynesian environment. The introduction of nominal rigidities enables us to study explicitly the link between nominal exchange rate fluctuations and nominal prices as in the microeconomic literature (see Burstein and Gopinath, 2014). From a modelling standpoint, nominal rigidities fundamentally alter the deep habits environment and its influence on exchange rate pass-through, since monetary policy and nominal exchange rate fluctuations influence the effective discount rate used by firms to evaluate expected profits from international sales. When nominal interest rates or exchange rates adjust to structural shocks, they lower the discount rate used to evaluate profits from export sales. This in turn implies that the present value of future export sales is raised. Consequently, the firm will resist transmitting the exchange rate fluctuation to the sales price, and instead will partially absorb the currency fluctuation into the price markup. We study the correlation between import price inflation and exchange rate depreciation conditional on two structural shocks found to be important drivers of the exchange rate in estimated DSGE models: a shock to strict uncovered interest parity (UIP) and a shock to monetary policy.<sup>2</sup>

The literature has seen diverse theoretical models of real rigidities that deliver deviations in the law of one price in flexible price environments similar to that of Ravn et al. (2012, 2007). In this set of papers, international price markups have variously been influenced by local distribution costs (Corsetti and Dedola, 2005), market shares (Atkeson and Burstein, 2008), consumer search costs (Alessandria, 2009), inventory considerations (Alessandria et al., 2010) or prices relative to those of competitors (Gust et al., 2010). The deep habits model is in spirit akin to the ‘customers as capital’ framework of Drozd and Nosal (2012b), in which firms need to build market shares by matching with their customers, and 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.

The unified treatment of the potential interaction between frictions on the real and nominal sides in determining the degree of exchange rate pass-through aligns our analysis

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<sup>2</sup>See e.g. Rabanal and Tuesta (2010) and Bergin (2006).

with that of Corsetti et al. (2008a). They study the interaction of distribution costs *à la* Corsetti and Dedola (2005) and local currency import price stickiness in a New Keynesian two-country model similar to ours. The important distinction, apart from the emphasis on a different real rigidity, is that we take our model to the data. Our empirical strategy is adapted from Choudhri et al. (2005) and Smets and Wouters (2002) who match the dynamics of the model triggered by a random deviation from uncovered interest parity to those observed conditional on an identified exchange rate shock in a VAR. The estimation of the deep habits model also relates our paper to that of Ravn et al. (2012) and Ravn et al. (2010b) who match the dynamics of deep habits models to VAR-based impulse responses conditional on shocks to government spending and monetary policy respectively.<sup>3</sup>

Finally Ravn et al. (2010a) demonstrate the ability of deep habits to generate incomplete pass-through of idiosyncratic cost shocks to the firm’s price level. Since a movement in the exchange rate alters the cost structure of the firm that produces internationally traded goods, at its heart the general equilibrium treatment of exchange rate pass-through presented in this paper is a generalization of the partial-equilibrium, closed-economy analysis of Ravn et al. (2010a).

The remainder of this paper is set out as follows. In the next section, we introduce deep habits into an otherwise standard two-country New Keynesian model environment and describe the primitive optimality conditions. Section 3 focuses on the log-linearized version of the model to understand how deep habits and sticky prices influence the firm’s markup adjustment and the related implications for the pass-through of exchange rate fluctuations to international prices. In Section 4, we compare the empirical performance of the New Keynesian model with deep habits to that of a restricted version that abstracts from deep habits. Section 5 draws the main conclusions.

## 2 A Two-Country Model with Deep Habits

### 2.1 Preliminaries

The model involves two symmetric countries populated by representative households and firms. Each country specializes in the production of a set of differentiated goods, We denote the set of goods produced by the home country by  $a$ , and the set of goods produced by the foreign country by  $b$ . The model also abstracts from capital accumulation, government spending, and non-traded goods. Only the home country’s problem is described here. The exposition of the model is based on Ravn et al. (2012, 2007). 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  $\hat{z}_t \equiv \frac{\partial z_t}{\bar{z}} = \log \frac{z_t}{\bar{z}}$ . The symbols  $\mathbb{E}$  and  $\Delta$  represent the mathematical operators for conditional expectations and temporal differencing respectively. In the interests of notational brevity, we avoid using the period  $t$

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<sup>3</sup>In a different context, Lubik and Teo (2014) find empirical support in favour of the influence of deep habits in reducing the degree of intrinsic inflation persistence in a single equation estimation of the closed-economy New Keynesian Phillips Curve.



subscript when we describe variables and functional forms in the main text, unless we refer to a dynamic relationship. We also suppress the indexation of the variable to the state of nature. The comprehensive derivation of the model is available on request.

## 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:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathbb{U}(\chi_t^j, n_t^j), \quad (1)$$

where

$$\chi_t = \left( \omega^{\frac{1}{\xi}} x_{a,t}^{\frac{\xi-1}{\xi}} + (1-\omega)^{\frac{1}{\xi}} x_{b,t}^{\frac{\xi-1}{\xi}} \right)^{\frac{\xi}{\xi-1}}, \quad (2)$$

and

$$\mathbb{U}(\chi_t, n_t) = \frac{\left( \chi_t^\phi (1-n_t)^{(1-\phi)} \right)^{1-\sigma_c} - 1}{(1-\sigma_c)}, \quad (3)$$

such that  $\beta \in (0, 1)$ ,  $\omega, \phi \in [0, 1]$  and  $\xi, \sigma_c > 0$ .

The variable  $\chi$  is a consumption aggregate that is formed by combining a home goods aggregate  $x_a$  and an imported aggregate  $x_b$  from the foreign country in Equation (2). The preferences defined over the consumption aggregate and hours worked  $n$  are given a standard CES form in Equation (3).

### 2.2.1 Deep Habits

As in Ravn et al. (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 (see e.g. Jacob and Peersman, 2013 and Adolfson et al., 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:<sup>4</sup>

$$x_{a,t} = \left[ \int_0^1 (c_{i,a,t} - h_a s_{i,a,t-1})^{1-1/\eta_c} di \right]^{\frac{1}{1-1/\eta_c}}, \quad h_a \in [0, 1), \quad \eta_c > 1. \quad (4)$$

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<sup>4</sup>For expositional reasons, we will ignore the superscript  $j$  for each household in the remainder of section 2.2.1.

The variable  $c_{i,a}$  denotes the consumption of variety  $i$  of goods belonging to the set  $a$ . The parameter  $h_a$  governs the degree of habit persistence, and in the absence of habit-formation when  $h_a = 0$  the parameter  $\eta_c$  denotes the elasticity of substitution between goods varieties. For  $h_a > 0$  the parameter  $\eta_c$  represents the long-run price elasticity of habit-adjusted demand for the goods variety. The variable  $s_{i,a}$  denotes the external habit stock of variety  $i$  of good  $a$  and evolves according to the law of motion:

$$s_{i,a,t} = \rho_a s_{i,a,t-1} + (1 - \rho_a) \tilde{c}_{i,a,t}, \quad \rho_a \in [0, 1]. \quad (5)$$

The variable  $\tilde{c}_{i,a}$  is the per capita consumption of good  $i$  of good  $a$  in the home country. The parameter  $\rho_a$  denotes the persistence of the habit stock so that  $(1 - \rho_a)$  indicates 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 programme  $\min_{c_{i,a,t}} \int_0^1 P_{i,a,t} c_{i,a,t}$  subject to Equation (4). The demand for good  $i$  of type  $a$  is given by:

$$c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x_{a,t} + h_a s_{i,a,t-1}, \quad (6)$$

where  $P_a = \left( \int_0^1 P_{i,a}^{1-\eta_c} di \right)^{\frac{1}{1-\eta_c}}$  indicates a price level for habit-adjusted demand for goods of type  $a$ . 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  $s_{i,a}$ . Total expenditure on goods of type  $a$  in period  $t$  can be expressed as  $\int_0^1 P_{i,a} c_{i,a} di = P_a x_a + \omega_a$  such that  $\omega_{a,t} = h_a \int_0^1 P_{i,a,t} s_{i,a,t-1} di$ .

Imports of good  $b$  from the foreign country is similarly influenced by habit persistence and the demand for the individual imported variety mirrors that for the home variety:

$$c_{i,b,t} = \left( \frac{P_{i,b,t}}{P_{b,t}} \right)^{-\eta_c} x_{b,t} + h_b s_{i,b,t-1}. \quad (7)$$

Ravn et al. (2006) demonstrate that the lag structure of the demand functions for the individual varieties alters the firms' price-setting behaviour 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 Equation (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, each household  $j$  has access to complete contingent claims markets. The variable  $d$  represents the state-contingent asset and  $r_{t,t+k}$  denotes the nominal stochastic discount factor such that  $\mathbb{E}_t r_{t,t+k} d_{t+k}$  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 et al. (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 to change wages as in Rotemberg (1982). The parameter  $\psi_w \geq 0$  governs the strength of the wage adjustment cost.

The domestic representative household’s period-by-period budget constraint is given by:

$$P_{a,t}x_{a,t}^j + \omega_{a,t}^j + P_{b,t}x_{b,t}^j + \omega_{b,t}^j + \mathbb{E}_t r_{t,t+1} d_{t+1}^j + \frac{\psi_w}{2} W_t n_t \left( \frac{W_t^j}{\bar{\pi}^{nw} W_{t-1}^j} - 1 \right)^2 = d_t^j + W_t^j n_t^j + \Pi_t^j. \quad (8)$$

In addition, households are assumed to be subject to a borrowing constraint of the form  $\lim_{t \rightarrow \infty} \mathbb{E}_t r_{t,t+z} d_{t+z} \geq 0$  which prevents them from engaging in Ponzi Games. The household’s optimization problem consists in choosing processes  $x_{a,t}^j$ ,  $x_{b,t}^j$ ,  $W_t^j$ , and  $d_{t+1}^j$  to maximize the lifetime utility function (1) subject to Equations (2) and (8), labour demand, and the Non-ponzi-game condition, taking as given the processes for  $\omega_{a,t}$ ,  $\omega_{b,t}$ , firm profits  $\Pi_t$ , 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:

$$\frac{\chi_{x_{a,t}}}{\chi_{x_{b,t}}} = \frac{P_{a,t}}{P_{b,t}}. \quad (9)$$

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

$$\mathbb{U}_{\chi,t} \chi_{x_{a,t}} r_{t,t+1} = \beta \mathbb{E}_t \frac{\mathbb{U}_{\chi,t+1} \chi_{x_{a,t+1}}}{\pi_{a,t+1}}, \quad (10)$$

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

$$\begin{aligned} & \mathbb{E}_t \beta \frac{\mathbb{U}_{\chi,t+1} \chi_{x_{a,t+1}}}{\mathbb{U}_{\chi,t} \chi_{x_{a,t}}} \frac{n_{t+1}}{n_t} \frac{(\pi_{t+1}^{nw})^2}{\pi_{a,t+1} \bar{\pi}^{nw}} \psi_w \left( \frac{\pi_{t+1}^{nw}}{\bar{\pi}^{nw}} - 1 \right) \\ &= \frac{\pi_t^{nw}}{\bar{\pi}^{nw}} \psi_w \left( \frac{\pi_t^{nw}}{\bar{\pi}^{nw}} - 1 \right) + \eta_n \left[ 1 - \frac{\psi_w}{2} \left( \frac{\pi_t^{nw}}{\bar{\pi}^{nw}} - 1 \right)^2 - \frac{\mathbb{U}_{n,t}}{\mathbb{U}_{\chi,t} \chi_{x_{a,t}} w_{a,t}} \right] - 1, \end{aligned} \quad (11)$$

where  $\pi^{nw}$  indicates the gross rate of nominal wage inflation. International financial markets are assumed to be complete and, consequently, the home and foreign households have access to the same state-contingent assets. 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 ( $rer_a = ner P_a^*/P_a$ ) is tied down by the ratio of the marginal utilities of

the two countries:

$$\frac{U_{\chi,t}^* \chi_{x_{a,t}}^*}{U_{\chi,t} \chi_{x_{a,t}}} = r e r_{a,t}. \quad (12)$$

We generate business cycle fluctuations by using two distinct stochastic processes. The first cyclical disturbance  $z^{uip}$  perturbs the UIP condition in Equation (13), which pins down the expected depreciation of the domestic currency to the differential in nominal home and foreign country interest rates,  $R$  and  $R^*$ :<sup>5</sup>

$$\beta \mathbb{E}_t \mathcal{M}_{t+1} \frac{ner_{t+1}}{ner_t} R_t^* z_t^{uip} = \beta \mathbb{E}_t \mathcal{M}_{t+1} R_t, \quad (13)$$

where  $\log z_t^{uip} = (1 - \rho_{uip}) \log \bar{z}^{uip} + \rho_{uip} \log z_{t-1}^{uip} + \vartheta_t^{uip}$ ,  $\vartheta_t^{uip} \sim \mathbb{N}(0, \sigma_{uip})$  and  $\mathcal{M}$  is the Lagrange multiplier on the consumer's nominal budget constraint in the home country. Devereux and Engel (2002) attribute the random deviation from strict interest parity to misaligned expectations from foreign currency traders for 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. The UIP shock is frequently employed in the set of disturbances in the estimation of open-economy DSGE models (e.g. Jacob and Peersman, 2013, Adolfson et al., 2007, and Bergin, 2006) and typically it explains much of the forecast variance of the exchange rate.

The second business cycle shock  $z^{mon}$  stimulates the Taylor-type rule that is used by the monetary authority to set the nominal interest rate:

$$\frac{R_t}{\bar{R}} = \left( \frac{R_{t-1}}{\bar{R}} \right)^{r_R} + \left( \frac{\pi_{a,t}}{\bar{\pi}_a} \right)^{(1-r_R)r_\pi} \left( \frac{y_t}{\bar{y}} \right)^{(1-r_R)r_y} z_t^{mon}, \quad (14)$$

where  $\log z_t^{mon} = (1 - \rho_{mon}) \log \bar{z}^{mon} + \rho_{mon} \log z_{t-1}^{mon} + \vartheta_t^{mon}$ , and  $\vartheta_t^{mon} \sim \mathbb{N}(0, \sigma_{mon})$ .

## 2.3 Firms

Each individual variety of good  $a$  is assumed to be produced by a monopolist. The variety indexed by  $i \in [0, 1]$  is manufactured using labour as the sole input in a linear production function:

$$y_{i,a,t} = n_{i,a,t}. \quad (15)$$

$y_{i,a}$  is the production of variety  $i$  and  $n_{i,a}$  is the labour required to produce it. The producer of variety  $i$  faces demands from the private sector at home and abroad that are respectively:

$$c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x_{a,t} + h_a s_{i,a,t-1}, \quad (16)$$

---

<sup>5</sup>The UIP condition is obtained by equating the nominal stochastic discount factors (expressed in the same currency) across the two countries. In equilibrium, the interest rate  $R$  is the reciprocal of the expected value of the contingent-claim prices  $r_{t,t+1}$ .

$$c_{i,a,t}^* = \left( \frac{P_{i,a,t}^*}{P_{a,t}^*} \right)^{-\eta_c} x_{a,t}^* + h_a^* s_{i,a,t-1}^*. \quad (17)$$

The consumer's optimal choices in Equations (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 alter profit-maximization in fundamental ways. Observe that the first component of each demand function,  $(P_i/P)^{-\eta_c} x$ , is price-elastic while the second component  $h s_{i,t-1}$  is purely predetermined. The habit term makes the firm's programme comparable to a case where procurement relationships are formed between buyers and sellers in which the buyer favours the seller that supplied the good in the past. Consequently, predetermined sales quantities affect pricing behaviour.

The price elasticity of demand  $-(\partial c_{i,t}/\partial p_{i,t})(p_{i,t}/c_{i,t})$  is now time-varying and in a symmetric equilibrium can be expressed as  $\epsilon_t = \eta_c(1 - h s_{t-1}/c_t)$ . In its log-linear form, the price elasticity is a function of the degree of habit persistence as well as growth in aggregate demand, so  $\hat{\epsilon}_t = \frac{h}{1-h}(\hat{c}_t - \hat{s}_{t-1})$ . If demand conditions differ across regions in the two-country environment, the country-specific short-run price elasticities vary and hence the firm can use different price markups between home and foreign markets. This leads to endogenous deviations from the law of one price.

In the price-setting problem firm  $i$  chooses labour input  $\{n_{i,a,t}\}_{t=0}^\infty$ , prices  $\{P_{i,a,t}, P_{i,a,t}^*\}_{t=0}^\infty$ , and quantities  $\{c_{i,a,t}, s_{i,a,t}, c_{i,a,t}^*, s_{i,a,t}^*\}_{t=0}^\infty$  to maximize the discounted 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, the demand functions at home and abroad, and the flow of habit stocks. The firm incurs Rotemberg-type quadratic costs  $\Psi_{a,t}()$  and  $\Psi_{a,t}^*()$  in adjusting nominal prices for domestic and export sales respectively.<sup>6</sup> 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).<sup>7</sup>

Revenue from export sales is evaluated in terms of home currency by using the nominal exchange rate  $ner$ , a rise in which indicates a depreciation of the home currency. The optimization programme that the firm faces is formally given as:

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

subject to

$$y_{i,t} = c_{i,a,t} + c_{i,a,t}^* \text{ where } y_{i,t} = n_{i,t}, \quad (18)$$

<sup>6</sup>The presence of deep habits makes the pricing problem dynamic even in the absence of nominal rigidities. Since accounting for additional dynamics due to Calvo (1983)-style pricing makes aggregation non-trivial, models with deep habits typically use Rotemberg pricing. Up to a first-order approximation, the two pricing frictions yield observationally equivalent dynamics.

<sup>7</sup>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 simply be the foreign-currency equivalent of the price that the home country firm sets for domestic sales. Hence, the pass-through of exchange rate fluctuations would be high, irrespective of the presence of deep habits.

$$c_{i,a,t} = \left( \frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta_c} x_{a,t} + h_a s_{i,a,t-1}, \quad (19)$$

$$c_{i,a,t}^* = \left( \frac{P_{i,a,t}^*}{P_{a,t}^*} \right)^{-\eta_c} x_{a,t}^* + h_a^* s_{i,a,t-1}^*, \quad (20)$$

$$s_{i,a,t} = \rho_a s_{i,a,t-1} + (1 - \rho_a) c_{i,a,t}, \quad (21)$$

$$s_{i,a,t}^* = \rho_a^* s_{i,a,t-1}^* + (1 - \rho_a^*) c_{i,a,t}^*, \quad (22)$$

$$\Psi_{a,t} = c_{a,t} P_{a,t} \frac{\psi_a}{2} \left( \frac{P_{i,a,t}}{\bar{\pi}_a P_{i,a,t-1}} - 1 \right)^2, \quad \psi_a \geq 0, \quad (23)$$

$$\Psi_{a,t}^* = c_{a,t}^* P_{a,t}^* \frac{\psi_a^*}{2} \left( \frac{P_{i,a,t}^*}{\bar{\pi}_a^* P_{i,a,t-1}^*} - 1 \right)^2, \quad \psi_a^* \geq 0, \quad (24)$$

with the nominal Lagrange multipliers  $nm_c$ ,  $V_{i,a} \equiv P_a \nu_{i,a}$ ,  $\Lambda_{i,a} \equiv P_a \lambda_{i,a}$ ,  $V_{i,a}^* \equiv ner P_a^* \nu_{i,a}^*$  and  $\Lambda_{i,a}^* \equiv ner P_a^* \lambda_{i,a}^*$  attached to the constraints in Equations (18), (19), (20), (21) and (22) respectively. The multiplier  $nm_c$  associated with the goods market clearing condition is the nominal marginal cost. The 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. Similarly, the multipliers  $\lambda_{i,a}$  and  $\lambda_{i,a}^*$  attached to the laws of the motion of the habit stocks, measure the real marginal profits gained from changes in the habit stocks. We will consider the optimality conditions in a symmetric equilibrium. The first order condition for labour equates the nominal marginal cost to the nominal wage,  $nm_c t = W_t$ . The optimal choice of domestic sales  $c_a$  provides a law of motion for the real marginal profit  $\nu_a$  of selling a unit of the good:

$$\nu_{a,t} = 1 + \lambda_{a,t} (1 - \rho_a) - \frac{nm_c t}{P_{a,t}}. \quad (25)$$

The real marginal profit equals the difference between the real marginal cost  $nm_c/P_a$  and the real marginal revenue, which in turn has two components. The first component is the unit real revenue 1 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  $s_a$ :

$$\lambda_{a,t} = \mathbb{E}_t r_{t,t+1} \pi_{a,t+1} (h_a \nu_{a,t+1} + \rho_a \lambda_{a,t+1}). \quad (26)$$

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 persistence of the habit stock  $\rho_a$  determines the degree to which the present value of marginal profits is affected by the next period's expectation of marginal profits from future sales.

The first order conditions for export sales  $c_a^*$  and export habit stock  $s_a^*$  are almost isomorphic to those for domestic sales:

$$\nu_{a,t}^* = 1 + \lambda_{a,t}^* (1 - \rho_a^*) - \frac{nm_c t}{ner_t P_{a,t}^*}, \quad (27)$$

$$\lambda_{a,t}^* = \mathbb{E}_t r_{t,t+1} \pi_{t+1}^{ner} \pi_{a,t+1}^* (h_a^* \nu_{a,t+1}^* + \rho_a^* \lambda_{a,t+1}^*). \quad (28)$$

Since the firm prices the exports  $P_a^*$  in the foreign currency, the nominal exchange rate enters these equilibrium conditions through its influence on the markup and profits. The real marginal cost of the exporter is given by  $nmc / (ner P_a^*)$  and the relevant price markup is simply its reciprocal:  $\mu_a^* = ner P_a^* / nmc$ . The effective discount factor used by the firm to evaluate marginal profits from future foreign sales is distinct from the analogue for domestic sales. In particular, the expected depreciation of the home currency, indicated by  $\pi_{t+1}^{ner} = ner_{t+1} / ner_t$  affects the discount rate. This is because the marginal profits  $\nu_a^*$  and  $\lambda_a^*$  are by definition ‘real’ in terms of the home currency equivalent of the export price, which is set in foreign currency. In the absence of deep habits, the present value of future profits  $\lambda_a^*$  as well as the effective discount rate are auxiliary variables, and do not play significant roles in the firm’s decision problem. This implies that the real marginal profit can be obtained by a simple rescaling of the price markup:  $\nu_a^* = (\mu_a^* - 1) / \mu_a^*$ .

Optimality implies the following paths for inflation in home and foreign sales price:

$$\mathbb{E}_t r_{t,t+1} \frac{c_{a,t+1}}{c_{a,t}} \frac{\pi_{a,t+1}^2}{\bar{\pi}_a} \psi_a \left( \frac{\pi_{a,t+1}}{\bar{\pi}_a} - 1 \right) = \frac{\pi_{a,t}}{\bar{\pi}_a} \psi_a \left( \frac{\pi_{a,t}}{\bar{\pi}_a} - 1 \right) + \eta_c \frac{x_{a,t} \nu_{a,t}}{c_{a,t}} - 1, \quad (29)$$

and

$$\mathbb{E}_t r_{t,t+1} \frac{c_{a,t+1}^*}{c_{a,t}^*} \frac{\pi_{t+1}^{ner} (\pi_{a,t+1}^*)^2}{\bar{\pi}_a^*} \psi_a^* \left( \frac{\pi_{a,t+1}^*}{\bar{\pi}_a^*} - 1 \right) = \frac{\pi_{a,t}^*}{\bar{\pi}_a^*} \psi_a^* \left( \frac{\pi_{a,t}^*}{\bar{\pi}_a^*} - 1 \right) + \eta_c \frac{x_{a,t}^* \nu_{a,t}^*}{c_{a,t}^*} - 1. \quad (30)$$

As in traditional sticky price models, these optimal pricing 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 real marginal cost is indirect, through the marginal profits  $\nu_a^*$  and  $\nu_a^*$  presented in Equations (25) and (27). We defer the discussion on pricing behaviour under deep habits to Section 3.1 when we examine the extent of exchange rate pass-through in the first-order approximation of the model. We will now focus on equilibrium conditions that have been log-linearized around a non-stochastic steady-state that abstracts from growth in all variables.

### 3 Price Markups and Exchange Rate Fluctuations

Here we examine the transmission of exchange rate fluctuations into the foreign economy’s export prices. In the empirical analysis that will follow in Section 4, the US will be positioned as the home country in the model while the foreign economy is the rest of the world (RoW). The discussion in the empirical exercise centres on the dynamics of the US import price. In the context of the model developed here, the US import price is simply the export price of the foreign economy. We begin by analyzing the composition of the foreign exporter’s Phillips curve and how the exchange rate affects the price markup in Section 3.1. In Section 3.2, we simulate the log-linearized model to illustrate how deep habits and price stickiness

interact with each other to diminish exchange rate pass-through, conditional on UIP and home monetary policy shocks.

### 3.1 The Foreign Exporter's Phillips Curve

We now present the log-linearized analogues of Equations (27), (28) and (30), the optimal choices 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 the export sales price  $P_b$  to the foreign nominal marginal cost  $nmc^*$  expressed in the same currency,  $\mu_b = (P_b/nmc^*)/nmc^*$ , the real marginal profit flows as:

$$\hat{\nu}_{b,t} = \frac{1}{\bar{\nu}_b \bar{\mu}_b} \hat{\mu}_{b,t} + (1 - \rho_b) \frac{\beta h_b}{1 - \beta \rho_b} \hat{\lambda}_{b,t}. \quad (31)$$

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

$$\hat{\lambda}_{b,t} = (1 - \beta \rho_b) \mathbb{E}_t \hat{\nu}_{b,t+1} + \beta \rho_b \mathbb{E}_t \hat{\lambda}_{b,t+1} - \left[ \hat{R}_t^* - \mathbb{E}_t (\hat{\pi}_{b,t+1} - \hat{\pi}_{t+1}^{ner}) \right]. \quad (32)$$

Observe the effect of the expected changes in the exchange rate on the effective discount rate used by the foreign exporter to evaluate future profits. A change in the value of the currency alters the present value of future profits. For instance, if the home currency is expected to depreciate,  $\mathbb{E}_t \hat{\pi}_{t+1}^{ner} > 0$ , the effective real discount rate increases, and this depresses the present value of profits. Finally, changes in the foreign exporter's optimal price are determined by:

$$\hat{\pi}_{b,t} = \beta \mathbb{E}_t \hat{\pi}_{b,t+1} - \frac{1}{\psi_b} (\hat{\nu}_{b,t} + \hat{x}_{b,t} - \hat{c}_{b,t}). \quad (33)$$

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, it is useful to abstract from persistence in the habit stock by setting  $\rho_b = 0$ . This adjustment implies that the present value of expected future profits reduces to:

$$\hat{\lambda}'_{b,t} = \mathbb{E}_t \hat{\nu}_{b,t+1} - \left[ \hat{R}_t^* - \mathbb{E}_t (\hat{\pi}_{b,t+1} - \hat{\pi}_{t+1}^{ner}) \right]. \quad (34)$$

The adjusted steady-state export markup can be simplified as:

$$\bar{\mu}'_b = \frac{\eta_c (1 - h_b)}{\eta_c (1 - h_b) - (1 - \beta h_b)}. \quad (35)$$

Substitute the following into Equation (33): the steady-state real marginal profit  $1/\bar{\nu}_b = \eta_c (1 - h_b)$ , the dynamics of the real marginal profit in Equation (31), the steady-state markup in Equation (35), and the definition of aggregate habit-adjusted demand,  $\hat{x}_{b,t} = \frac{\hat{c}_{b,t} - h_b \hat{c}_{b,t-1}}{1 - h_b}$ .<sup>8</sup> The dynamics of the export markup, i.e. the wedge between the foreign export

<sup>8</sup>All the expressions have been modified to account for the fact that we have now set  $\rho_b = 0$ .



price and the foreign marginal cost expressed in the same currency, are given by:

$$\underbrace{(\hat{p}_{b,t} - \widehat{nm}c_t^* - \widehat{ner}_t)}_{\hat{\mu}_{b,t}} = \frac{\beta\psi_b\mathbb{E}_t\hat{\pi}_{b,t+1} - \psi_b\hat{\pi}_{b,t} - (\beta h_b\hat{\lambda}'_{b,t} + \hat{\varepsilon}_{b,t})}{\eta_c(1-h_b) - (1-\beta h_b)}, \quad (36)$$

where  $\hat{\varepsilon}_{b,t} = \frac{h_b}{1-h_b}\Delta\hat{c}_{b,t}$  is the relevant short-run price elasticity of demand. Other things being constant, consider an exogenous depreciation of the home currency, that is a rise in the exchange rate so that  $\widehat{ner}_t > 0$ . 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 depresses the exporter's price markup. 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 presence of the habit component implies that the reduction in the current markup (or prices) stimulates positively not only current export demand, but also generates profits into the future. When the home currency depreciates, the economy *expects* it to appreciate in the future so that it returns to the long run level,  $\mathbb{E}_t\hat{\pi}_{t+1}^{ner} < 0$ . The expected appreciation raises the present value of future profits  $\hat{\lambda}'_{b,t}$ , which gives the foreign exporter an incentive to keep the current markup low and prices stable (see Equation 32). Finally, the reduction of the markup can be reinforced by a rise in current export demand, which increases the price elasticity of demand  $\hat{\varepsilon}_{b,t}$ . In sum, the stronger the degree of habit formation, the more the exporter has an incentive to suppress the price markup and keep prices stable. 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 changes to react to the movement in the markup. It is important to note that even if prices could be adjusted costlessly, export price adjustment would be slow due to the compression of the markup due to deep habits. In particular, if  $h_b > 0$ ,  $\psi_b = 0$  :

$$\underbrace{(\hat{p}_{b,t} - \widehat{nm}c_t^* - \widehat{ner}_t)}_{\hat{\mu}_{b,t}} = -\frac{\beta h_b\hat{\lambda}'_{b,t} + \hat{\varepsilon}_{b,t}}{\eta_c(1-h_b) - (1-\beta h_b)}. \quad (37)$$

Alternatively, in the absence of deep habits but with costly price adjustment, the change of the markup would again show up slowly in the price level. Formally, if  $h_b = 0$ ,  $\psi_b > 0$  :

$$\underbrace{(\hat{p}_{b,t} - \widehat{nm}c_t^* - \widehat{ner}_t)}_{\hat{\mu}_{b,t}} = \beta\psi_b\mathbb{E}_t\hat{\pi}_{b,t+1} - \psi_b\hat{\pi}_{b,t}. \quad (38)$$

In the absence of deep habits, neither time-varying price elasticities nor the present value of future profits exerts a direct influence on the markup. The cost of price adjustment moderates the degree of pass-through. 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, if  $h_b = \psi_b = 0$  :

$$\hat{p}_{b,t} = \widehat{nm}c_t^* + \widehat{ner}_t. \quad (39)$$

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 *can* adjust prices freely, as indicated by zero or low nominal price adjustment costs.

### 3.2 Deep Habits, Sticky Prices and Exchange Rate Pass-through

We will use numerical experiments to demonstrate the dampening influence of deep habits on the degree of exchange rate pass-through when the economy is hit by UIP shocks and monetary policy shocks. Of particular interest is a contrast of the effect of deep habits against that of the more conventional friction used to generate incomplete exchange rate pass-through in open-economy models, i.e. stickiness in prices as embodied by the Rotemberg adjustment cost. In this simple illustration, we will assume the same degree of habit persistence for domestic and foreign sales in both countries so that  $h_a = h_a^* = h_b^* = h_b = h$ , 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 values we pick for the baseline parameterization of the model are in the ballpark of estimated values or calibrations for the US available in the literature, e.g. Ravn et al. (2010b), Ravn et al. (2012) and Jacob and Peersman (2013). The parameter values are reported in Table 1.

The habit and price adjustment cost parameters are allowed to vary over fixed intervals. Models with deep habits are prone to indeterminacy at higher levels of habit, due to mutually reinforcing interactions between expectations of future demand and current markups (see Zubairy, 2014). The parameter ranges are hence chosen with these considerations in mind. Firstly, we choose the interval  $[0, 0.75]$  for the habit parameter. For the Rotemberg price adjustment cost, we set a lower bound of 1 so that the firm can change prices fairly flexibly, and the upper bound is set at 25. In the absence of deep habits, and given the baseline values given to the elasticity of substitution ( $\eta_c$ ) between habit-adjusted demands and the discount factor ( $\beta$ ), these values for the Rotemberg cost parameter correspond to price durations ranging between 1.17 quarters and 2.81 quarters.<sup>9</sup>

For each combination  $\{h, \psi\}$ , we simulate the model using one structural shock at a time and compute the ordinary least squares (OLS) coefficient of a static regression of foreign export price inflation  $\hat{\pi}_b$  on nominal depreciation of the home currency  $\hat{\pi}^{ner}$ .<sup>10</sup> We will label the OLS slope coefficient computed from simulated data as the ‘pass-through’ coefficient.

<sup>9</sup>This can be achieved by abstracting from deep habits, and comparing the slopes of the Rotemberg Phillips curves with those of the Calvo-style analogues and interpreting the associated Calvo probability in terms of price duration.

<sup>10</sup>The model simulations are executed using the Matlab-based toolbox Dynare Version 4.4.3 (see Adjemian et al., 2011).

Table 1: Parametrization

Parameter Symbol	Description	Value
$\psi_a, \psi_a^*, \psi_b^*, \psi_b = \psi$	Rotemberg price adjustment cost	[1 (1.17Q), 25 (2.81Q)]
$h_a, h_a^*, h_b^*, h_b = h$	Habit	[0, 0.75]
$\rho_a, \rho_a^*, \rho_b^*, \rho_b$	Persistence of habit stock	0
$\rho_{uip}$	Persistence of UIP shock	0
$\rho_{mon}$	Persistence of monetary policy shock	0
$\sigma_{uip}, \sigma_{mon}$	Standard deviation of shocks	1
$\beta$	Subjective discount factor (quarterly)	0.99
$1/\sigma_c$	Intertemporal elasticity of substitution	1
$1/\sigma_n = (1 - \bar{n})/\bar{n}$	Frisch elasticity of labour supply	0.50
$\omega$	Home-bias in consumption	0.987
$\xi$	Elast. of subst. between home and foreign goods	0.75
$\eta_c = \eta_n$	Elast. of subst. between goods/labour varieties	6
$r_R$	Interest rate smoothing	0.8
$r_\pi$	Interest rate reaction to domestic inflation	1.5
$r_y$	Interest rate reaction to output	0.1
$\psi_w$	Rotemberg wage adjustment cost	25

Notes: The above table lists the parameter values used to generate the surface plots presented in Figure 1. Other steady-state parameters are derived from the restrictions of the model. The home-bias parameter  $\omega$  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.Q1-2015.Q4.

The measurement of pass-through in general equilibrium is non-trivial because prices respond contemporaneously to factors other than the fluctuation in the currency's value, irrespective of the structural origin of the cyclical disturbance. A reduction in the simple least squares correlation is only one of the several possible ways of confirming incomplete exchange rate pass-through to international prices. In the empirical application presented in Section 4, we view pass-through through a different lens using VAR dynamics. The OLS pass-through coefficient, used in this section, provides a useful starting point.

We abstract from the decaying habit stocks by setting the persistence parameters  $\rho_a = \rho_a^* = \rho_b^* = \rho_b = 0$  as in Section 3.1, so that the habit stock depends only on lagged consumption. Recall that the central implication of this restriction is that the dynamics of the present value of expected future profits is reduced to the relationship established in Equation (34).

In the first graph of Panel (a) in Figure 1, we present the surface plot for the pass-through coefficient for the case in which we consider i.i.d. shocks to the UIP condition. The more interesting scenario is when we keep prices only mildly sticky 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. This pattern can be traced to the related impulse responses of the key variable in our framework: the price markup of the foreign exporter.<sup>11</sup>

In the central graph of Panel (a), we present a surface plot of the impact response of the price markup to a depreciation of the home currency triggered by a positive UIP shock, corresponding to the  $\{h, \psi\}$  parameter combinations that yield the pass-through surface on the left of Panel (a). In the final graph of Panel (a), we plot the corresponding nominal exchange rate response to provide a sense of the relative strength of the movements. As we increase habit at low price stickiness, the nominal exchange rate depreciation does not change dramatically. However the decrease in the price markup is stronger at higher degrees of habit persistence which contributes to the declining degree of pass-through.

The second set of stochastic simulations uses home monetary shocks and the results are presented in Panel (b) of Figure 1. The impulse response surfaces of the markup and nominal exchange rate, shown in the middle and right graphs respectively, are triggered by negative home monetary policy shocks. These findings yield qualitatively similar results to those obtained for the UIP shocks in Panel (a). Again, when the habit parameter is increased at low degrees of price stickiness, the nominal exchange rate depreciations generated by the model are quantitatively in the same neighbourhood. In contrast, the falls in the markup are more pronounced.

Weaker pass-through can be achieved for both structural shocks 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. It is clear from the pass-through surfaces that demand stickiness through deep habits and price stickiness can substitute each other in lowering exchange rate pass-through. Not surprisingly, when prices get stickier, pass-through is weakened at lower levels of habit persistence. Since markup adjustment and incomplete pass-through under sticky prices are widely understood, we will now delve deeper into how the deep habits mechanism affects the transmission of each structural shock by examining the impulse response functions.

In Figure 2, we restrict our attention to the case when the Rotemberg cost is set very low at 1, and we inspect the dynamics firstly without deep habits, and later when deep habits are prevalent. Since the peak responses are observed in the first period of impact of the shock, we will focus on this horizon. The key finding here is along the lines of the observation that the OLS pass-through coefficient from the simulations declines at higher levels of habit. The impulses triggered by both structural shocks confirm that the covariance between foreign export prices and the exchange rate is lower when deep habits are present.

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<sup>11</sup>The OLS pass-through coefficient in Figure 1 is computed from artificial data using sequences of (positive as well as negative) shocks. In contrast, impulse responses are conditional on the realization of a single structural innovation and hence can only provide a flavour of how the mechanism plays out and the related OLS pass-through coefficient is affected.

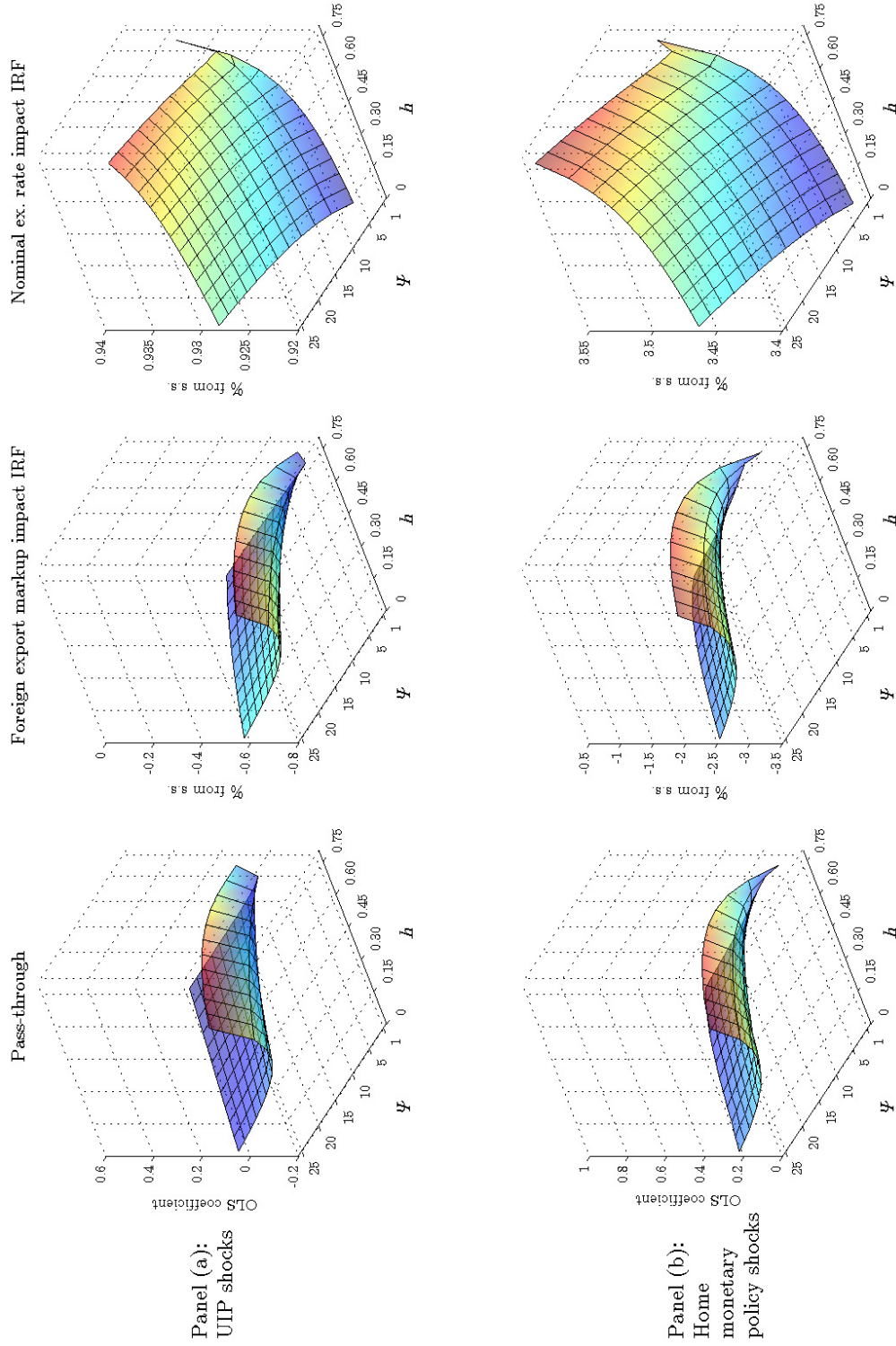
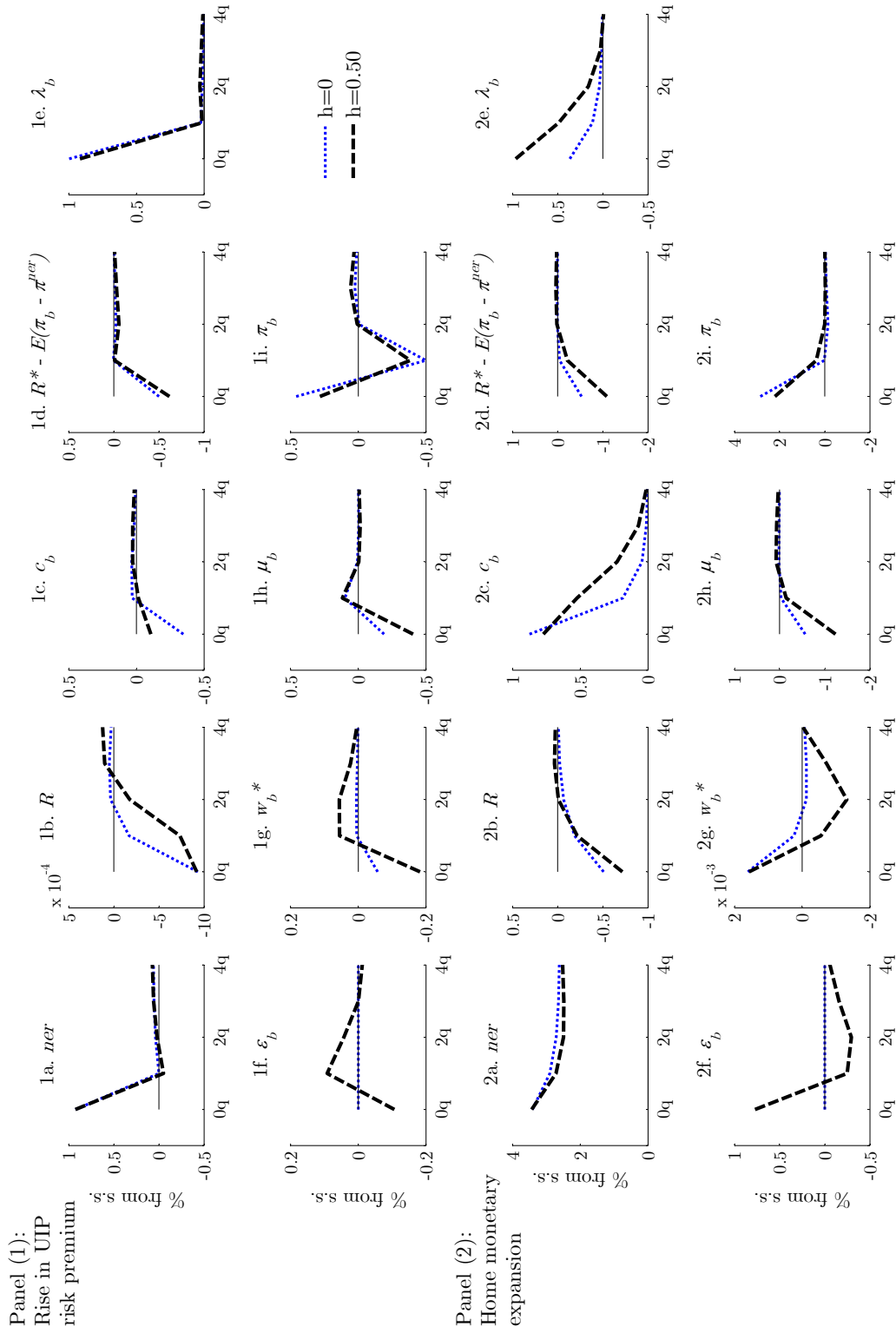


Figure 1: Exchange rate pass-through with i.i.d. shocks

Notes:  $h$  represents the deep habit parameter and  $\psi$  represents the Rotemberg price adjustment cost parameter. The bounds set on  $\psi$  correspond to price-durations of 1.17 and 2.82 quarters respectively. 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 home import (foreign export) price inflation on nominal exchange rate depreciation and the average across samples is plotted for each parametric combination. The response of the foreign export markup on impact is also the peak effect.



In a world without deep habits, a rise in the UIP risk premium depreciates the home currency, raising foreign export prices in home currency terms, and suppressing the demand for foreign exports. Once deep habits are activated by setting  $h = 0.5$ , the transmission of the UIP shock is magnified considerably. Since a current depreciation of the home currency implies that it is expected to appreciate in the future, the effective discount rate of the foreign exporter falls. This raises the present value of foreign export sales, exerting downward pressure on the markup (see Equation 31).<sup>12</sup> In the presence of deep habits, foreign export volumes fall, but since they are more inertial, the decline is not as strong as in the case without habit persistence. Since the price elasticity of demand is now a positive function of demand growth, it falls on impact, exerting a positive influence on the price markup.

Thus, the intertemporal and price elasticity effects of deep habits exert opposing forces on the markup in the first period. The overall effect of deep habits on the foreign export markup is a strong downward movement due to the dominance of the intertemporal effect.<sup>13</sup> Though the nominal exchange rate movements for the models without and with deep habits are virtually identical, the price response in the latter case is more muted. Thus deep habits dampen exchange rate pass-through to foreign export prices even when prices are quite flexible.

We now alter the source of the exchange rate fluctuation. We generate a home currency depreciation by using a negative monetary policy shock in the home country. In response to the home monetary policy expansion, aggregate demand in the home economy rises, stimulating the demand for foreign exports. When deep habits are prevalent, the home currency depreciation (and the resulting expected appreciation) that is generated by the fall in the home interest rate raises the present value of foreign export profits, exerting a negative influence on foreign export markup and prices. Concurrently, the rise in export demand also raises the price elasticity of demand, which lowers the price markup. In this scenario, the intertemporal and price elasticity effects of deep habits work in the same direction to lower the foreign export price markup. This is in contrast to the case where the source of the exchange rate depreciation was the UIP shocks and the two effects worked in opposite directions in the period of impact.

In Jacob and Uusküla (2016), we also consider exchange rate pass-through simulations for the case where the economy is hit by persistent shocks and generate more inertial movements in the nominal exchange rate. In the face of a persistent depreciation of the home currency, the cost structure of the foreign exporter firm is expected to remain unfavourable for many periods. For this reason, firms are willing to pass through a higher proportion of the currency depreciation to the consumer in the home country. The higher the persistence of the shocks, the more inertial the habit stocks need to be in order to increase the firm's incentive to retain demand by absorbing exchange rate fluctuations into the markup, dampening the degree of pass-through. Once persistent habit stocks are reintroduced, the present value of expected future profits follows the more inertial path dictated by Equation (32). We do not present the results here since the observed pattern in the OLS pass-through coefficient for

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<sup>12</sup>In the absence of deep habits, the present value of future profits and the effective discount rate are simply auxiliary variables, and do not directly influence the firm's decisions.

<sup>13</sup>The price elasticity reverses sign and is positive in the following period as the demand for foreign exports rises to return to its long run level.

various combinations of the habit and sticky price parameters are qualitatively similar to those obtained for the case of i.i.d. shocks. However, we allow for shocks to be persistent in the empirical analysis in Section 4.

### 3.2.1 Home Export Price Pass-through

What do deep habits imply for the exchange rate pass-through to home export prices or, equivalently in our set-up, the import prices in the foreign country? In Figure 3, we compare the patterns of exchange rate pass-through to home import and home export prices in the face of UIP shocks and home monetary shocks, for various combinations of the habit parameters and Rotemberg price adjustment cost. Panel (a) examines the case of UIP shocks. The first two graphs present the behaviour of pass-through to home import prices, and the related dynamics of the foreign exporter's markup, earlier exhibited in Figure 1. In the third graph, we present the pass-through of the home currency depreciation to the foreign currency price of the home good.

When price stickiness is very low in the economy without deep habits, the home export price falls considerably after the home currency depreciation. Once habits are activated, the home exporter has a stronger incentive to smooth profits by keeping prices stable in local currency. Therefore, the firm will increase the price markup to limit the fall in the foreign currency price of the home good. The associated adjustment in home export price markup is presented in the final graph of Panel (a). Note how at extreme degrees of habit formation, the home export markup increases are fairly strong and the home export price in foreign currency even rises after a depreciation of the home currency. When habit is deactivated, by contrast, increasing the price rigidities also achieves higher home export price markups to diminish the pass-through of the currency depreciation to the foreign currency prices of the home good.

In Panel (b), we exhibit the results for the home monetary shock. In this case, the influence of deep habits on pass-through and the home export markup, at low degrees of price stickiness, is very weak. The impetus from the home monetary shock drives up the domestic demand for home and imported goods, and increasing habit persistence does not alter the home exporter's pricing behaviour materially. Alternatively, if we abstract from habits and simply increase the price stickiness of home exports in foreign currency, the home export markup increases and reduces the fall of the price of the home good in the foreign market.



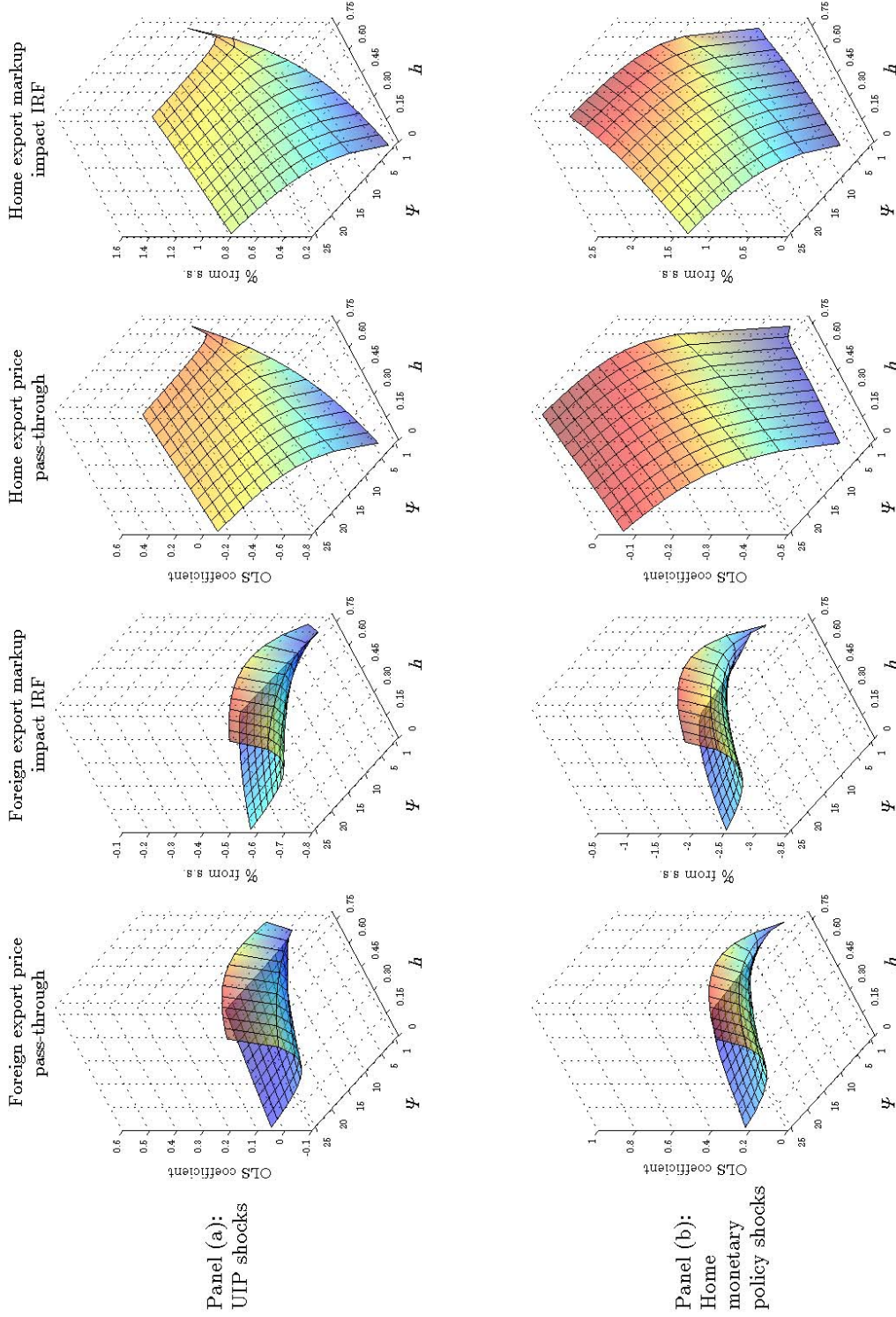


Figure 3: Foreign versus home export price pass-through with i.i.d. shocks

Notes:  $h$  represents the deep habit parameter and  $\psi$  represents the Rotemberg price adjustment cost parameter. The bounds set on  $\psi$  correspond to price-durations of 1.17 and 2.82 quarters respectively. 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 home import (foreign export) price inflation on nominal exchange rate depreciation and the average across samples is plotted for each parametric combination. The response of the foreign export markup on impact is also the peak effect.

The relationship between export prices and exchange rates has also been studied by Drozd and Nosal (2012a), who evaluate several theoretical mechanisms that lead to pricing-to-market. In the context of this paper, one of their findings deserves careful consideration. In particular, Drozd and Nosal (2012a) find that deep habits generate a negative correlation between home export prices and the exchange rate, US export prices measured in US dollars fall when the dollar depreciates.<sup>14</sup> This is contrary to the corresponding positive unconditional correlation found using Hodrick-Prescott filtered US data. There are substantial differences between our framework and that of Drozd and Nosal (2012a) since we use a New Keynesian model with UIP and monetary shocks, while they use an international real business cycle (RBC) model with productivity shocks.<sup>15</sup> We do not pursue a replication of their model here, but will indicate the aspects of their modelling strategy that may explain their result.

As we have seen in this section and elsewhere in the literature, different sources of the business cycle – be it the structural interpretation or the country of origin – can have different implications for pass-through. Equally importantly, as observed in Figures 1 through 3, the strength of habit persistence and the rate of decay of the habit stock are important determinants of the degree of exchange rate pass-through, be it to import or export prices. Conditional on commonly-used parameterizations, open-economy models generate a fall in the price of the home good and a depreciation of the home currency (rise in the exchange rate), producing a negative correlation for an exogenous surge in domestic productivity which lowers production costs (see *e.g.* Lubik and Schorfheide, 2006).<sup>16</sup> Drozd and Nosal (2012a), given their broader purpose of contrasting diverse models of pricing-to-market, use a single parameter configuration for their calibration of the deep habits model that is drawn from Ravn et al. (2006). The degree of habit persistence may not be strong enough in their framework to weaken the fundamental negative correlation between export prices and exchange rates generated in productivity shock-driven international business cycle models.<sup>17</sup>

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<sup>14</sup>Prices of US exports and imports published by the Bureau of Economic Analysis are quoted in US dollar terms.

<sup>15</sup>Drozd and Nosal (2012a) also use a different formulation of deep habit persistence. In their paper the habit-adjusted aggregate is defined in terms of the ratio  $c_t/s_{t-1}^h$ ,  $h < 0$ . This ‘relative’ habits specification eliminates the short-run price elasticity effect of deep habits on the markup which is present in the more commonly used ‘additive’ specification where habit-adjustment is made using the difference  $c_t - hs_{t-1}$ ,  $h \in [0, 1)$ . The latter specification yields both the intertemporal sales substitution effect as well as the price elasticity effect. See also Ravn et al. (2006).

<sup>16</sup>An exception is the negative transmission of productivity shocks detailed in Corsetti et al. (2008b). Under extreme home-bias and high complementarity between home and foreign goods, the wealth effect after a positive home productivity shock of near-unit root persistence can lead to an appreciation of the home terms of trade.

<sup>17</sup>In other experiments (not presented in this paper) using home productivity shocks at very low degrees of price stickiness, increasing habit persistence diminishes exchange rate pass-through to home export prices. However, even for higher levels of habit persistence, the depreciation of the home currency is accompanied by a fall in the home export price, i.e. the conditional correlation continues to be negative. Hence the productivity-shock driven version of our model does not generate the positive unconditional correlation observed in the US data by Drozd and Nosal (2012a). These additional results are available on request.

## 4 Deep Habits versus Sticky Prices: An Empirical Evaluation

In this section, we take the model to the data. We adapt the strategy of Choudhri et al. (2005) who estimate the responses of various prices in a panel of advanced economies to an exchange rate shock identified in a recursive VAR, and we match the corresponding dynamics triggered by the shock to UIP in a suite of New Keynesian small open economy models.<sup>18</sup> The parallel that we draw between the UIP shock and the identified empirical exchange rate shock, is imperfect; the zero restrictions imposed in the VAR identification are unlikely to be satisfied by our general equilibrium environment. However, as a horserace between the two competing model frictions – deep habits and local currency price stickiness – in dampening the conditional exchange rate pass-through observed in the VAR, the matching exercise is instructive.

### 4.1 The Identified Exchange Rate Shock

We focus on the cyclical dynamics of three US time series: the price deflator of imported consumption goods ( $p^m$ ), the price deflator of consumption goods ( $p^c$ ), and the nominal effective exchange rate ( $neer$ ) of the US dollar that covers exchange rates with a broad basket of trading partners.<sup>19</sup> We select consumption-based prices since the theoretical model abstracts from physical capital and government expenditures. The data span 1983.Q1 to 2015.Q4 and the variables are presented in their natural logarithms. Formally, the VAR is represented as:

$$A \begin{bmatrix} \Delta neer_t \\ \Delta p_t^m \\ \Delta p_t^c \end{bmatrix} = B(L) \begin{bmatrix} \Delta neer_{t-1} \\ \Delta p_{t-1}^m \\ \Delta p_{t-1}^c \end{bmatrix} + \epsilon_t. \quad (40)$$

The parameter matrix  $A$  is of size 3 by 3 and factor  $B(L)$  denotes a lag polynomial with  $L$  denoting the lag operator. Finally  $\epsilon_t$  is the vector of residuals. We include linear trends in the model and use 2 lags.

We identify the exchange rate shock by placing the nominal effective exchange rate first in the system of variables. The matrix  $A$  has zero elements above the diagonal. A consequence of this constraint is that while the exchange rate can affect price indices instantaneously, the price indices do not have a contemporaneous effect on the exchange rate. The identification is equivalent to a Cholesky decomposition when the exchange rate is placed first in the

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<sup>18</sup>A vast empirical literature on exchange rate pass-through uses single equation models (see e.g. Burstein and Gopinath, 2014), that do not allow dynamic feedback between the variables of interest and hence are less suitable empirical benchmarks for our DSGE model.

<sup>19</sup>The nominal effective exchange rate is taken from the FRED2 database of the Federal Reserve Bank of St.Louis (mnemonic TWEXBMTH). The remaining series are drawn from the National Economic Accounts of the Bureau of Economic Analysis. The import price of consumption goods (mnemonic B652RG3) is from Table 4.2.4 while the deflator for personal consumption expenditures (mnemonic DPCERG3) is from Table 1.1.4. The choice of the aggregate consumption import price implies that an aggregate of US trade partners constitutes the second region in our model. The unavailability of bilateral trade price data eliminates the possibility of using a single currency zone, like the euro area, as the foreign country.

system and is essentially a generalization of the single equation approach used by Burstein and Gopinath (2014). In order to concentrate on the dynamics of import and consumption prices, we use a much smaller VAR than Choudhri et al. (2005).

To understand the influence of deep habits in the determination of exchange rate pass-through, we will now estimate two model variants by matching their dynamics to the VAR benchmark. While the first variant features deep habits, the second abstracts from the friction. The two variants of the theoretical model will share a common trigger of the business cycle, the shock to UIP given in Equation (13).

## 4.2 Model Variants and Estimation Methodology

To prepare the two model variants for estimation, we alter the baseline model in two dimensions. As a first step, we introduce price indexation in the firm's optimization programme so that lagged inflation influences the Phillips curves. Specifically, the US import Phillips curve in the model variant with deep habits is now given as:

$$\hat{\pi}_{b,t} = \frac{\iota_b}{1 + \beta\iota_b} \hat{\pi}_{b,t-1} + \frac{\beta}{1 + \beta\iota_b} \mathbb{E}_t \hat{\pi}_{b,t+1} - \frac{(\hat{\nu}_{b,t} + \hat{x}_{b,t} - \hat{c}_{b,t})}{\psi_b (1 + \beta\iota_b)}, \quad (41)$$

where  $\iota_b \in [0, 1]$  represents the degree of indexation. Secondly, in the version of the model without deep habits, we retain price indexation but also introduce standard superficial habit formation, so that habits only affect the demand-side of the economy as in conventional models and are eliminated from the firm's profit-maximisation programme. We will refer to the latter variant of the model with superficial habits and price indexation as the pure sticky price model. The US import Phillips curve in the pure sticky price model is expressed as:

$$\hat{\pi}_{b,t} = \frac{\iota_b}{1 + \beta\iota_b} \hat{\pi}_{b,t-1} + \frac{\beta}{1 + \beta\iota_b} \mathbb{E}_t \hat{\pi}_{b,t+1} - \frac{\hat{\mu}_{b,t}}{\psi_b (1 + \beta\iota_b)}. \quad (42)$$

In the two model variants, a subset  $\Theta$  of the model parameters will be estimated while the rest, represented by the vector  $\alpha$ , take the baseline values given in Table 1. We depart from our simple baseline parametrization in Section 3 and allow the estimated parameters to span a wider range of values, further easing the estimation. We relax the constraint that all deep habit parameters are identical and allow the habit persistence for domestic sales and export sales to be different. However, to simplify the solution of the modified steady-state, the habit parameters are still restricted to be the same across countries, so that  $h_a = h_b^*$  and  $h_a^* = h_b$ . We approach the estimation of decay parameters for the habit stocks similarly. In the pure sticky price model, in contrast, we estimate the superficial habit parameter and the associated persistence of the habit stock. The other important set of estimated coefficients involves the parameters that govern price stickiness. We allow the Rotemberg price adjustment costs and price indexation coefficients to differ for domestic and export sales in both countries, leading to a total of eight estimated price stickiness parameters. In addition, we estimate parameters related to wage stickiness and the UIP shock process, the latter being allowed to be possibly persistent, unlike in Section 3.

The estimation procedure involves assigning values for the structural parameters in vector  $\Theta$  to minimize the distance between the empirical pass-through impulse response functions ( $IRF^{var}$ ) and the corresponding theoretical pass-through impulse response functions ( $IRF^{theory}$ ) implied by the theoretical model(s). Since we focus on a forecast horizon of 16 periods for the dynamics of US import and consumer prices relative to those of the exchange rate, the relevant vector is of order  $32 \times 1$ . Formally, the estimated parameter vector  $\hat{\Theta}$  is chosen to minimise the loss function:

$$\hat{\Theta} = \min_{\Theta} (IRF^{var} - IRF^{theory}(\Theta | \alpha)) \mathbb{W}^{-1} (IRF^{var} - IRF^{theory}(\Theta | \alpha)). \quad (43)$$

The weighting matrix  $\mathbb{W}$  is the  $32 \times 32$  diagonal variance matrix estimated from the bootstrapped empirical exchange rate pass-through. The weighting matrix places a larger weight on VAR impulses that are estimated precisely and a smaller weight on VAR impulses that are estimated imprecisely. The estimate of the variance-covariance matrix  $\Sigma_{\hat{\Theta}}$  of the estimated parameters  $\hat{\Theta}$  is given by  $\Sigma_{\hat{\Theta}} = \left( J'_{\hat{\Theta}} \mathbb{W}^{-1} J_{\hat{\Theta}} \right)^{-1}$  where  $J_{\hat{\Theta}}$  denotes the Jacobian of the theoretical impulse response functions with respect to the estimated parameters.<sup>20</sup>

### 4.3 Estimation Results

We present the estimation results in Figure 4 and Table 2. In contrast to the calibration exercise in Section 3, our empirical measure of pass-through is dynamic and conditional on the effects of a single realization of the shock. In particular, as in Choudhri et al. (2005), pass-through is computed by dividing the cumulated impulse responses of changes in prices by the cumulated impulse responses of the changes in the exchange rate. Figure 4 presents the effects of the identified exchange rate shock on pass-through, up to a forecast horizon of 16 quarters. The median response is indicated by a solid black line while the shaded grey area represents the non-centred 90% confidence bands based on 5000 replications obtained from non-parametric bootstrapping.

The exchange rate pass-through to US import prices increases steadily from 15% on the impact of the shock to a maximum of 37% after about 10 quarters. As one would expect in a relatively closed economy like the US, the exchange rate pass-through to consumer prices is much lower: on the impact of the shock, pass-through reaches 5% and levels off at just above 8% after 10 quarters. In the underlying impulse responses (not presented), a 1% increase in the exchange rate (depreciation of the US dollar) is very persistent, staying at around 1% after 16 quarters after the shock implying that the underlying impulse responses for prices exhibit similar qualitative patterns. Our dynamic pass-through estimates for the US conditional on the exchange rate shock are in the ballpark of the analogous results for other countries available in Choudhri et al. (2005) for a panel of non-US G7 economies and in Faruqee (2006) for the euro area.

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<sup>20</sup>For the empirical estimation, the model is solved using the method of undetermined coefficients as in Uhlig (1999), and the matching exercise is implemented in Matlab.

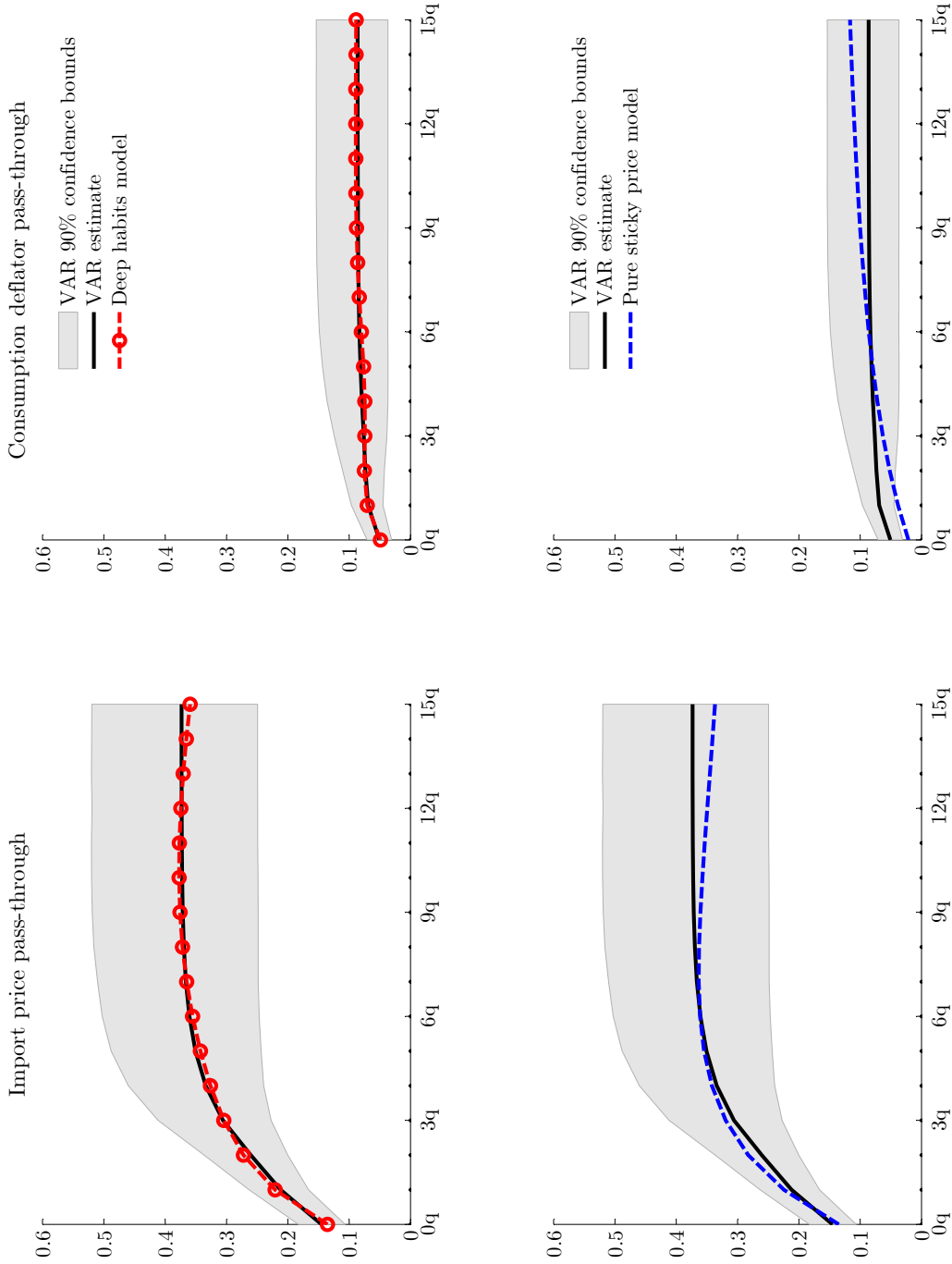


Figure 4: Matching model dynamics to SVAR dynamics conditional on an exchange rate shock

Notes: The recursive VAR is estimated on the US dollar's nominal effective exchange rate and the price deflators for US consumption imports and aggregate consumption, expressed in natural logarithms and first-differenced. The data spans 1983:Q1 to 2015:Q4. The VAR includes linear trends and 2 lags. The exchange rate pass-through is computed by dividing the cumulated impulse responses of changes in prices by the cumulated impulse responses of the changes in the exchange rate. The confidence bands are computed from 5000 replications obtained from non-parametric bootstrapping.

Table 2: Estimated Structural Parameters

Parameter Symbol	Description	Deep habits model		Pure sticky price model	
		Estimate	Std. Err.	Estimate	Std. Err.
$h_a = h_b^*$	Domestic sales habit	0.7403	0.0006		
$h_a^* = h_b$	Export sales habit	0.7337	0.0006		
$\rho_a = \rho_b^*$	Domestic sales habit stock persistence	0.9997	0.0000		
$\rho_a^* = \rho_b$	Export sales habit stock persistence	1.0000	-		
$\tilde{h}$	Superficial habit			0.9975	0.5392
$\tilde{\rho}$	Superficial habit stock persistence			0.0000	-
$\psi_a$	Domestic sales price adj. cost (Home)	1.4369 (1.23Q)	0.1060	24749.0127 (100Q)	0.0641
$\psi_b^*$	Domestic sales price adj. cost (Foreign)	7.2623 (1.82Q)	0.0000	0.0000 (1Q)	24.6376
$\psi_a^*$	Export sales price adj. cost (Home)	0.0145 (1.002Q)	0.1784	1121879.5262 (1000Q)	0.0006
$\psi_b$	Export sales price adj. cost (Foreign)	5.5552 (1.66Q)	0.4993	84.6130 (4.7Q)	342.6079
$l_a$	Domestic sales price indexation (Home)	0.0000	-	0.0000	-
$l_b^*$	Domestic sales price indexation (Foreign)	0.0012	0.0000	0.9983	23.8261
$l_a^*$	Export sales price indexation (Home)	1.0000	-	0.0000	-
$l_b$	Export sales price indexation (Foreign)	0.0000	-	0.0000	-
$\psi_w = \psi_w^*$	Wage adj.cost	26.7406 (2.9Q)	4.4539	0.0000 (1Q)	115.5581
$\rho_{uip}$	Persistence of UIP shock	0.9731	0.0019	1.0000	-
-	Value of quadratic form		0.0056		0.1576

Notes: When the estimation reaches the bounds set for the parameter, we do not report the standard error. We also report the quarterly price-duration interpretation of the Rotemberg price and wage adjustment cost parameters in parentheses. In the absence of deep habits, and given the baseline values of the elasticity of substitution ( $\sigma$ ) between habit-adjusted demands or labour varieties and the discount factor (0.99), we compare the slopes of the Rotemberg Phillips curves with those of the Calvo (1983)-style analogues. We then interpret the associated Calvo probability in terms of price duration.

In the top and bottom panels of Figure 4, we compare the dynamics obtained from the two model variants. The dynamics from the deep habits model are indicated by red circular markers while those from the pure sticky price model are indicated by dashed blue lines. Both model variants are able to fit the pass-through fairly well, with their implied dynamics mostly lying in the estimated empirical 90% confidence intervals. An exception is the case of the pure sticky price model, where the consumption deflator pass-through mildly breaches the VAR confidence bands in the initial periods following the impact of the shock.

The estimated structural parameters that underpin the dynamics in Figure 4 are presented in Table 2. The first column presents the parameter estimates and associated standard deviations of the deep habits model while the second column does the same for the pure sticky price model. In the discussion, we will mainly examine the differences in the habit and price stickiness parameters across the model variants.

The main insight from the estimation results is that the deep habits model can fit the pass-throughs without relying heavily on price stickiness. The estimated Rotemberg price adjustment cost parameters are very low, ranging between 0.01 for home export sales to about 5.55 for foreign domestic sales. These cost parameters, if interpreted in terms of the price-duration scale associated with Calvo (1983), imply price changes that on average occur at 1.002 and 1.66 quarters respectively. Price indexations are at zero with the exception of the domestic export price indexing, for which the Rotemberg cost is estimated to be very close to zero. At negligibly low price stickiness, deep habits play a pivotal role in matching the pass-through dynamics. The habit parameters for domestic and export sales are estimated just below the 0.75 mark. Both the habit stocks are extremely persistent, with the related AR(1) coefficients approaching unity, which implies that the stocks do not depreciate over time.

These estimates are consistent with the previous US data-based estimates of the deep habits parameter by matching government spending shocks by Ravn et al. (2012) who find a deep habit parameter above 0.5 and the habit stock persistence close to one. The results are also similar to the estimates of the deep habit parameter found by matching monetary policy shocks by Ravn et al. (2010b) who find a habit parameter of 0.85. Wage stickiness also appears to play a supporting role in matching the pass-through; the estimate for the adjustment cost approaches 27, which corresponds to an average wage duration of 2.9 quarters. All parameters in the deep habits model are estimated with extreme precision.

The parameter estimates that emerge from the pure sticky price model are starkly different. This variant of the model requires the home domestic good adjustment cost to be about 24,749 which corresponds to an average price spell of about 100 quarters. The foreign export adjustment cost is equal to 85, which implies a price change every 4.7 quarters. The home export price stickiness parameter is also extremely high, exceeding 1,121,879, and indicating a price duration that exceeds 1000 quarters. Wages become fully flexible in this model variant, the cost of wage-adjustment approaching zero. The superficial habit parameter is estimated at a very high value of about 0.998, but there appears to be no persistence in the corresponding habit stock. A notable feature in the parameter estimates in the pure sticky price model is the extreme large standard errors in many cases. Not surprisingly,



the pass-through dynamics predicted by the model are not very sensitive to changes in the parameters at the extremely high price adjustment cost values.

The relatively poor fit of the pure sticky price model is confirmed by the much higher value of the corresponding quadratic loss function, presented in the last row of Table 2. Clearly, the deep habits model matches the SVAR dynamics better, quite in line with the observation that the dynamics from the deep habits model were closer to the empirical analogues in Figure 4.

The qualitative results are preserved in several robustness checks that we conducted; the deep habits model continues to match the pass-through dynamics with very little dependence on nominal price stickiness. These checks include (a) constraining all the habit parameters to be the same, (b) estimating the pure sticky price model without employing superficial habits (which even worsens fit), (c) fixing the persistence of the habit-stock at 0.9876 as estimated by Ravn et al. (2012), and (d) matching the SVAR dynamics for a shorter horizon. These additional results are available on request.

## 5 Conclusion

Stickiness in demand can dampen the pass-through of exchange rate fluctuations into international prices, even when stickiness in nominal prices is fairly low. We demonstrate this by embedding preferences featuring good-specific or deep habits into an otherwise standard two-country New Keynesian model. In an economy with deep habits, firms can maximize expected discounted profits by adjusting sales over time: stronger habit persistence implies a higher positive covariance between current sales of the firm with future sales, and consequently with future profits. Furthermore, the price elasticity of demand is a positive function of demand growth. Against this backdrop, we generate depreciations of the currency in which the exporter's price is denominated, using random deviations from uncovered interest parity and shocks to monetary policy. The deep habits mechanism operates through two channels to generate the suppression of the export price markup, lowering exchange rate pass-through. Specifically, if the shock raises either the current value of expected future profits or the price elasticity of demand, the currency depreciation is partially absorbed into the price markup and not fully passed through to international prices. The directions of the cyclical movements in these two variables are dictated by the structural origin of the disturbance. For the baseline calibration, the intertemporal and price elasticity effects exert opposing forces on the markup for the UIP shock while the two effects work in the same direction for the monetary policy shock. Deep habits and sticky prices complement each other to reduce pass-through in the case of both shocks: with increasing price stickiness, pass-through is reduced by a milder degree of habit persistence, while stronger habits weaken pass-through even when prices are quite flexible.

We compare the empirical performance of a pure sticky price model with that of the New Keynesian model with deep habits by formally matching the dynamics triggered by a UIP shock in the two variants to those generated by an exchange rate shock identified in a VAR. The deep habits model fits the dynamics better than the competing sticky price model

does. Crucially, the deep habits model is able to replicate the pass-through dynamics well even with a fairly low estimate for the price adjustment cost parameter. However, once we abstract from deep habits, the pure sticky price model requires the adjustment cost to reach extremely high, empirically implausible values to match the VAR dynamics.

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