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ABSTRACT

Introducing heterogeneous households to a New Keynesian small open economy model amplifies the real income channel of exchange rates: the rise in import prices from a depreciation lowers households' real incomes, and leads them to cut back on spending. When the sum of import and export elasticities is one, this channel is offset by a larger Keynesian multiplier, heterogeneity is irrelevant, and expenditure switching drives the output response. With plausibly lower short-term elasticities, however, the real income channel dominates, and depreciation can be contractionary for output. This weakens monetary transmission and creates a dilemma for policymakers facing capital outflows. Delayed import price pass-through weakens the real income channel, while heterogeneous consumption baskets can strengthen it.

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1 Introduction

How do open economies respond to exchange rate shocks, such as those caused by capital flows? What is the role of exchange rates in monetary transmission? The canonical answers to these questions are derived from models with a representative agent.[1] In these models, marginal propensities to consume are small, muting the income effects of exchange rates for shocks at business cycle frequencies.

In this paper, we revisit these questions in a Heterogeneous Agent New Keynesian model that features higher marginal propensities to consume, in line with empirical evidence.[2] We first provide novel neutrality results under which heterogeneity is irrelevant. We then argue that, in the empirically relevant case, heterogeneity generates a powerful *real income channel* that limits or even undoes the expansionary effects of depreciations and weakens monetary transmission. This provides an explanation for the common policy view that depreciations can cause declines in output, even when foreign currency borrowing is not an issue.[3]

To isolate the forces that make heterogeneity relevant, we take as our benchmark the canonical representative-agent (RA) model of Galí and Monacelli (2005). This is a complete-market model of a small open economy, in which the law of one price holds for individual goods. Instead of complete markets, we consider incomplete markets for both aggregate and idiosyncratic risk. A large mass of domestic residents faces idiosyncratic income uncertainty and borrowing constraints. We consider two main types of shocks: exchange rate shocks (shocks to the foreign interest rate that do not affect foreign demand) and domestic monetary policy shocks.

For exchange rate shocks, we show, using a sequence-space representation of the model (Auclert, Rognlie and Straub 2018, Auclert, Bardóczy, Rognlie and Straub 2021b) that the output response combines three effects: an expenditure switching channel, a real income channel, and a Keynesian multiplier channel. The RA model only has expenditure switching, whose magnitude is governed by the composite parameter χ, equal to

[1] See Obstfeld and Rogoff (1995), Corsetti and Pesenti (2001), Clarida, Galí and Gertler (2002) and Galí and Monacelli (2005), as well as the textbook treatments in Galí (2008) and Uribe and Schmitt-Grohé (2017).

[2] High MPCs have been documented in advanced economies and emerging markets alike, see for instance Johnson, Parker and Souleles (2006) for the United States, Jappelli and Pistaferri (2014) for Italy, Fagereng, Holm and Natvik (2020) for Norway, and Hong (2020) for Peru.

[3] On contractionary devaluations, Frankel (2005) says: "Why are devaluations so costly? Many of the currency crises of the last 10 years have been associated with output loss. Is this, as alleged, because of excessive reliance on raising the interest rate as a policy response? More likely, it is because of contractionary effects of devaluation." Although widespread, this policy view is difficult to back up empirically because it is very challenging to identify exogenous exchange rate shocks in the data. This makes it even more important to study the conditions under which contractionary depreciations can emerge in microfounded general equilibrium models.

the sum of the price elasticities of imports and exports (the *trade elasticity*).[4] This channel is unchanged in the heterogeneous agent (HA) model. Instead, there are two new forces, both of which work through households' real income: the "real income channel" through which rising import prices reduce aggregate consumption, and the multiplier on aggregate output. Since the multiplier depends on the overall output response, its importance grows with χ. Our first neutrality result states that, when $\chi = 1$, the two new forces exactly cancel, and the RA and HA models have identical responses to any exchange rate shock. In fact, the response is independent of the market structure both across and within countries. Intuitively, when the trade elasticity is equal to 1, the rise in output from expenditure switching is exactly enough to offset rising import prices, leaving each household's real income and therefore its consumption unchanged. The trade balance also remains constant, as reallocation from foreign to domestic goods offsets higher prices on the foreign goods.

When the trade elasticity χ is below 1 instead, the real income channel dominates. This makes the output response in the HA model lower than in the RA model. For χ sufficiently below one, this response turns negative: a contractionary depreciation emerges. Qualitatively, the same effect is also at play in a representative-agent model with incomplete markets for aggregate risk (henceforth RA-IM). But we show that it is quantitatively much larger in an HA model calibrated to feature realistically high MPCs. In other words, heterogeneity "sizes up" the real income channel that Díaz Alejandro (1963) and Krugman and Taylor (1978) had emphasized as a potential source of contractionary devaluations.[5] By contrast, when $\chi > 1$, the multiplier effect dominates, and depreciations are even more expansionary. Hence, our theoretical result is one of *complementarity* between heterogeneity and trade elasticities. Later, we argue that the relevant empirical counterpart of χ is the short-run trade elasticity, which tends to be less than 1.

We next study the case where the country's export prices, just like its import prices, are sticky in foreign currency—the so-called "dollar currency pricing" (DCP) paradigm, which the literature has recently argued to be the relevant empirical benchmark for a broad set of countries (Gopinath 2016, Boz et al. 2020). Working with representative-agent models, this literature has emphasized the fact that there is less expenditure switching under DCP than in the producer currency pricing (PCP) setting, so that the output response

[4]This is the elasticity that enters the well-known Marshall-Lerner condition, which states that, in partial equilibrium, depreciations improve the trade balance when $\chi > 1$. We show that in our model, this condition also applies in general equilibrium.

[5]We show that a two agent (TA) model calibrated to the same MPCs as our HA model also generates quantitatively large contractionary devaluations at low χ. To our knowledge, this result is new to the literature on two agent models. However, in the HA model, the contraction is larger and more persistent, due to the larger "intertemporal marginal propensities to consume" (Auclert, Rognlie and Straub 2018).

to depreciations is lower under DCP than under PCP. In an HA model, however, we show that there is another force, because the depreciation causes an increase in exporter profit margins that can in turn spur increased spending at home. We find that, when χ is sufficiently small, this new force can dominate: then, our HA model with DCP has *less* of a contraction in response to a depreciation than our HA model with PCP.

For monetary policy, we show that there also exists a threshold level of the trade elasticity for which heterogeneity is irrelevant. This result requires an elasticity of intertemporal substitution of 1, and a trade elasticity of $\chi = 2 - \alpha$, with $\alpha \in (0, 1)$ denoting the openness of the country. As in the exchange rate case, this involves a constant trade balance; here we need a higher trade elasticity χ to offset the increase in import demand from rising consumption in a monetary expansion. The $\chi = 2 - \alpha$ level includes the Cole-Obstfeld parametrization, in which both domestic and foreign agents have unitary elasticities of substitution. In fact, our neutrality result is reminiscent of the original Cole and Obstfeld (1991) result, which established that with Cobb-Douglas elasticities, market structure was irrelevant for the effect of productivity shocks. Our result shows that the same is true for monetary policy shocks, and also for a much broader set of market structures including within-country incomplete markets with respect to idiosyncratic shocks. In that sense, our result also generalizes Werning (2015)'s seminal neutrality result for closed economies to an open economy setting.[6]

Away from this benchmark, when $\chi < 2 - \alpha$, the output response is lower in the HA model than in the RA model—another manifestation of a dominant real income effect. One way to understand this result is that, with elasticities below Cobb-Douglas, a temporary monetary expansion induces a current account deficit, as in Tille (2001). The resulting negative net foreign asset position must be repaid later. However, absent further monetary stimulus, repayment must occur without a depreciated exchange rate, and hence without increased exports. Instead, the trade balance improves via depressed imports—which can only be achieved through a domestic contraction. Thus, in an HA model with $\chi < 2 - \alpha$, monetary easing raises current demand at the expense of a future contraction: it "steals demand from the future". Since this mechanism operates through the current account, it is different from the effect of durable goods or indebted demand in closed economies (McKay and Wieland, 2019, Mian, Straub and Sufi, 2020).

Our benchmark model allows for clean analytical results, but it says nothing of the empirically relevant level of the trade elasticity χ. A simple quantification is difficult because trade elasticities are well documented to be dynamic: smaller in the short run than in the

[6]We show that our neutrality result can be extended to productivity shocks, as in the original Cole and Obstfeld (1991) paper.

medium to long run.[7] We address this shortcoming of our baseline model by building a quantitative extension. In it, we incorporate a tractable model of "delayed substitution", in which consumers can only substitute between goods with a given Calvo probability.[8] Calibrating to the evidence in Boehm, Levchenko and Pandalai-Nayar (2020), we find that our model generates a "*J* curve", with a trade elasticity that is smaller than 1 in the short-run, but larger than 1 in the long-run. As a consequence, our quantitative model finds that transitory depreciation shocks are contractionary in the short run.

Aside from accounting for dynamic trade elasticities, the quantitative model also allows us to speak to several other issues: we show that when consumption baskets of the poor are skewed towards imported goods (as in e.g. Cravino and Levchenko, 2017), the real income channel is amplified and a depreciation is more likely to be contractionary; we find that the real income channel is larger than a balance sheet channel calibrated to the net currency exposure of a typical country (which has shrunk in recent decades, e.g. Lane and Shambaugh 2010); and we find that the real income channel is stronger the faster exchange rates pass through to retail prices of imported goods—and hence, likely stronger in emerging markets.

Our model can speak to the common perception of a dilemma for policymakers facing capital outflows—captured in our model as exchange rate depreciation shocks. On the one hand, outflows are contractionary, and fighting them with accommodative monetary policy exacerbates the depreciation. On the other hand, stabilizing the exchange rate by tightening monetary policy comes with the negative side effects of higher interest rates domestically, as in Gertler, Gilchrist and Natalucci (2007) and Gourinchas (2018). We use our model to derive the unique output-stabilizing monetary policy. For countries with fast import price pass-through, such as many emerging markets, this policy involves hiking interest rates to stabilize the exchange rate; for countries with slow import price pass-through, such as many advanced economies, this policy involves easing interest rates to stabilize output. This finding aligns well with the contrasting responses of developed and emerging markets to U.S. monetary policy shocks documented in Kalemli-Özcan (2019).

Our paper relates to a literature that stresses the importance of the real income channel, which was first studied by Díaz Alejandro (1963) and Krugman and Taylor (1978) in the context of IS-LM models. Working with a first-generation new open economy model

[7] See, e.g., Hooper, Johnson and Marquez (2000), Fitzgerald and Haller (2018), Feenstra, Luck, Obstfeld and Russ (2017), Auer, Burstein, Erhardt and Lein (2019), Amiti, Itskhoki and Konings (2020), Boehm, Levchenko and Pandalai-Nayar (2020), and Auer, Burstein and Lein (2021).

[8] This approach complements a structural literature on models of delayed adjustment of firms export and import decisions, as in e.g., Baldwin (1988), Baldwin and Krugman (1989), Ruhl (2008), Drozd and Nosal (2012), Alessandria and Choi (2019). See Alessandria, Arkolakis and Ruhl (2020) for a review of this literature.

with prices set one period in advance, Corsetti and Pesenti (2001) analytically showed that monetary accommodations have a "beggar-thyself effect" through this channel. Their model featured unitary elasticities, so while this effect reduced country welfare, it did not lower aggregate consumption or output. Later, Tille (2001) extended this model to feature a non-unitary elasticity substitution between goods and noted that, when this elasticity was low enough, his model "allow[ed] for the possibility of a devaluation to reduce consumption", though not output.[9]

Our two neutrality results relate to a large international macro literature that, building on the original Cole and Obstfeld (1991) result, studies the extent to which the structure of asset markets matters for the aggregate effects of international shocks (Baxter and Crucini 1995, Heathcote and Perri 2002). In the context of a representative-agent model, Itskhoki (2020) generalizes the Cole-Obstfeld equivalence between complete markets and financial autarky to a broader range of shocks, including monetary policy shocks. We provide similar neutrality results for monetary policy and exchange rate shocks, showing that this requires different trade elasticities, and consider a much broader set of market structures.

Finally, our paper relates to an emerging literature that analyzes the effects of international shocks in the context of heterogeneous-agent, New Keynesian open economy models.[10] This literature has mostly focused on heterogeneous effects of shocks. Giagheddu (2020) studies the distributional effects of fiscal devaluations. de Ferra, Mitman and Romei (2020) study the distributional effect of depreciations when agents hold different amounts of foreign currency debt. Guo, Ottonello and Perez (2021) study the distributional effects of international shocks when agents differ by their sector of work and their financial integration, finding that these sources of heterogeneity can play a major role, and create trade-offs in the conduct of monetary policy. Other recent papers studying the redistributive effects of external shocks include Zhou (2020), Oskolkov (2021) and Otten (2021). Relative to these papers, ours focuses on aggregate rather than distributional effects, provides sharp benchmark results on when heterogeneity matters and when it does not, and shows that heterogeneity can cause contractionary depreciations.

Layout. Section 2 sets up our baseline model. Section 3 considers the effect of exchange rate shocks, while section 4 considers the transmission of monetary policy. Section 5 introduces our quantitative model, which we use to study the role of delayed substitution, delayed import price pass-through, heterogeneous consumption baskets, and the response

[9] In related work, Corsetti, Dedola and Leduc (2008) showed that the real income effect can explain the Backus-Smith correlation in response to productivity shocks.

[10] See Farhi and Werning (2016), Farhi and Werning (2017), and Cugat (2019) for New Keynesian open economy models with two agents.

of monetary policy to contractionary capital outflows. Appendix A contains details on our benchmark model, appendix B collects all proofs, and appendix C contains details on our quantitative model. Appendix D presents three alternative models, which we show can reinterpreted as versions of ours: one with nontraded goods, one with imported intermediates, and one in which the country is a commodity exporter.

2 A baseline heterogeneous-agent open economy model

Our modeling approach merges two New Keynesian traditions: the heterogeneous-agent ("HANK") framework for closed economies and the New Open Economy macro framework for open economies. Specifically, our model builds on the open-economy model of Galí and Monacelli (2005). To this model we add incomplete markets, heterogeneous households, and sticky wages as in Auclert, Rognlie and Straub (2018).

Model setup. Time is discrete and the horizon is infinite. We focus directly on the problem of a small open economy understood, as in Galí and Monacelli (2005), as part of a world economy consisting of a continuum of countries. We denote variables with a star superscript when they correspond to the world economy as a whole. We consider perfect-foresight impulse responses to shocks starting from a steady state without aggregate uncertainty ("MIT shocks"). We use the solution method from Auclert et al. (2021b), which linearizes with respect to these shocks. By certainty equivalence, its impulse responses are therefore the same as those of the model with aggregate risk.

There are two goods in the economy: domestically produced "home" goods H, which can be exported, and "foreign" goods F, which are produced abroad and imported.

Domestic households. The economy is populated by a continuum of households. Each household is subject to idiosyncratic income risk in the form of productivity shocks e_{it}, which follow a first-order Markov chain with mean $\mathbb{E}e_{it} = 1$. Households can only insure this risk by investing their assets in a domestic mutual fund, whose returns cannot be indexed to idiosyncratic productivity. A household with asset position a and productivity level e at time t optimally chooses her consumption of the two goods, c_H, c_F, and saving a', by solving the dynamic program

$$\begin{aligned} V_t(a,e) \quad &= \quad \max_{c_F, c_H, a'} u(c_F, c_H) - v(N_t) + \beta \mathbb{E}_t \left[V_{t+1}(a', e') \right] \\ \text{s.t.} \quad & \frac{P_{Ft}}{P_t} c_F + \frac{P_{Ht}}{P_t} c_H + a' = \left(1 + r_t^p\right) a + e \frac{W_t}{P_t} N_t \\ & a' \geq \underline{a} \end{aligned} \tag{1}$$

Here, P_{Ft} is the nominal price of foreign goods in domestic currency units, P_{Ht} is the price of domestic goods, r_t^p denotes the ex-post mutual fund return in units of the consumer price index P_t, W_t is the nominal wage, N_t denotes labor supplied by households, determined by union demand as specified below; and $\underline{a} \leq 0$ parametrizes the borrowing constraint agents face. Households share the common per period utility function

$$u(c_F, c_H) = \frac{c^{1-\sigma}}{1-\sigma}, \qquad v(N) = \psi \frac{N^{1+\varphi}}{1+\varphi}$$

where c is the consumption basket

$$c = \left[\alpha^{1/\eta} c_F^{(\eta-1)/\eta} + (1-\alpha)^{1/\eta} c_H^{(\eta-1)/\eta} \right]^{\eta/(\eta-1)} \tag{2}$$

The parameter $\sigma > 0$ is the inverse elasticity of intertemporal substitution, $\varphi > 0$ the inverse Frisch elasticity of labor supply, and $\eta > 0$ is the elasticity of substitution between home and foreign goods. α measures the openness of the economy ($1-\alpha$ is the degree of home bias in preferences). $\psi > 0$ is a normalization constant. The consumer price index for these preferences is

$$P_t \equiv \left[\alpha P_{Ft}^{1-\eta} + (1-\alpha) P_{Ht}^{1-\eta} \right]^{1/(1-\eta)} \tag{3}$$

Households differ in their level of spending but have the same consumption basket and use the same price index.[11] Standard results imply that a household in state (a, e), with consumption $c_t(a, e)$, splits her purchases between foreign and home goods according to

$$c_{Ft}(a, e) = \alpha \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} c_t(a, e) \tag{4}$$

$$c_{Ht}(a, e) = (1-\alpha) \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} c_t(a, e) \tag{5}$$

Monetary policy abroad keeps the price of foreign goods in foreign currency constant, $P_{Ft}^* = P_t^* = 1$. For now, we assume that imports are denominated in foreign currency and that there is perfect pass-through of exchange rates into domestic goods prices: the law of one price holds at the good level, so that $P_{Ft} = \mathcal{E}_t$, where $\mathcal{E}_t$ is the nominal exchange rate.[12] The real exchange rate is then given by

$$Q_t \equiv \frac{\mathcal{E}_t}{P_t} \tag{6}$$

[11] Section 5 considers non-homothetic preferences, under which poor households can consume foreign goods in different proportions than rich households.

[12] We relax this assumption in section 5.

With this convention, an increase in $\mathcal{E}_t$ indicates a nominal depreciation, and an increase in Q_t a real depreciation.

Foreign households. Foreign households face the same problem as domestic households. We set up their problem in appendix A.1 along the lines of Galí and Monacelli (2005), so that they consume an exogenous and constant quantity C^* of worldwide goods, and spread their own consumption of foreign goods across all foreign countries, with an elasticity of substitution across countries of $\gamma > 0$. Denoting by P^*_{Ht} the foreign-currency price of domestically produced goods, export demand for home goods is given by

$$C^*_{Ht} = \alpha \left(\frac{P^*_{Ht}}{P^*} \right)^{-\gamma} C^* \tag{7}$$

We assume that the law of one price holds for foreign goods as well, so that P^*_{Ht} is equal to the cost $P_{Ht}/\mathcal{E}_t$ of a domestic good in foreign currency units:

$$P^*_{Ht} = \frac{P_{Ht}}{\mathcal{E}_t} \tag{8}$$

This formulation effectively assumes the *producer currency pricing* (PCP) paradigm from the celebrated Mundell-Fleming model, adopted by Galí and Monacelli (2005) and many others, in which exchange rates fully pass through to foreign-currency prices of exported goods. Below, we also consider *dollar currency pricing* (DCP), where the foreign currency price of home goods P^*_{Ht} is sticky in foreign currency.

Trade elasticities of imports and exports. Aggregating equation (4) across consumers, the volume of aggregate imports is $C_{Ft} = \alpha \left(\frac{P_{Ft}}{P_t} \right)^{-\eta} C_t$. Holding aggregate consumption C_t fixed, the elasticity of imports with respect to the relative price of imports P_{Ft}/P_{Ht} is $\eta (1 - \alpha)$. The volume of exports is given by C^*_{Ht} in equation (7). The elasticity of exports with respect to the relative price that foreigners see, P^*_{Ht}/P^*_{Ft}, holding foreign consumption C^* fixed, is equal to γ.[13] We denote by χ the sum of these two elasticities,

$$\chi \equiv \eta (1 - \alpha) + \gamma \tag{9}$$

which we henceforth refer to as the *trade elasticity*. It plays a key role in our analysis.

Production of home goods. Home goods are produced from domestic labor with constant returns,

$$Y_t = Z N_t \tag{10}$$

[13] That is, $\frac{\partial \log C_{Ft}}{\partial \log P_{Ft}/P_{Ht}} = -\eta \frac{\partial \log P_{Ft}/P_t}{\partial \log P_{Ft}/P_{Ht}} = -\eta (1 - \alpha)$, while $\frac{\partial \log C^*_{Ht}}{\partial \log P^*_{Ht}/P^*_{Ft}} = -\gamma \frac{\partial \log P^*_{Ht}/P^*_t}{\partial \log P^*_{Ht}/P^*_{Ft}} = -\gamma$. The latter does not depend on foreign home bias because the home country is too small to affect the foreign CPI.

where N_t is aggregate labor supplied and Z is the constant level of labor productivity. There is a continuum of monopolistically competitive firms producing home goods with technology (10). Let ϵ denote the elasticity of substitution between varieties produced within a country. For now, we assume that prices are fully flexible, so that the price of home goods is set at a constant markup μ over nominal marginal costs,

$$P_{Ht} = \mu \frac{W_t}{Z} \tag{11}$$

where $\mu = \epsilon/(\epsilon - 1)$. Real dividends by firms are equal to

$$D_t = \frac{P_{Ht}Y_t - W_t N_t}{P_t} + \frac{\mathcal{E}_t P^*_{Ht} - P_{Ht}}{P_t} C^*_{Ht} \tag{12}$$

The second term is zero under PCP, and captures profits from exporter's unhedged currency exposure under DCP. Firms have a unit mass of shares outstanding, with end-of-period price p_t. As is usual, their objective is to maximize firm value $D_t + p_t$.

Financial sector. We assume frictionless capital flows across countries. At home, an unconstrained, risk-neutral mutual fund issues claims to households, with aggregate real value A_t at the end of period t, and can invest in four types of assets: domestic nominal bonds with an interest rate i_t, foreign nominal bonds with an interest rate i^*_t, domestic firm shares with return $(p_{t+1} + D_{t+1})/p_t$, and foreign firm shares. Its objective is to maximize the (expected) real rate of return on its liabilities r^p_{t+1}. In equilibrium, this implies that expected returns on all four assets are equal, and that the mutual fund's portfolio choice is indeterminate. Appendix A.1 shows that equality of expected returns implies the standard uncovered interest parity (UIP) condition,

$$1 + i_t = (1 + i^*_t) \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \tag{13}$$

Moreover, defining the ex-ante real interest rate as

$$1 + r_t \equiv (1 + i_t) \frac{P_t}{P_{t+1}} \tag{14}$$

gives the ex-post return at $t + 1$ on the mutual fund, as well as the ex-ante return on domestic stocks:

$$1 + r_t = 1 + r^p_{t+1} = \frac{p_{t+1} + D_{t+1}}{p_t} \tag{15}$$

The ex-post mutual fund return r^p_0 at date 0 depends on its portfolio, and our baseline is to resolve portfolio indeterminacy by assuming that coming into date 0, the mutual fund is invested entirely in domestic stocks. Given this assumption, which we relax in section

5.6, the second equality in (15) holds for $t = -1$ as well, with $p_{-1} = p_{ss}$.

Combining (6), (13), and (14), we obtain a real version of the UIP condition

$$1 + r_t = (1 + i_t^*) \frac{Q_{t+1}}{Q_t} \tag{16}$$

which we appeal to extensively in our analysis. We define the net foreign asset position to be the difference between the value of assets accumulated domestically, A_t, and the total value of assets in net supply domestically, p_t, i.e.

$$\text{nfa}_t \equiv A_t - p_t \tag{17}$$

The foreign interest rates i_t^* in equation (16) are exogenous. Appendix A.1 microfounds their variation at fixed aggregate foreign demand C^* by assuming exogenous variations in the time preference rate of foreign households. This assumption allows us to derive a clear complete market benchmark.[14]

Unions. We assume a standard formulation for sticky wages with heterogeneous households, similar to Auclert, Rognlie and Straub (2018). A union employs all households for an equal number of hours N_t, and is in charge of setting nominal wages by maximizing the welfare of the average household. We choose the union objective function so that this problem leads to the wage Phillips curve

$$\pi_{wt} = \kappa_w \left(\frac{v'(N_t)}{\frac{1}{\mu_w} \frac{W_t}{P_t} u'(C_t)} - 1 \right) + \beta \pi_{wt+1} \tag{18}$$

where π_{wt} denotes nominal wage inflation,

$$\pi_{wt} \equiv \frac{W_t}{W_{t-1}} - 1$$

Wage inflation rises when marginal disutility of average work $v'(N_t)$ is higher than the product of the marked-down real wage by the marginal utility of average consumption $\frac{1}{\mu_w} \frac{W_t}{P_t} u'(C_t)$, now or in the future.[15] If we derive this equation from a Calvo specification

[14] We show in appendix A.2 that we obtain an identical model if we instead microfound exogenous movements in i_t^* as exogenous "UIP shocks", such as risk premium or noise trader shocks, as in e.g. Farhi and Werning (2014), Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2020). In section 5.7, we also consider an extension of this model in which UIP deviations are endogenous to the country's net foreign asset position.

[15] In Auclert, Rognlie and Straub (2018)'s formulation of the union problem, the consumption level that enters the Phillips curve in (18) is equal to a consumption aggregator $\overline{C_t} \equiv (u')^{-1} (\mathbb{E}[e_{it} u'(c_{it})])$ that takes into account inequality in labor earnings. Here we opt for the simpler formulation in (18), because it helps streamline some of our analytical results.

where the probability of keeping the wage fixed is θ_w, then $\kappa_w = \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w}$.

Fiscal policy and monetary policy. The government does not spend, tax or use transfers, and domestic bonds are in zero net supply. The monetary authority sets the nominal interest rate according to a monetary rule. It is standard in the open-economy literature to consider a few of these rules. For the analytical results that we develop in the next two sections, we consider a specification in which monetary policy holds the real interest rate constant:

$$i_t = r_{ss} + \pi_{t+1} + \epsilon_t \tag{19}$$

This is a CPI-based Taylor rule with a coefficient of 1 on expected inflation. This monetary rule achieves a middle ground between standard CPI-based Taylor rules with responsiveness larger than 1, and zero-lower-bound specifications with a fixed nominal interest rate, and is widely used in the literature as a device to partial out the effects of monetary policy in the study of the effects of shocks to aggregate demand (e.g. Woodford 2011, McKay, Nakamura and Steinsson 2016, Auclert, Rognlie and Straub 2018, Auclert, Rognlie and Straub 2020). In section 5 and in appendix B.9, we consider, as an alternative, a standard Taylor rule based on producer prices,

$$i_t = r_{ss} + \phi\pi_{Ht} + \epsilon_t \tag{20}$$

with $\pi_{Ht} = \frac{P_{Ht}}{P_{Ht-1}} - 1$ and $\phi > 1$, which, as we show below, yields similar results to (19).

Equilibrium. We define an equilibrium as follows.

Definition. Given sequences of foreign interest rate shocks $\{i_t^*\}$ and monetary shocks $\{\epsilon_t\}$, an initial wealth distribution $\mathcal{D}_0(a,e)$, and an initial portfolio allocation for the mutual fund, a *competitive equilibrium* is a path of policies $\{c_{Ht}(a,e), c_{Ft}(a,e), c_t(a,e), a_{t+1}(a,e)\}$ for households, distributions $\mathcal{D}_t(a,e)$, prices $\{\mathcal{E}_t, Q_t, P_t, P_{Ht}, P_{Ft}, W_t, p_t, i_t, r_t, r_t^p\}$, and aggregate quantities $\{C_t, C_{Ht}, C_{Ft}, Y_t, A_t, D_t, \text{nfa}_t\}$, such that all agents optimize, firms optimize, and the domestic goods market clears:

$$C_{Ht} + C_{Ht}^* = Y_t \tag{21}$$

where $C_{Ht} \equiv \sum_e \pi_e \int c_{Ht}(a,e)\, \mathcal{D}_t(a,e)$ denotes aggregate consumption of home goods, and C_t, C_{Ft}, A_t are defined similarly. We focus on equilibria in which the long-run exchange rate returns to its steady state level, $Q_\infty = Q_{ss}$.

Appendix A.3 shows that, in equilibrium, the current account identity holds:

$$\text{nfa}_t - \text{nfa}_{t-1} = \frac{P_{Ht}}{P_t} Y_t - C_t + r_{t-1}\text{nfa}_{t-1} + \left(r^p_t - r_{t-1}\right) A_{t-1} \tag{22}$$

where $\frac{P_{Ht}}{P_t} Y_t - C_t \equiv NX_t$ is the value of net exports (or, equivalently, the trade balance) in units of the CPI, and the valuation effect term $\left(r^p_t - r_{t-1}\right) A_{t-1}$ is zero for all $t \geq 1$.

We consider a steady state with no inflation and no initial gross positions across borders. That is, the domestic mutual fund owns all stocks issued by domestic firms and the net foreign asset position is zero. Without loss of generality, we normalize prices to 1 in this steady state, implying that $P_{Hss}, P_{Fss}, P_{ss}, P^*_{Hss}, \mathcal{E}_{ss}, Q_{ss}$ are all equal to 1. Moreover, we normalize domestic steady-state output Y_{ss} to 1. Hence, C_{ss} and C^* also equal 1. Appendix A.4 shows that the unique $Q_\infty = 1$ steady state, to which the economy returns after transitory shocks, also has no net foreign asset position and $C_\infty = Y_\infty = 1$. Hence, our heterogeneous-agent model is stationary without the need for a debt-elastic interest rate, as in Schmitt-Grohé and Uribe (2003) or the large literature that followed.[16]

Complete-market representative-agent model ("RA model"). Throughout the paper, we compare the heterogeneous-agent model just described with the canonical representative-agent model of Galí and Monacelli (2005), in which there are complete markets across households and across countries. We spell out the details of this model in appendix A.5, where we show that that the consumption behavior of the representative domestic household is described by the Backus-Smith condition

$$\frac{Q_t}{\mathcal{B}_t} C_t^{-\sigma} = C_{ss}^{-\sigma} \tag{23}$$

where $\mathcal{B}_t \equiv \prod_{s \geq t} \left(\frac{1+i^*_s}{1+r_{ss}}\right)$ is the exogenous preference shifter of foreign households, assumed to satisfy $\mathcal{B}_\infty = 1$.[17] We further show that this complete-market model admits the exact same log-linear equations as the original Galí and Monacelli (2005) model, extended to allow for foreign discount factor shocks. In particular, since we are not considering productivity shocks, our assumption that wages rather than prices are sticky is innocuous.[18]

[16]Ghironi (2006) also observed that his non-Ricardian model, based on overlapping generations, automatically achieved stationarity.

[17]In this model, the primitive is the path of $\mathcal{B}_t$. Foreign interest rates follow from $1 + i^*_t = (1 + r_{ss}) \frac{\mathcal{B}_t}{\mathcal{B}_{t+1}}$.

[18]As explained in Auclert, Bardóczy and Rognlie (2021a) and Broer, Hansen, Krusell and Öberg (2020), the assumption of sticky wages and flexible prices is better suited to heterogenous-agent models than the opposite assumption of sticky prices and flexible wages.

Incomplete-market representative-agent model ("RA-IM model"). We briefly touch on two additional models in section 3 below. In the incomplete-market representative-agent model, a representative agent in the domestic country only has access to a foreign and a domestic bond, but not to state-contingent securities. As a result, the Backus-Smith condition (23) does not hold, and the representative agent's consumption behavior is just described by an Euler equation

$$C_t^{-\sigma} = \beta (1 + r_t) C_{t+1}^{-\sigma} \tag{24}$$

This model is not stationary, and we describe its solution in appendix A.6.

Two-agent model ("TA model"). We also compare our model to a two-agent model (as in the closed-economy work of Galí, López-Salido and Vallés 2007 and Bilbiie 2008, and the open-economy work of Farhi and Werning 2017 and Cugat 2019). In this model, we assume a fraction λ of hand-to-mouth households, and a fraction $1 - \lambda$ of households with access to complete international markets, for whom an equation analogous to (23) holds. We describe this model further in appendix A.7.

3 Exchange rate shocks

We start by considering shocks to foreign interest rates i_t^* in (16), caused by preference shocks $\mathcal{B}_t = \prod_{s \geq t} \left(\frac{1+i_s^*}{1+r_{ss}} \right)$ to foreign households. Combining the real UIP condition (16), the fact that $Q_\infty = 1$, and the constant real rate (19), we find that the real exchange rate is given by

$$Q_t = \prod_{s \geq t} \left(\frac{1 + i_s^*}{1 + r_{ss}} \right) = \mathcal{B}_t \tag{25}$$

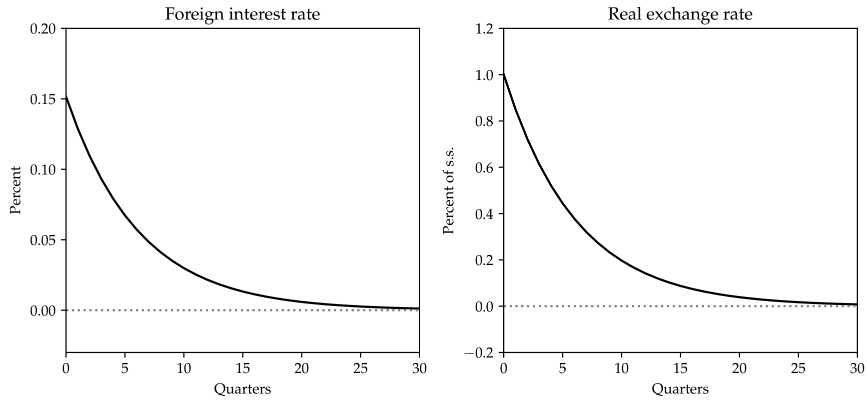
Intuitively, when foreign households become more impatient (rising $\mathcal{B}_t$), they push up foreign interest rates i_t^*, leading to capital outflows that depreciate the exchange rate (rising Q_t). Given (25), the real exchange rate is effectively exogenous in this section.

Our analysis is centered around the home goods market clearing condition (21). After substituting in the demands (5)-(7) and the price-setting condition for PCP (8), we can write this condition as

$$Y_t = (1 - \alpha) \left(\frac{P_{Ht}}{P_t} \right)^{-\eta} C_t + \alpha \left(\frac{P_{Ht}}{\mathcal{E}_t} \right)^{-\gamma} C^* \tag{26}$$

The relative prices in equation (26) are tied to the real exchange rate Q_t. A depreciation

Figure 1: The exchange rate shock



Note: AR(1) shock to i_t^* with persistence 0.85, and corresponding impulse response of the real exchange rate Q_t. The shock is normalized so that the real exchange rate depreciates by 1% on impact.

lowers the price of home goods relative to the domestic CPI, P_{Ht}/P_t, and relative to the foreign CPI, $P_{Ht}/\mathcal{E}_t$. This leads domestic and foreign consumers to substitute towards home goods. In addition to these traditional expenditure switching effects, the volume of domestic spending C_t may change. In this section, we characterize how this response is affected by the market structure and heterogeneity among agents.

Throughout this section and the next, we illustrate our results with a numerical calibration, which we describe in detail in section 5 below. We intentionally leave the trade elasticity χ (and thus η, γ) unspecified for now. We choose an openness of $\alpha = 0.40$ as in Galí and Monacelli (2005). We assume that i_t^* follows an AR(1) shock with quarterly persistence of $\rho = 0.85$, and that it is normalized to have an impact effect of 1 on the real exchange rate dQ_0 (see figure 1).[19]

3.1 Complete-market benchmark

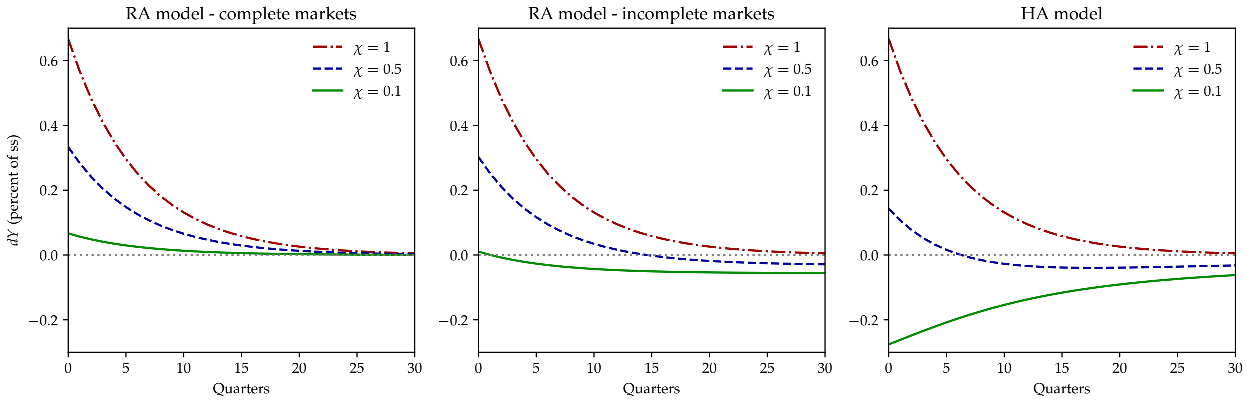
We start by considering the complete-market representative-agent model ("RA model"). Combining (25) with the Backus Smith condition (23), we immediately find that consumption does not respond to the shock, $C_t = C_{ss} = 1$.[20] Equation (26) then implies that domestic production is only affected by expenditure switching.

Proposition 1. *In the complete-market representative-agent model with real interest rate rule (19), the linearized deviations from steady state consumption over output,* $dC_t = (C_t - C_{ss}) / Y_{ss}$

[19] This quarterly persistence is typical for exchange rate shocks in estimated models (see e.g. Eichenbaum, Johannsen and Rebelo 2021 for a recent example), as well as to standard estimates of the (HP-filtered) unconditional persistence of the real exchange rate, such as those in Chari, Kehoe and McGrattan (2002).

[20] Consumption comoves negatively with real exchange rates in response to other shocks that keep $\mathcal{B}_t = 1$, since the Backus-Smith condition (23) dictates that $Q_t C_t^{-\sigma}$ is constant in response to these shocks.

Figure 2: Effect of exchange rate shocks on output for various χ's



Note: impulse response in all three models to the shock to i_t^* displayed in Figure 1. χ is the trade elasticity (the sum of the import and export elasticity to the exchange rate). The HA model generates a contraction on impact for $\chi < \chi^* = 0.37$.

and output $dY_t = (Y_t - Y_{ss})/Y_{ss}$ in response to shocks to the real exchange rate $dQ_t = (Q_t - Q_{ss})/Q_{ss}$ are given by

$$dC_t = 0 \quad \forall t \tag{27}$$
$$dY_t = \frac{\alpha}{1-\alpha}\chi dQ_t \quad \forall t \tag{28}$$

Proposition 1 captures a common view in the literature: depreciations are expansionary due to expenditure switching, and a greater trade elasticity χ leads to a greater expansion dY_t. The left panel of figure 2 shows the output response for various values of χ. A 1% real depreciation lowers the relative price of home goods by $\frac{1}{1-\alpha}$%, with a combined effect on imports and exports of $\frac{\chi}{1-\alpha}$% of initial imports, so of $\frac{\alpha}{1-\alpha}\chi$% of GDP.

Going forward, it will be convenient to express impulse responses as vectors, e.g. $d\mathbf{Y} = (dY_0, dY_1, \ldots)$. With this notation, (27)–(28) become $d\mathbf{C} = 0$ and $d\mathbf{Y} = \frac{\alpha}{1-\alpha}\chi d\mathbf{Q}$.

3.2 Incomplete markets and the real income channel

We next examine the effects of exchange rate shocks in our heterogeneous-agent model. In that model—as in any incomplete-market model—consumption is no longer insulated from movements in real income. To see this, consider the two components of real income: wages and dividends. First, the price-setting condition (11) combined with the production function (10) implies that households' real wage income is given by

$$\frac{W_t}{P_t}N_t = \frac{1}{\mu}\frac{P_{Ht}}{P_t}Y_t \tag{29}$$

Combining (29) with equation (12), we see that real dividends are equal to

$$D_t = \left(1 - \frac{1}{\mu}\right) \frac{P_{Ht}}{P_t} Y_t \tag{30}$$

Both wage income and dividends matter for aggregate consumption. Wage income enters households' budget constraints (1). Dividends affect the value of home firms, pinning down r_0^p via (15), given our assumption on the initial mutual fund portfolio.[21] Hence, real wage income and dividends are the only two aggregate variables needed to solve the consumption-saving problem of domestic households, and therefore their consumption policy functions at each date t. Aggregating up and using (29) and (30), we find that that the path of aggregate consumption C_t is entirely a function of the path of aggregate real income $\frac{P_{Ht}}{P_t} Y_t$. We denote this "consumption function" by $C_t = \mathcal{C}_t\left(\left\{\frac{P_{Hs}}{P_s} Y_s\right\}_{s=0}^{\infty}\right)$.[22] Around the steady state, we denote the derivative (Jacobian) of $\mathcal{C}$ by $\mathbf{M}$, a matrix with elements $M_{t,s} \equiv \frac{\partial \mathcal{C}_t}{\partial Y_s}$ that characterize the date-t consumption response to a date-s change in real income. Following Auclert, Rognlie and Straub (2018), we refer to the elements of $\mathbf{M}$ as "intertemporal MPCs".[23]

Since Y_t enters the consumption function, the equilibrium response dY_t to an exchange rate shock dQ_t is now the solution to the following fixed point problem.

Proposition 2. *In response to a shock to the real exchange rate $d\mathbf{Q}$, the impulse response of consumption is given by*

$$d\mathbf{C} = -\underbrace{\frac{\alpha}{1-\alpha}\mathbf{M}d\mathbf{Q}}_{\text{Real income channel}} + \underbrace{\mathbf{M}d\mathbf{Y}}_{\text{Multiplier}} \tag{31}$$

and the impulse response of output $d\mathbf{Y}$ is determined by an "international Keynesian cross"

$$d\mathbf{Y} = \underbrace{\frac{\alpha}{1-\alpha}\chi d\mathbf{Q}}_{\text{Exp. switching channel}} - \underbrace{\alpha \mathbf{M} d\mathbf{Q}}_{\text{Real income channel}} + \underbrace{(1-\alpha)\,\mathbf{M}d\mathbf{Y}}_{\text{Multiplier}} \tag{32}$$

Proposition 2 shows that the impulse responses of consumption and output only depend on the openness parameter α, the trade elasticity χ, and the matrix of intertemporal MPCs $\mathbf{M}$. Equation (31) finds that there are two ways in which real income $\frac{P_{Ht}}{P_t} Y_t$, and hence consumption $d\mathbf{C}$, are affected by an exchange rate depreciation $d\mathbf{Q}$. First, a depre-

[21] For $t > 0$, r_t^p is equal to r_{t-1}, which is held constant by monetary policy in this experiment.

[22] A similar logic underlies the consumption functions used in Kaplan, Moll and Violante (2018), Farhi and Werning (2019), and Auclert, Rognlie and Straub (2018).

[23] The MPC is most often defined as the immediate response of an individual to a transitory increase in income. Our $M_{0,0}$ corresponds to the average of this MPC, weighted by each individual's share of total income.

ciation lowers $\frac{P_{Ht}}{P_t}$ by $\frac{\alpha}{1-\alpha}dQ_t$, that is, it lowers the price of the goods that the country produces relative to the price of those that it buys. This reduces real income, leading agents to cut consumption by $\mathbf{M} \times \frac{\alpha}{1-\alpha}d\mathbf{Q}$. We refer to this as the *real income channel*. Second, a depreciation affects the path of output $d\mathbf{Y}$, which also enters real income, and changes consumption by $\mathbf{M} \times d\mathbf{Y}$. This is a standard (Keynesian) *multiplier* effect.

Linearizing goods market clearing (26) and substituting in (31), we obtain equation (32), whose form is like that of a standard Keynesian cross, where the relevant multiplier is the product of MPCs $\mathbf{M}$ by the degree of home bias $(1-\alpha)$. Including expenditure switching, there are altogether three distinct channels that jointly determine the output response to any given shock. The next proposition derives the general solution to (32).

Proposition 3. *Assuming $\mathbf{M} \geq 0$, the equilibrium output response is unique and given by*

$$d\mathbf{Y} = \underbrace{\left(\sum_{k\geq 0} (1-\alpha)^k \mathbf{M}^k\right)}_{=(\mathbf{I}-(1-\alpha)\mathbf{M})^{-1}} \left(\frac{\alpha}{1-\alpha}\chi d\mathbf{Q} - \alpha \mathbf{M} d\mathbf{Q}\right) \tag{33}$$

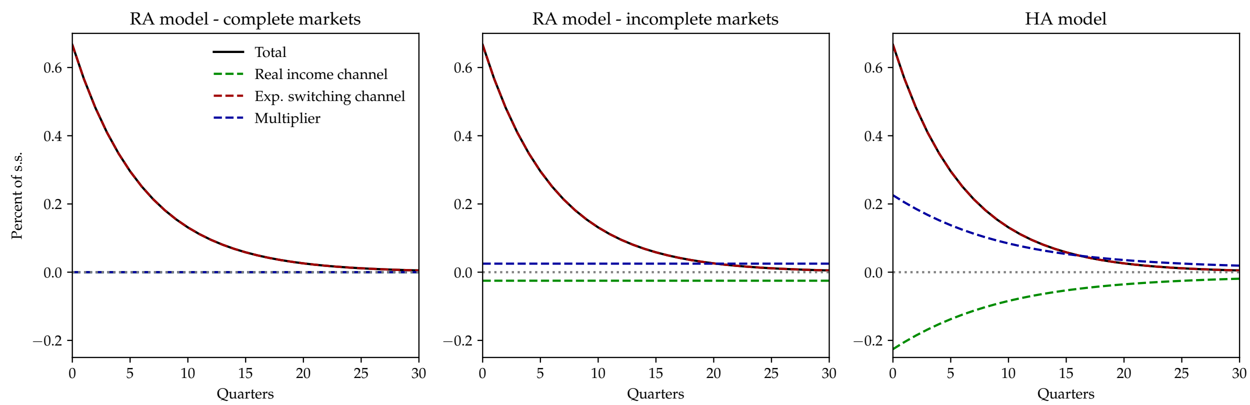
Alternative models of consumption. One advantage of these results is that they apply not only to any calibration of our heterogeneous-agent model, but also to any model that admits a consumption function of the form $C_t = \mathcal{C}_t\left(\left\{\frac{P_{Hs}}{P_s}Y_s\right\}_{s=0}^{\infty}\right)$ with derivative $\mathbf{M}$. This includes the (complete-market) RA model above, for which $\mathbf{M} = 0$, but also the TA model and the RA-IM model, whose closed-form solutions we derive in appendices B.7 and B.8, respectively.[24] In addition, appendices D.1 and D.2 show that our results also apply in a model with nontradable goods or with imported intermediate goods. These models are isomorphic to our baseline model, under a reinterpretation of parameters.

We use the result in proposition 3 to solve for $d\mathbf{Y}$ in both the RA and RA-IM models as well as the HA model, and decompose $d\mathbf{Y}$ following (32). Figure 3 presents the outcome of this exercise for the case where $\chi = 1$. As we noted already, the output response in the RA model (left panel) is entirely driven by expenditure switching. In the RA-IM model (middle panel), there is a small negative real income channel, and a small positive multiplier effect. Both are an order of magnitude larger in the HA model (right panel). In other words, the HA model "sizes up" the real income channel.

An intriguing property of figure 3 is that the multiplier effect exactly undoes the increased real income channel, in both the RA-IM and the HA model. The aggregate output

[24] Bianchi and Coulibaly (2021) independently arrived at a decomposition for consumption in a tradable-nontradable RA-IM model. Their decomposition is distinct from ours, in that they allow i_t^* to enter the consumption function directly.

Figure 3: Exchange rate shock when $\chi = 1$ and its transmission channels



Note: impulse response in all three models to the shock to i_t^* displayed in Figure 1, with decomposition from proposition 2.

responses $d\mathbf{Y}$ are therefore identical across models in figure 3. Our next result proves that this is no coincidence.

Proposition 4. *Consider any model of consumption characterized by a matrix $\mathbf{M}$, and an arbitrary exchange rate shock $d\mathbf{Q}$. If $\chi = 1$, all aggregate quantities and prices are the same as in the RA model, and in particular, $d\mathbf{Y} = d\mathbf{Y}^{RA}$. Moreover, provided that $\mathbf{M} > 0$, for a depreciation shock $d\mathbf{Q} \geq 0$, we have*

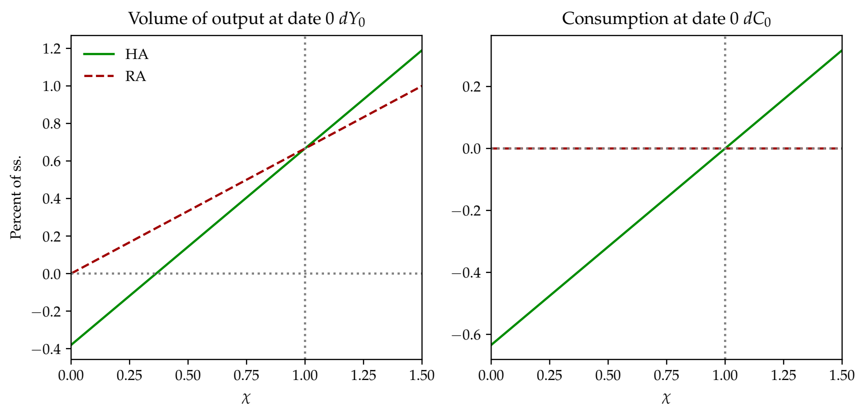
$$d\mathbf{Y} \lesseqgtr d\mathbf{Y}^{RA} \quad \textit{and} \quad d\mathbf{C} \lesseqgtr 0 \qquad \Leftrightarrow \qquad \chi \lesseqgtr 1$$

The first part of proposition 4 formally establishes a neutrality result for exchange rate shocks: when $\chi = 1$, the details of household behavior and market structure are irrelevant as long as there exists an aggregate consumption function of the form $C_t = \mathcal{C}_t\left(\left\{\frac{P_{Hs}}{P_s}Y_s\right\}_{s=0}^{\infty}\right)$. This result follows directly from substituting $\chi = 1$ into (33). To understand why this works, note that when we substitute $d\mathbf{Y} = d\mathbf{Y}^{RA} = \frac{\alpha}{1-\alpha}d\mathbf{Q}$ into (31), we get $d\mathbf{C} = 0$: for $\chi = 1$, the rise in output from expenditure switching is just large enough to offset the loss of real income from higher prices, leaving total real income and therefore consumption unchanged in every period. Since consumption is unchanged, the only effect on output is from expenditure switching, just as in the RA model.

Our result in proposition 4 is closely related to the *Marshall-Lerner condition*, which posits that the response of the trade balance after an exchange rate shock depends on the position of χ, the sum of import and export elasticities, relative to 1. Indeed, appendix B.3 shows that, in our model, the response of the trade balance is given by

$$dNX_t = \frac{\alpha}{1-\alpha}(\chi - 1)\, dQ_t - \alpha dC_t \tag{34}$$

Figure 4: Complementarity between expenditure switching elasticity χ and high MPCs



Note: changes on impact in output and consumption following the shock to i_t^* displayed in Figure 1. The HA model generates a contraction for output on impact for $\chi < \chi^* = 0.37$ and a contraction for consumption on impact for $\chi < 1$. The complete-market RA model never generates a contraction.

Since the sign of dC_t depends on $\chi - 1$, the Marshall-Lerner condition holds here in general equilibrium.[25] At the threshold $\chi = 1$, reduced imports and increased exports exactly offset increased import prices, and the trade balance is unchanged.

Going beyond the neutrality result, proposition 4 shows that when χ lies below 1, expenditure switching is weaker, reducing the output response Y_t, and therefore reducing the multiplier term. The real income channel is now no longer fully offset, pushing the output response in the HA model below that in the RA model. The opposite happens when $\chi > 1$.

Proposition 4 therefore describes a complementarity between the trade elasticity χ and incomplete markets. Reducing χ below 1 has a disproportionate effect on output in the heterogeneous-agent model, as it reduces the multiplier channel while the real income channel remains unchanged. We illustrate this point in figure 4, which shows the impact responses of output dY_0 and consumption dC_0 for the shock considered in figure 1 at various values of χ.

As the right panel in figure 4 illustrates, an interesting implication of $\chi < 1$ is that aggregate consumption falls in response to an exchange rate depreciation in our setting. This finding is in line with the empirical Backus-Smith correlation, and complements the recent results of Itskhoki and Mukhin (2020), who show that a similar correlation can be obtained in a representative-agent model with an active Taylor rule.

[25] Observe that $\chi = 1$ does not correspond to the famous Cole and Obstfeld (1991) parametrization, which, using (9), is given by $\chi = 2 - \alpha$. The Cole and Obstfeld (1991) parametrization turns out to be the relevant one for monetary policy (see section 4).

3.3 Contractionary depreciations

A novel feature of the model is that, with χ sufficiently below 1, consumption falls by so much after an exchange rate depreciation that it causes a contraction in output. In other words, the economy displays *contractionary depreciations.*

Proposition 5. *If $\chi < 1-\alpha$, the output response to a depreciation shock $dQ_t \geq 0$ has negative net present value, $\sum_{t=0}^{\infty}(1+r)^{-t}dY_t < 0$ in the heterogeneous-agent model. Moreover, given a depreciation shock, there is a threshold χ^* between $(1-\alpha)M_{0,0}$ and 1 such that for any $\chi < \chi^*$, the output response is negative on impact, $dY_0 < 0$.*

When $\chi < 1-\alpha$, the present value of the real income channel overwhelms the expenditure switching channel in (32), leading to an output response with negative present value.[26] For low enough χ, expenditure switching is overwhelmed by the real income channel on impact as well. For instance, if there is a one-time shock to dQ_0, the real income effect at $t=0$ is $-\alpha M_{0,0}dQ_0$, compared to expenditure switching of $\frac{\alpha}{1-\alpha}\chi dQ_0$. When $\chi < (1-\alpha)M_{0,0}$, the former dominates. This dominant real income channel is only reinforced by the multiplier in (32), since the real income effect on consumption persists after the shock has passed, and this persistence feeds back to date 0 via the multiplier. Overall, for any depreciation, there is a threshold χ^* at which it becomes contractionary: χ^* is at least $(1-\alpha)M_{0,0}$, and usually greater due to multiplier effects.

Since this result is driven by the real income channel, it is different from, and complementary to, the commonly studied balance sheet channel with currency mismatch (e.g. Aghion, Bacchetta and Banerjee 2004, Céspedes, Chang and Velasco 2004). It can potentially explain the continued relevance of fear of floating (Ilzetzki, Reinhart and Rogoff 2019) and reserve hoarding (Bianchi and Lorenzoni 2021) among countries for which currency mismatch is no longer an issue (see appendix C.4).

The right panel of figure 2 illustrates contractionary depreciations. Since $\alpha = 0.4$, the present value of the output response is negative whenever $\chi < 0.6$—for instance, the $\chi = 0.5$ impulse response features this property. The threshold trade elasticity χ^* for this calibration is given by $\chi^* = 0.37$.

3.4 Dollar currency pricing

We have seen that the degree of expenditure switching crucially influences whether a depreciation is expansionary in the HA model. One reason for a weaker expenditure

[26] Since $\mathbf{M}$ conserves present value, taking the present value of both sides of (32) gives $PV(d\mathbf{Y}) = \left(\frac{\alpha}{1-\alpha}\chi - \alpha\right) PV(d\mathbf{Q}) + (1-\alpha)PV(d\mathbf{Y})$, so for $d\mathbf{Q} \geq 0$, $PV(d\mathbf{Y})$ has the same sign as $\chi - (1-\alpha)$.

switching channel is the prevalence of dollar (or dominant) currency pricing (DCP). With DCP, exports are invoiced in dollars. This means that export prices do not immediately adjust in response to exchange rate fluctuations (Gopinath, 2016), limiting the response of export demand (Gopinath et al., 2020).

To explore the effects of DCP for our model, we replace equation (8) with $P^*_{Ht} = \overline{P^*_H}$. Hence, all exports are invoiced in dollars, and for simplicity these dollar prices are fixed.[27] This influences our analysis in two ways. First, it lowers the trade elasticity χ from $\eta(1-\alpha)+\gamma$ to simply $\eta(1-\alpha)$: the volume of export demand no longer responds to a depreciation. We refer to this as the "standard effect" of DCP. Second, domestic firms' markups on exports are now endogenous to the exchange rate: after a depreciation, markups increase, raising profits via equation (12).[28] These profits are earned by domestic shareholders, generating a positive effect on spending. We refer to this as the "profit effect" of DCP.

To investigate the role of the two effects of DCP, figure 5 compares the output response to a depreciation under PCP to the responses under DCP with (i) only the standard effect and (ii) both effects.[29] The left panel shows the case of larger elasticities $\eta = \gamma = 1/(2-\alpha)$, chosen to give $\chi = 1$. Here, the standard DCP effect causes a large reduction in the output response, as it effectively sets γ to zero. The profit effect is positive for output, as asset owners spend some of the additional profit earned on exports, but here this is not enough to overturn the lack of export demand, since these asset owners have low MPCs.

The right panel shows the case of smaller elasticities. There, since γ is already small, the standard effect is much weaker, and it is now reversed by the profit effect: DCP increases the output response, making the depreciation less contractionary.

To shed further light on this effect, consider the effect of a one-time depreciation dQ_0 on output. For any given agent i, the depreciation causes a reduction in real wage income of $\frac{1}{\mu}e_{i0}$, where e_{i0} is the idiosyncratic productivity of agent i at date 0, and it raises real dividend income by $\left(1-\frac{1}{\mu}\right)\frac{a_{i0}}{A_{ss}}$ where $\frac{a_{i0}}{A_{ss}}$ is the wealth owned by agent i relative to mean wealth. Let us define the *net exchange rate exposure* NXE_i of agent i by

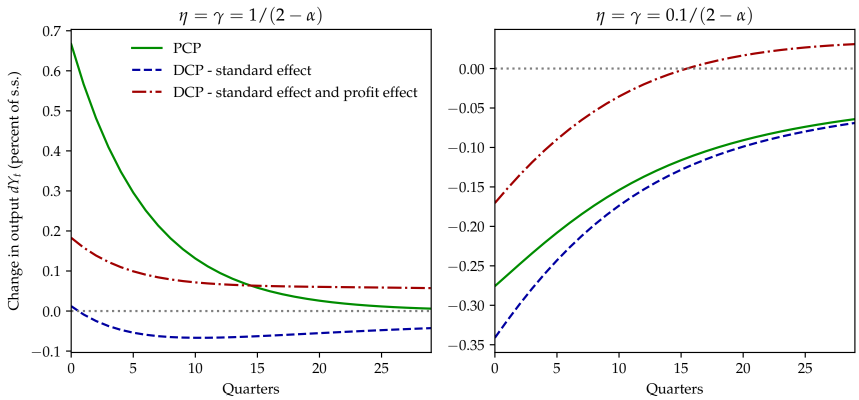
$$NXE_i \equiv \left(\frac{a_{i0}}{A_{ss}} - e_{i0}\right)\cdot\frac{1}{\mu} \tag{35}$$

[27] In section 5 we relax this assumption by allowing for dynamic adjustment of the dollar price.

[28] Barbiero (2020) empirically documents these foreign-exchange-induced variations in the profits of French firms that price in foreign currency.

[29] One can think of (i) as the case in which exporters are perfectly hedged against exchange rate movements.

Figure 5: Capital outflows under dollar currency pricing



Note: impulse responses to the shock to i_t^* displayed in Figure 1. PCP corresponds to producer currency pricing, DCP to dollar currency pricing. The standard (reduced expenditure switching) and the profit effect are discussed in the main text.

We show in appendix B.4 that the impact output response is then given by

$$dY_0 = \frac{\alpha}{1-\alpha}\chi dQ_0 + \alpha \text{Cov}\left(MPC_i, NXE_i\right) dQ_0 + (1-\alpha)\sum_{s\geq 0} M_{0,s} dY_s \tag{36}$$

Compared with (32), we see that the real income channel is now given by the *cross-sectional covariance* of MPCs and net exchange rate exposures. In our model, this covariance is endogenously negative, since firms' shareholders tend to be richer and have lower MPCs than agents who predominantly rely on labor income. Our model thus provides a micro-founded counterpart to Díaz Alejandro (1963) and Krugman and Taylor (1978), who previously discussed this mechanism in the context of IS-LM models. We regard measuring net exchange rate exposures such as (35) in the data, and analyzing their aggregate implications using equation (36), as a very promising avenue for future research.

In commodity exporting countries, exchange rate depreciations also create a profit effect: they raise the domestic price at which commodity exporting firms sell, so that depreciations redistribute from workers, whose real income falls, to the owners of these firms. Appendix D.3 proves that there is, in fact, a formal analogy: by reinterpreting α and χ, a model with produced nontradables and endowed tradables (e.g. commodities) is exactly equivalent to the model with DCP and fixed dollar prices studied here.

4 Monetary policy

One of the most important ways in which monetary policy is transmitted in open economies is through exchange rates. We next ask how the transmission is affected by heterogeneous agents and incomplete markets. Throughout this section we assume log preferences $\sigma = 1$, which allows for a clean analytical characterization. In the interest of space we focus on real interest rate rules; appendix B.9 considers Taylor rules.

4.1 Transmission of real interest rates

Given our monetary policy rule (19), monetary policy affects aggregate activity in our model by directly changing the path of domestic real interest rates $\{r_t\}$. This has two distinct effects on household behavior. First, it affects the path of the real exchange rate $\{Q_t\}$ through the real UIP condition (16). Given that $Q_\infty = 1$ and $i^* = r_{ss}$, we now have

$$Q_t = \prod_{s \geq t} \left(\frac{1 + r_{ss}}{1 + r_s} \right) \tag{37}$$

These changes in the real exchange rate operate through the expenditure switching and real income channels analyzed in section 3.

Second, changes in domestic interest rates affect the economy directly as r_t moves asset prices and therefore returns at all dates, including by revaluating wealth at date 0. This induces income and substitution effects that are well-studied in the closed economy literature (e.g. Auclert 2019). We refer to these effects as the *interest rate channel*. Formally, aggregate consumption is now also directly affected by real interest rates, $C_t = \mathcal{C}_t \left(\left\{ r_s, \frac{P_{Hs}}{P_s} Y_s \right\} \right)$. The interest rate response matrix $\mathbf{M}^r$, which we define as $M^r_{t,s} \equiv (1 + r) \cdot \partial \mathcal{C}_t / \partial r_s$, captures these closed-economy effects.

To characterize the effect of monetary policy on output, we again proceed by linearizing the goods market clearing condition. Consider a change $\{dr_t\}$ to real interest rates, and let $d\mathbf{r} \equiv \left(\frac{dr_0}{1+r_{ss}}, \frac{dr_1}{1+r_{ss}}, \ldots \right)'$. Given (37), the real exchange rate responds by $dQ_t = -\sum_{s \geq t} \frac{dr_s}{1+r_{ss}}$, or in matrix notation, $d\mathbf{Q} = -\mathbf{U} d\mathbf{r}$, where $\mathbf{U}$ is a matrix with 1's on and above the diagonal. Linearizing (21) again, we obtain a generalized version of the international Keynesian cross (32):

$$d\mathbf{Y} = \underbrace{(1-\alpha)\,\mathbf{M}^r d\mathbf{r}}_{\text{Interest rate channel}} + \underbrace{\frac{\alpha}{1-\alpha} \chi d\mathbf{Q}}_{\text{Exp. switching channel}} - \underbrace{\alpha \mathbf{M} d\mathbf{Q}}_{\text{Real income channel}} + \underbrace{(1-\alpha)\,\mathbf{M} d\mathbf{Y}}_{\text{Multiplier}} \tag{38}$$

The representative-agent model is still covered as a special case of equation (38), in which $\mathbf{M} = 0$ and $\mathbf{M}^r = -\mathbf{U}$.[30] In that case, equation (38) delivers the simple expression $d\mathbf{Y}^{RA} = -\left((1-\alpha) + \frac{\alpha}{1-\alpha} \chi \right) \mathbf{U} d\mathbf{r}$.

[30]Recall that $\sigma = 1$ in this section. In general, $\mathbf{M}^r = -\frac{1}{\sigma} \mathbf{U}$.

In the HA model, it is well-understood from the closed-economy literature that the interest rate channel is less powerful, since agents have less ability to substitute intertemporally. In a closed economy, this weaker interest rate channel can be offset by a stronger multiplier (Werning 2015). In the open economy, however, the multiplier is weaker, since only a share $1-\alpha$ of domestic demand is spent on home goods. Hence, with $\chi = 1$, the HA model has a weaker output response to monetary policy. However, as we prove next, equivalence is restored at a greater value for χ, namely $\chi = 2-\alpha$.

Proposition 6. *Assume $\sigma = 1$, and consider an arbitrary first-order monetary policy shock $d\mathbf{r}$. If $\chi = 2-\alpha$, all aggregate quantities and prices are identical in heterogeneous and representative-agent models. Moreover, provided that $\mathbf{M} > 0$, for an accommodative shock $d\mathbf{r} \leq 0$,*

$$d\mathbf{Y} \lesseqgtr d\mathbf{Y}^{RA} \quad \Leftrightarrow \quad \chi \lesseqgtr 2-\alpha$$

Proposition 6 is the analogue of Proposition 4 for monetary policy. The neutral case, $\chi = 2-\alpha$, applies in particular to the commonly-studied Cole and Obstfeld (1991) parameterization in which $\eta = \gamma = \sigma = 1$.[31] This result generalizes the representative-agent result in Itskhoki (2020) to heterogeneous-agent models, and the closed economy result of Werning (2015) to the open economy.

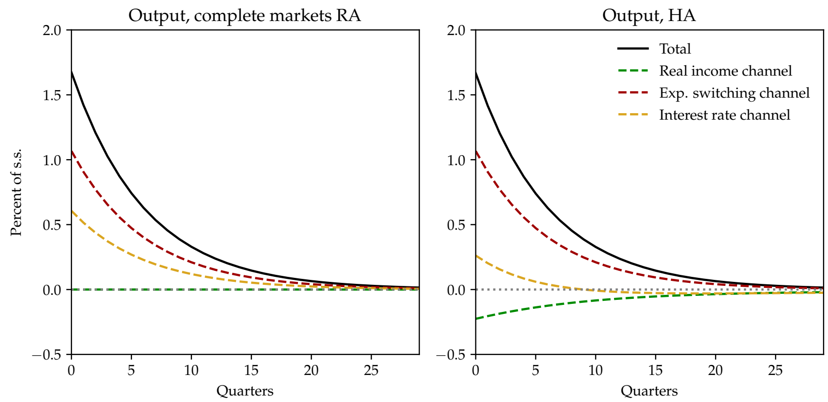
To understand this result, it is helpful to consider the effects of monetary policy on the trade balance. Suppose that consumption changes as in the RA model: the Backus-Smith condition then implies that $dC_t = dQ_t$. Then, equation (34) implies that $dNX_t = \frac{\alpha}{1-\alpha}\left(\chi - (2-\alpha)\right) dQ_t$. Hence, at $\chi = 2-\alpha$, expenditure switching offsets *both* the increase in import prices and the higher import demand, and the economy behaves as if it were a closed economy. Given this, we can apply Werning (2015)'s result for closed economies to validate our guess that consumption behaves as if there was a representative agent.

The top panels of figure 6 illustrate this neutrality result. We consider an accommodative interest rate shock that generates the same path for the real exchange rate as that considered in section 3. In the right panel, we show the output response in the HA model, as well as its decomposition using equation (38). Compared to the RA model (left panel), it shows a clearly negative real income effect, and a weaker interest rate effect. Both are exactly offset by a positive multiplier effect from the increased production (not shown), so that the output response is identical. In the bottom panels of figure 6, we consider what happens when $\chi = 0.5$ instead. The interest rate and real income channels are unchanged relative to $\chi = 2-\alpha$, but after a few quarters, the muted expenditure switching channel

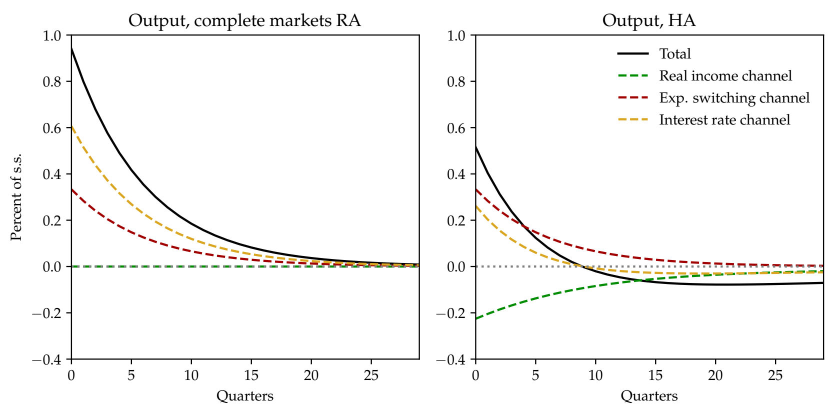
[31] In fact, in this special case, it is even possible to prove that proposition 6 holds for unanticipated non-linear shocks. We can generalize our results further when $\chi = 2-\alpha$, e.g. by allowing for arbitrary monetary policy rules. See appendix B.9.

Figure 6: The effects of monetary policy

(a) Neutral case: $\chi = 2 - \alpha$



(b) Lower trade elasticity: $\chi = 0.5$



Note: impulse response to a shock to r_t that has the same shape and magnitude as the i_t^* shock in figure 1, but with opposite sign. This leads to the same real exchange rate path as in the right panel of that figure. The decomposition follows equation (38).

now no longer longerundoes their negative influence on output. Overall, the response of output is below that of the RA model everywhere, consistent with proposition 6.

4.2 Stealing demand from the future through current account deficits

An intriguing aspect of the bottom right panel of figure 6 is that the output response in the HA model turns negative after 9 quarters. In other words, monetary stimulus successfully raises aggregate demand for a few quarters, but at the cost of lowering it afterwards. It "steals" demand from the future.

What explains this pattern? As discussed above, when $\chi < 2 - \alpha$, monetary stimulus generates a current account deficit: agents borrow from abroad, both to finance higher spending today, spurred by the low rates, and to smooth the real income losses from higher import prices. These current account deficits accumulate into a negative net foreign asset position over time. Once the interest rate and real exchange rate are back close to their steady states, the country is faced with a negative NFA. To rebalance the current account, agents cut back on spending, causing a downturn in aggregate demand. The size of the necessary consumption adjustment can be computed in present values from equation (38).

Proposition 7. *Facing an initial net foreign position of dnfa, with no change in the exchange rate* $d\mathbf{Q} = 0$*, the present value of the consumption adjustment and output response is given by*

$$PV(d\mathbf{C}) = -\frac{1}{\alpha}d\text{nfa} \qquad PV(d\mathbf{Y}) = -\frac{1-\alpha}{\alpha}d\text{nfa}$$

To obtain an intuition for this result, recall that our HA model is stationary. Any initial negative NFA will eventually be repaid. If there is no depreciation, this must involve a recession. Proposition 7 shows that the more closed the economy (the smaller α), the larger the reduction of spending and output required to repay a given negative NFA, since most of the reduced spending falls on home goods, which does not contribute to the international adjustment.[32]

Our "stealing demand from the future" effect is a close cousin to the "limited ammunition" effect in closed-economy models that has been recently described by McKay and Wieland (2019), Caballero and Simsek (2020) and Mian, Straub and Sufi (2020). There is one crucial difference, however. In our open economy setting, the effect of monetary policy can be so weak that the present value of the output response to monetary stimulus, $PV(d\mathbf{Y})$, is *negative*. Appendix B.6 shows that this happens in our model when $\chi < 1 - \alpha$.

5 Quantitative model

We have shown that the extent to which heterogeneity matters for the effects of exchange rates or monetary policy depends on the level of the trade elasticity χ. We derived these results under the standard assumption of static CES demand, for which χ is a constant structural parameter. Yet a host of empirical evidence suggests that the response of the trade balance to exchange rate shocks takes time to play out and depends on the nature of the shock, notably on agents' expectations of its persistence (e.g. Ruhl 2008, Fitzgerald and Haller 2018). For transitory shocks to exchange rates, the elasticity can be close to 0 in the short run (e.g. Hooper, Johnson and Marquez 2000); for more permanent shocks,

[32] See Krugman (1987) for an earlier articulation of this point. Of course, a less open economy is less likely to accumulate a large negative NFA in the first place.

such as tariff changes, it can be 4 or more in the long run (e.g. Caliendo and Parro 2015). Any plausible quantification exercise needs to confront this evidence.

In this section, we develop a quantitative version of the benchmark model studied so far. To this benchmark, we add a stylized model of delayed substitution, which exhibits shock-dependent and time-varying elasticities of imports and exports to movements in relative prices (a "J curve"). The model's aggregate dynamics are similar to those of the richer models in Ruhl (2008), Drozd and Nosal (2012) and Alessandria and Choi (2019), but it abstracts away from the behavior of firms and focuses directly on that of of households. In doing so, it captures the essence of these theories in reduced form, and is straightforward to integrate into broader general equilibrium environments, such as that of our heterogeneous-agent model.[33]

In addition to delayed substitution, our quantitative model allows for price rigidities on top of wage rigidity (and hence intermediate degrees of exchange rate pass-through), non-homotheticities in consumption, currency mismatch in balance sheets, and a standard Taylor rule for monetary policy.

5.1 Additional model elements

We next introduce our new model elements.

Non-homothetic preferences. Cravino and Levchenko (2017) document that, in Mexico, households at the bottom of the income distribution consume a larger share of imported goods than households at the top, implying that they experience larger declines in real income during a depreciation.[34] Since poor households typically have higher MPCs, accounting for this fact could magnify the importance of the real income channel. To allow for this possibility, we follow Carroll and Hur (2020) and Fanelli and Straub (2020) and assume agents consume a Stone-Geary CES bundle, with a positive subsistence need $\underline{c}$ for imported tradables,[35]

$$c = \left[\alpha^{1/\eta}\left(c_F - \underline{c}\right)^{(\eta-1)/\eta} + (1-\alpha)^{1/\eta} c_H^{(\eta-1)/\eta}\right]^{\eta/(\eta-1)} \tag{39}$$

Monetary policy. Galí and Monacelli (2005) show that, in their framework, optimal

[33] See Arkolakis, Eaton and Kortum (2012) and Drozd, Kolbin and Nosal (2021) for alternative reduced-form models that share the same objective.

[34] The importance of this phenomenon in other countries is subject to an empirical debate. Borusyak and Jaravel (2018) argue that the share of imports in consumption baskets is flat across the income distribution in the United States. Bems and di Giovanni (2016) argue that the fall in aggregate income during the 2008 crisis in Latvia caused consumers to shift towards lower-quality, domestically produced goods.

[35] Appendix C.1 describes how to modify our solution method to incorporate this form of non-homothetic demand.

policy targets producer-price-index (PPI) based inflation. We replace the constant–r monetary rule in the previous sections by the PPI inflation based Taylor rule (20).

Sticky prices and imperfect exchange rate pass-through. We allow for price stickiness in domestic prices, modeled a la Calvo with a price stickiness coefficient of θ_H. This leads to a Phillips curve for inflation in domestic prices P_{Ht} of

$$\pi_{Ht} = \kappa_H \left(\mu \frac{W_t}{Z_t P_{Ht}} - 1 \right) + \frac{1}{1+r} \mathbb{E}_t \left[\pi_{H,t+1} \right] \tag{40}$$

with $\kappa_H = (1-\theta_H) \left(1 - \frac{1}{1+r}\theta_H\right) / \theta_H$.

We also allow for imperfect pass-through of the exchange rate into import and export prices. To model imperfect pass-through to import prices, we assume that local retailers import foreign goods at a flat cost of $\mathcal{E}_t$ per unit, differentiate them, and sell them domestically at a sticky price P_{Ft}. The elasticity of substitution between these imported differentiated varieties is $\mu_F / (\mu_F - 1)$. This formulation leads to a Phillips curve for imported goods P_{Ft} of

$$\pi_{Ft} = \kappa_F \left(\mu_F \frac{\mathcal{E}_t}{P_{Ft}} - 1 \right) + \frac{1}{1+r} \mathbb{E}_t \left[\pi_{F,t+1} \right] \tag{41}$$

with $\kappa_F = (1-\theta_F) \left(1 - \frac{1}{1+r}\theta_F\right) / \theta_F$. We make the same assumption for retailers in the foreign country to model imperfect pass-through to export prices. Then, inflation in the price $P^*_{H,t}$ of home goods that foreigners see, expressed in their currency, is

$$\pi^*_{Ht} = \kappa_{H^*} \left(\mu_{H^*} \frac{P_{Ht}}{\mathcal{E}_t P^*_{Ht}} - 1 \right) + \frac{1}{1+r} \mathbb{E}_t \left[\pi^*_{H,t+1} \right] \tag{42}$$

with $\kappa_{H^*} = (1-\theta_{H^*}) \left(1 - \frac{1}{1+r}\theta_{H^*}\right) / \theta_{H^*}$.

Delayed substitution. We introduce delayed substitution by modifying the household problem. Instead of being able to flexibly adjust their relative consumption of home and foreign goods in each period, we now assume that households can only do so with a certain probability $1-\theta$. With probability θ, they are forced to keep the ratio of foreign good to home good consumption constant. Crucially, while relative consumption choices are restricted in that case, agents are still able to adjust their overall expenditure. This ensures that agents never involuntarily violate their borrowing constraint.

As we show in appendix C.2, this model generates dynamics for the *target ratio* $\hat{x}_t$ of foreign to home good consumption. At home,[36] these dynamics are described by:

$$d\log\hat{x}_t = \eta(1-\beta\theta)d\log\frac{P_{Ht}}{P_{Ft}} + \beta\theta d\log\hat{x}_{t+1} \tag{43}$$

This is similar to a Calvo model of pricesetting, but here, consumers reset their *bundles* based on their perceptions of current and future relative prices. The aggregate ratio $x_t = C_{Ft}/C_{Ht}$, in turn, evolves sluggishly, with dynamics described by

$$d\log x_t = (1-\theta)d\log\hat{x}_t + \theta d\log x_{t-1} \tag{44}$$

Together, these equations determine the dynamic response of x_t to any shock to relative prices. Finally, spending at home follows

$$dC_{Ht} = (1-\alpha)\,dC_t - \alpha\,(1-\alpha)\,d\log x_t \tag{45}$$

This delivers a model in which the trade elasticity is both shock- and time-dependent. For instance, the long-run elasticity to a permanent shock is simply η. By constrast, the short-run elasticity to the same permanent shock is lower, at $\eta\,(1-\theta)$, since it takes time for consumers to adjust. Finally, the short-run elasticity to a one-time shock is even lower, at $\eta\,(1-\theta)\,(1-\beta\theta)$, since even those who change their bundles choose to adjust little, as they anticipate adjusting back in the other direction after the shock has passed.

5.2 Calibration

Aggregate calibration. We calibrate the model at a quarterly frequency. Our aggregate calibration is standard. Our goal is to capture the essential features of a typical Latin American economy such as Mexico. Table 1 summarizes this calibration. We assume discount factor heterogeneity, a standard feature in the literature to deliver a realistic level of average MPCs with a non-trivial amount of aggregate wealth. We opt for permanent heterogeneity, with a three point distribution at $\left\{\beta-\frac{\Delta}{2},\beta,\beta+\frac{\Delta}{2}\right\}$ and a third of agents in each. We set β to achieve an annualized real interest rate of $r = 4\%$ in steady state. We set the initial steady state net foreign asset position to 0, with all mutual fund assets invested in domestic stocks, to avoid interactions between exchange rates and pre-existing trade deficits. We consider standard values of $\sigma = 1$ for the elasticity of intertemporal substitution, and $\varphi^{-1} = 0.5$ for the Frisch elasticity of labor supply. For the elasticity of substitution across goods, we proceed as follows. Since there is limited evidence that this

[36] The equations for foreign households are analogous, except with γ in lieu of η, and all consumption ratios, quantities and prices with star superscripts.

Parameter	Benchmark model	Quantitative model	Parameter	Benchmark model	Quantitative model
σ	1	1	μ	1.03	1.028
φ	2	2	s.s. nfa	0	0
η	$\frac{\{0.1,0.5,1,2-\alpha\}}{2-\alpha}$	4	σ_e	0.6	0.6
γ	$=\eta$	$=\eta$	ρ_e	0.92	0.92
θ	n.a.	0.987	θ_w	0.95	0.95
β	0.954	0.947	θ_H	0	0.66
Δ	0.06	0.067	θ_{H^*}	0	0.66
α	0.4	0.323	θ_F	0	0
$\underline{c}$	0	0.114	ϕ	n.a.	1.5
		Moment	Data	Benchmark model	Quantitative Model
		Average annual MPC	0.632	0.636	0.637
		Std of annual MPC	0.152	0.151	0.149
		Average tradable share	0.400	0.400	0.400
		Std of tradable share	0.042	n.a.	0.042

Notes: all parameters are for the quarterly calibration, but MPCs are annual. Average and standard deviations are computed across deciles of income. β heterogeneity is discretized with 3 points, and Δ is the spread between the highest and the lowest β. The income process is discretized with 7 points.

Table 1: Calibration

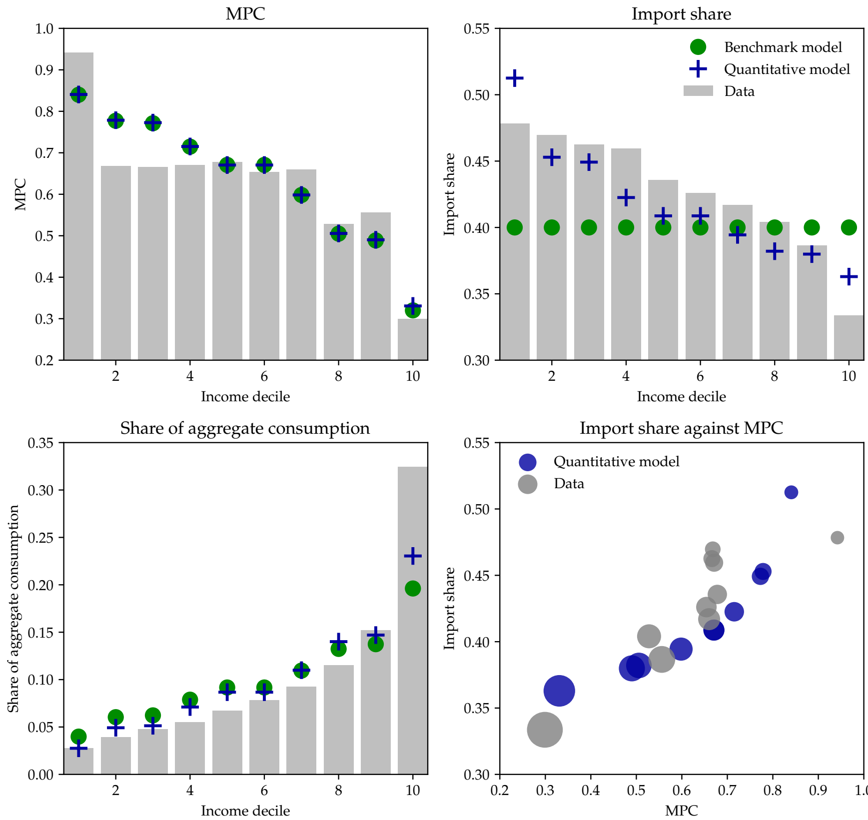
elasticity is different for imported vs domestic goods relative to between imported goods, we set $\gamma = \eta$. This implies that $\chi = (2-\alpha)\gamma$. In our benchmark model, we considered a range of values for χ. By contrast, our quantitative model relies on delayed substitution, which we calibrate below.

MPCs. To calibrate the aggregate consumption behavior of the model, and in the absence of good disaggregated MPC evidence from Mexico, we target moments of the Peruvian MPC data from Hong (2020). Hong (2020) reports an estimated MPC at each decile of the income distribution in Peru. Table 1 reports the average and the standard deviation of MPCs from his estimation exercise. We assume an AR(1) process for log income, with a persistence of $\rho_e = 0.92$ and a cross-sectional standard deviation of logs of $\sigma_e = 0.60$, reflecting typical estimates.[37] We set the borrowing constraint to $\underline{a} = 0$. We adjust the markup μ, which mostly affects the level of steady-state liquidity in the model, so as to target the average (annual) MPC, and set the discount factor spread Δ to target the standard deviation of MPCs across income deciles. This delivers $\mu = 1.03$, so an average wealth to GDP ratio of 73%.[38]

[37] Since our quantitative model has subsistence needs, we make sure that our discretization procedure respects the constraint that the agent at the lowest level of income can always afford the subsistence level of consumption.

[38] This compares to a Mexican wealth-GDP ratio of 350% in 2018. Our estimate is smaller and best under-

Figure 7: Calibration targets and outcomes



Note: calibration of the benchmark model from section 2 and of the quantitative model from section 5. The benchmark model targets the average and standard deviation of MPC across income deciles and the average consumption share of foreign goods. The quantitative model also targets the standard deviation of consumption share of foreign good across income deciles.

Foreign good shares. To calibrate the spending behavior of households across goods, we target moments of the Mexican spending survey reported in Cravino and Levchenko (2017), and summarized in Figure 7. From their data, we obtain the average tradable share at each income decile, as well as that decile's share of aggregate consumption. We then assume that the share of imports within tradables is the same across the income distribution, and compute income-specific import shares so that the economy-wide share lines up with the Mexican import/GDP ratio of 40%, as reported in appendix table A.1.[39] In the benchmark model, we set $\alpha = 0.4$, while in the quantitative model we adjust α, the asymptotic import share, and $\underline{c}$, the subsistence level on the imported good, to target an average import share of 0.4 together with the standard deviation of import shares across

stood as capturing liquid wealth. We decided not to target aggregate wealth to GDP in order to hit realistic MPCs, whose importance is emphasized by our theoretical results.

[39] Appendix D.1 spells out a formal model with nontradables, domestically produced tradables and imported tradables, and shows that it is equivalent to our model provided that α is calibrated to the import/GDP ratio.

income groups from Figure 7.

Figure 7 compares the calibration of our household model against the data by income decile. Overall our model does a very good job at capturing both the MPC variation and the import share variation across the income distribution. In particular, the spending share on imported goods is strongly declining in income, as emphasized by Cravino and Levchenko (2017).

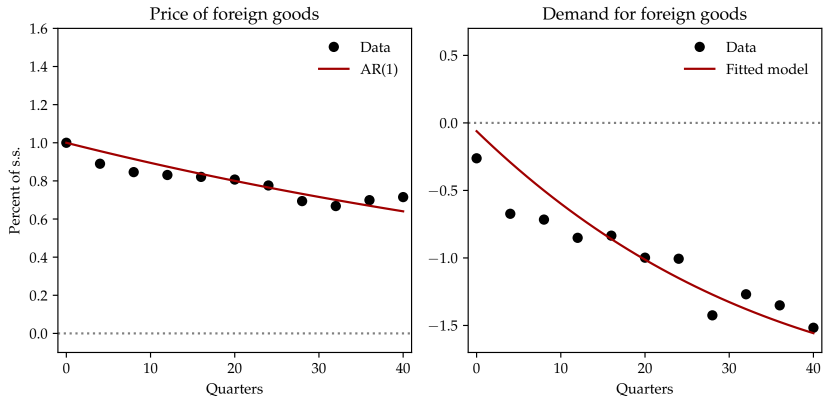
Phillips curve parameters. Appendix C.3 provides details on our calibration of Phillips curve parameters. Among the price rigidity parameters, the Calvo coefficient for import prices θ_F is the most important as it directly affects the magnitude of the real income effect. We calibrate θ_F using evidence from the 1994 Mexican devaluation as reported by Burstein and Gopinath (2015). For this particular devaluation, we find perfect pass-through to import prices, so $\theta_F = 0$.[40] By contrast, given the widespread evidence in Boz et al. (2020) for dollar pricing of exports in Latin American countries, we set $\theta_{H^*} > 0$. We assume that the degree of price rigidity in dollar prices, just as the price rigidity of domestic goods prices, corresponds to an average price reset frequency of 9 months, as is standard in the literature. This leads us to set $\theta_H = \theta_{H^*} = 0.66$. We then find the wage stickiness parameter that is able to simultaneously replicate the path of home good prices after the Mexican devaluation and keep dividends reasonably acyclical in response to exchange rate shocks (see figure A.2). Regarding monetary policy rules, we set the Taylor rule coefficient on PPI inflation to $\phi = 1.5$.

Delayed substitution model. We assume that our delayed substitution model applies equally to domestic and foreign households, with the same parameter θ. We calibrate the model to the evidence in Boehm, Levchenko and Pandalai-Nayar (2020) (henceforth, BLP). BLP identify plausibly exogenous changes in tariffs and trace out the entire dynamic response of trade flows. To be precise, BLP observe how a country A's exports within an industry to a specific importing country B respond to a persistent increase in tariffs levied by B on imports from A. This elasticity captures γ, the elasticity of export demand by the rest of the world. Figure 8 plots the evidence from their estimates. The left panel shows the changes in tariffs. The right panel shows the response of trade flows.

We replicate this experiment in our model as follows. We begin by setting the long-run γ to 4, since this is a consensus estimate for the long-term trade elasticity (e.g. Caliendo and Parro 2015). We then interpret the tariff change in the BLP data as a change in the relative price $d \log \frac{P_{Ht}}{P_{Ft}}$, which we assume follows an AR(1) with persistence ρ. We choose ρ to minimize the sum of squared distances to the tariff response in the left panel in figure 8, finding $\rho = 0.989$ quarterly. We then feed this process into (43)–(44) and calibrate

[40] We recalibrate to evidence from other countries in appendix C.3.

Figure 8: Calibrating delayed substitution in the quantitative model



Note: calibration of delayed substitution in the quantitative model. We fit an AR(1) to the change in tariffs from Boehm, Levchenko and Pandalai-Nayar (2020) and estimate θ to minimize the sum of squared residuals between the model response and the data response of the demand for foreign goods.

θ to minimize the sum of squared distances to the estimates displayed in the right panel in figure 8. This delivers $\theta = 0.987$ quarterly. Finally, we also set $\eta = \gamma$.

5.3 Revisiting contractionary depreciations

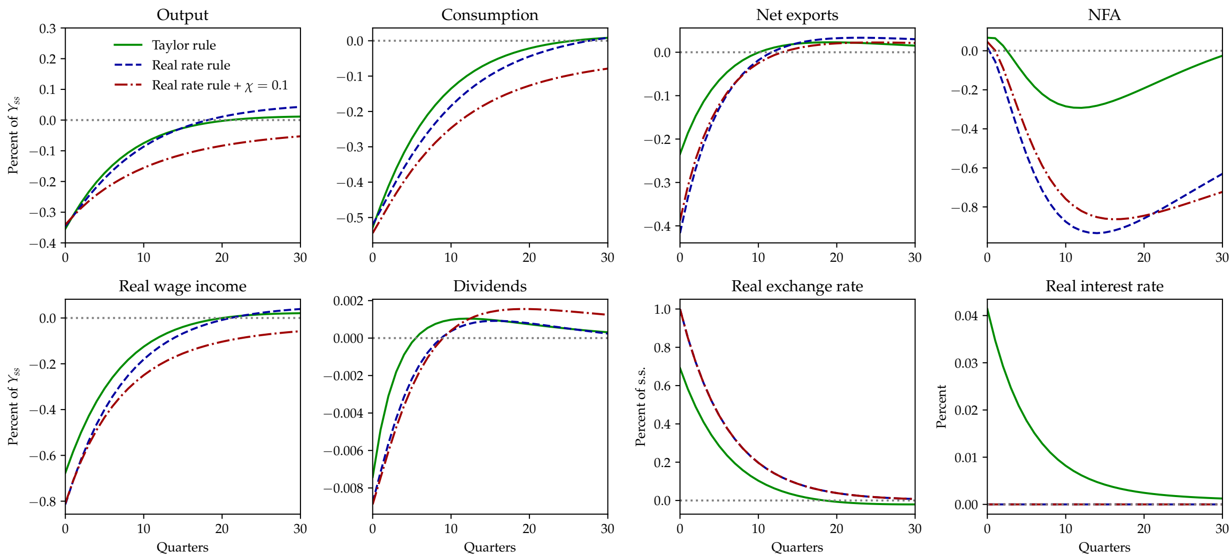
We use our quantitative model to revisit the effect of exogenous depreciation shocks. Proposition 5 showed that, in the benchmark model, these shocks generate output contractions when the trade elasticity χ is small enough. Figure 9 shows that in our quantitative model (green line), depreciations are also contractionary, in spite of an active Taylor rule and a high long-run trade elasticity. This is because, in the short run, the quantitative model behaves like a model with a real rate rule and a low trade elasticity.[41]

The international adjustment mechanism described in section 4.2, acting via the net foreign asset position of the country, is at play in figure 9. In response to the loss of real income from higher import prices, agents dissave to prevent a large decline in consumption.[42] Agents do so for two to three years, during which the country builds up a large negative NFA, which it progressively later repays by depressing its spending and therefore its output. This generates a J curve pattern for net exports in response to the depreciation.

[41] See the dashed red line of figure 9. The dashed blue line further shows that the real rate rule and the Taylor rule have very similar properties.

[42] Most of this dissaving is done by wealthy agents, who have a larger initial buffer stock of assets.

Figure 9: Contractionary depreciations



Note: impulse response in the quantitative model to the shock to i_t^* displayed in Figure 1. The model with Taylor rule is our quantitative model; the one with real rate rule is our quantitative model without the Taylor rule; the model with real rate and $\chi = 0.1$ features CES demand for imports and exports.

5.4 Managing contractionary depreciations

Our analysis shows that depreciations can be contractionary because of a real income channel. We now discuss how monetary policy should respond if its goal is to stabilize output. The question is non-trivial, due to the following dilemma: should monetary policy hike interest rates to fight the depreciation, which is the root cause of the recession? Or should it stimulate by cutting interest rates, as is traditional to fight a recession? To illustrate this tradeoff, we first consider two simple policies.

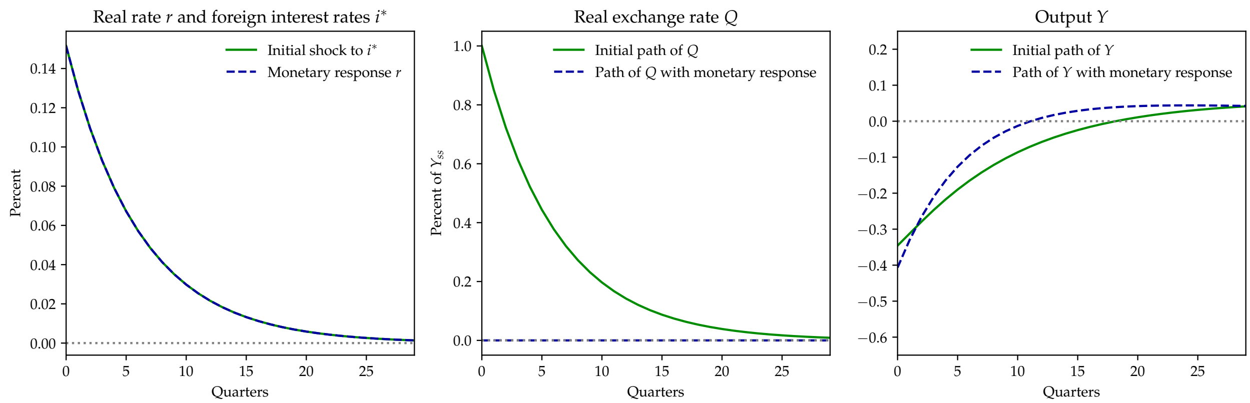
Panel (a) of figure 10 shows what happens when the central bank stabilizes the exchange rate. This policy leads to an even worse recession in the short-run, but it helps improve output further out. The intuition for this finding is that hiking rates replaces one evil (contractionary depreciation) with another (contractionary monetary policy), as highlighted by Gourinchas (2018) and Kalemli-Özcan (2019). For our baseline calibration, the additional contraction is short lived. The contraction is greater for less open economies.

Panel (b) of figure 10 illustrates what happens if monetary policy instead stabilizes output for four quarters. As can be seen, this is achieved with aggressive monetary easing. However, lower interest rates depreciate the exchange rate by even more. This worsens the real income channel, deteriorating the current account even further, and leading to an even greater recession after the four quarters of output stabilization.

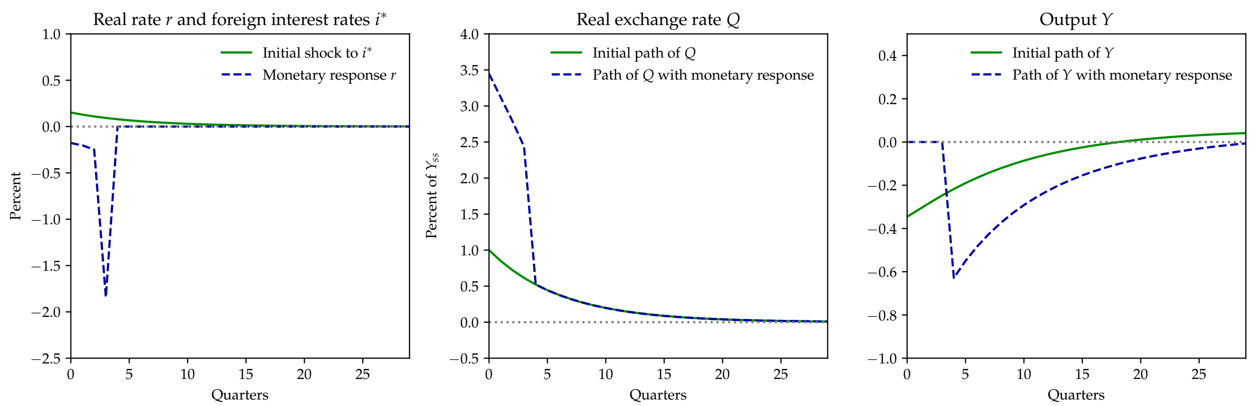
These two scenarios suggest that the policy that fully stabilizes output in all periods

Figure 10: Policies to deal with contractionary depreciations

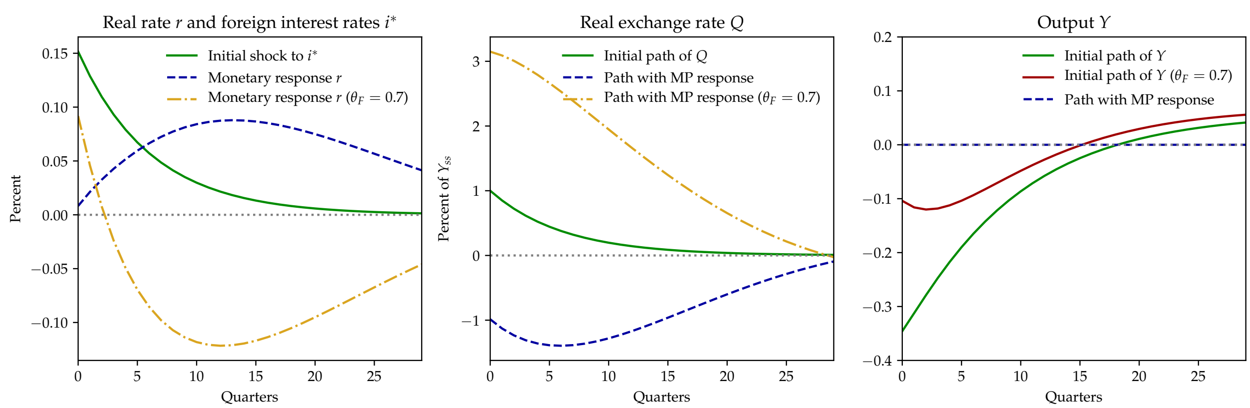
(a) Fighting the depreciation



(b) Fighting the recession



(c) Fully stabilizing output: full import pass-through (baseline $\theta_F = 0$) vs limited pass-through ($\theta_F = 0.7$)



Note: impulse responses to the shock to i_t^* displayed in Figure 1 with and without monetary policy. In panel (a), the green line shows the impulse without monetary policy response. The blue dotted lines show the impulse when monetary policy stabilizes the real exchange rate. In panel (b), the blue dotted lines show the impulse when monetary policy stabilizes output for 4 quarters. In panel (c), the blue dotted lines show the impulse when monetary policy stabilizes output permanently in our quantitative economy with full import pass-through. The orange dotted lines show the impulse when monetary policy stabilizes output permanent for an economy with limited import pass-through.

is complex. The dashed blue line of panel (c) displays it.[43] Here, monetary policy does not change interest rates much initially, and instead promises to hike them later on. By relying on forward guidance in this way, monetary policy not only manages to fight the depreciation: it even appreciates the exchange rate. Meanwhile, because interest rate hikes come in the future, the appreciation does not come at the cost of an immediate recession, and interest rates increase later on when the economy, having built a positive net foreign asset position, is in a better situation to weather them.

The dashed yellow line of panel (c) shows the output-stabilizing policy in an economy with less import price pass-through. In this case, interest rates are cut for an extended period of time. The reason here is that, with less import price pass-through, the economy is more insulated from the real income channel—the recession at constant policy is smaller, as the solid red line shows—so the cost in terms of a depreciation of the exchange rate is smaller, and the benefits of monetary accommodation dominate. This starkly contrasting behavior of monetary policy with high and low import price pass-through may rationalize why, in response to hikes in foreign interest rates, emerging markets tend to hike even more, while advanced economies hike by less or even ease (e.g. Kalemli-Özcan 2019).

5.5 When does the real income effect matter?

Table 2 explores the role of economy-wide characteristics more systematically. For each column, we vary a single parameter in the model, and we report both the on impact response of output and its two-year cumulative response. The first column, labeled "Baseline", corresponds to our quantitative model, as displayed in the green line of Figure 9.

The second column shows that lower openness reduces the impact effect of an exchange rate shock on output. This is natural, as both the real income channel and the expenditure switching channel of exchange rates scale with α. Notably, however, the two-year cumulative change is reduced by less: this is because the multiplier channel is larger at lower α, as any given change in aggregate consumption has a stronger effect on domestic output in a more closed economy.

In the third column, we vary the steady state level of markups μ to generate a higher MPC. This amplifies the real income and multiplier channels, leading depreciations to be more contractionary. DCP, as in section 3.4, slightly softens the contraction, as do homothetic preferences and a higher short-term substitution elasticity. Less exchange rate pass-through into import prices significantly reduces the strength of the real income

[43] This is the unique output-stabilizing policy, which is simple to obtain with our methods. Optimal policy would be very interesting to study, but is still out of reach at present.

	Baseline	Low α	High MPC	Full DCP	Homothetic	High ST χ	$\theta_F = 0.7$	$\theta_F = 0.9$
dY_0	- 0.35	- 0.26	- 0.39	- 0.31	- 0.32	- 0.30	- 0.09	- 0.02
$\sum_{t=0}^{7} dY_t$	- 1.81	- 1.48	- 1.85	- 1.53	- 1.54	- 1.14	- 0.95	- 0.22

Note: change on impact and 2-year cumulated impulse response of output to the shock to i_t^* displayed in Figure 1 for various parametric assumptions. The baseline corresponds to our quantitative model. For low alpha we target a share of tradable of 20% instead of 40%; for high MPC we target an average annual MPC of 80% instead of 63%; for full DCP we assume no pass-through of exchange rate into export prices ($\theta_{H^*} = 0.99$) instead of an intermediate pass-through ($\theta_{H^*} = 0.66$); for homothetic we target a constant tradable share across the income distribution; for high short-term elasticity we target an elasticity of substitution between home and foreign goods of 1 after 1 year, relative to 0.3 in our baseline.

Table 2: Effects of exchange rate shock under various assumptions

channel. Since it also dampens domestic expenditure switching, the output response is mostly scaled down, rather than flipping sign.

These patterns suggest that different countries are likely to respond differently to exchange rate depreciations. In appendix C.3, we calibrate the model to seven countries that have experienced depreciation episodes. We find that the degree of inferred import price pass-through is the most important cross-country determinant of the magnitude of the contraction after a depreciation.

5.6 Comparison with balance sheet effects

A well-documented feature of international investment positions is that the net foreign asset position consists of the difference between gross assets and gross liabilities that are both very large, and often differ in terms of their risk profile and currency composition (e.g. Gourinchas and Rey 2007, Lane and Shambaugh 2010). While we cannot easily capture the risk dimension, we can accommodate currency mismatch in the net foreign asset position.

We relax the assumption that the domestic mutual fund holds 100% of its assets in domestic stocks, and that the government has no gross assets or liabilities. Instead, we assume that one of these has initially borrowed in foreign currency to invest in domestic stocks, while keeping their net position unchanged. Throughout, we assume that gross foreign currency liabilities are 50% of GDP and have an average duration of 18 quarters. Appendix C.4 provides details and shows that this calibration provides an upper bound on the magnitude of valuation effects: data from Bénétrix, Gautam, Juvenal and Schmitz (2020) show that few countries have historically had such large gross currency mismatches in their external balance sheets, and that most countries have dramatically reduced these gross mismatches in the past two decades.

In Table 3 we report how our benchmark results for the output effect of the devaluation

	Baseline	Mutual fund	Gov, lump-sum	Gov, proportional tax	Gov, deficit-finance
dY_0	- 0.35	- 0.41	- 0.70	- 0.63	- 0.53
$\sum_{t=0}^{7} dY_t$	- 1.81	- 2.19	- 2.58	- 2.53	- 2.53

Note: change on impact and 2-year cumulated impulse response of output to the shock to i_t^* displayed in Figure 1 for different balance sheet specifications. The baseline corresponds to our quantitative model. In the second column we assume that the mutual fund holds the equivalent of 50% of annual GDP in debt denominated in foreign currency; for government with lump-sum transfers we assume that the government owes foreign currency debt and owns local currency assets, and adjusts following the depreciation using lump sum taxes to balance budget period by period; for government with proportional taxes we assume that taxes are proportional to labor income; for government deficit financed we assume that the government does not balance budget period by period but can run a deficit. In all our specifications we assume that debt takes the form of long-term bonds with average duration of 18 quarters.

Table 3: Balance sheet effects under various distribution assumptions

(repeated in the first column) are altered in this scenario. We consider four cases. In the first, called "mutual fund", the gross foreign currency debt is held by the mutual fund. This brings down the output response on impact by a further 0.06% on impact, and by 0.38% over 2 years. In other words, foreign currency debt causes some amplification of the contractionary effect of the depreciation, but even in this calibration to a very large net currency mismatch, this effect is small in comparison to the real income effect. In the next three columns, we consider what happens if instead the foreign currency exposure is held on the government balance sheet, and then rebated to households according to various tax schemes. The first two columns report the effect of immediately taxing households lump sum or proportionally, while the third reports the effect of deficit-financing and taxing later with a proportional tax. The amplification is largest with an immediate lump-sum tax, which is most regressive. This echoes the findings in de Ferra, Mitman and Romei (2020) and Zhou (2020), who show that that valuation effects are especially powerful at reducing output when they are concentrated on high-MPC households.

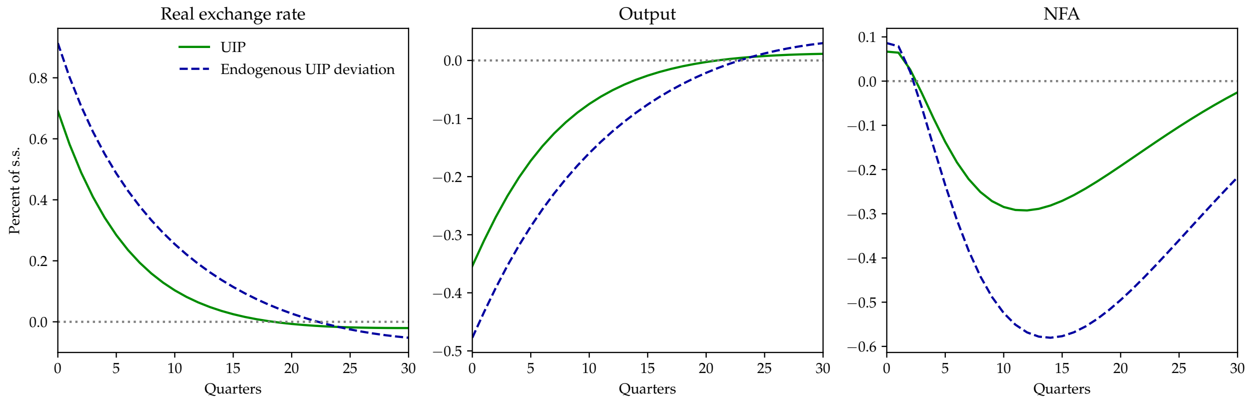
5.7 Endogenous UIP deviations

We finally consider an extension with endogenous UIP deviations, as in Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2020). In this extension, which we spell out in appendix A.2, we assume that mutual funds cannot directly access foreign bond markets. Instead, foreign financial intermediaries trade in both domestic and foreign bond markets, with an imperfectly elastic demand for domestic bonds. This gives the standard condition

$$(1+i_t)\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right) = 1 + i_t^* - \Gamma \cdot \text{nfa}_t$$

which, compared to the UIP (13), includes a UIP deviation term $\Gamma \cdot \text{nfa}_t$. The deviation captures the idea that when the country borrows from the rest of the world, $\text{nfa}_t < 0$, it is

Figure 11: Depreciations with endogenous UIP deviations



Note: impulse response to the shock to i_t^* displayed in Figure 1. The green line shows the impulse in the quantitative model (UIP) while the blue dotted line shows the impulse in the model with endogenous UIP deviations.

required to pay a greater interest rate i_t.

Figure 11 simulates an i_t^* shock in this extension. As before, the shock depreciates the exchange rate and leads to increased domestic interest rates i_t. As the NFA declines due to greater import prices, however, foreign intermediaries require even higher domestic interest rates i_t, captured by a more positive UIP deviation $-\Gamma \text{nfa}_t$. This amplifies the exchange rate depreciation and ultimately worsens the contractionary effects of the depreciation. Thus, endogenous UIP deviations amplify contractionary depreciations, especially in countries with high Γ. This presents another reason why interest rates may be procyclical in open economies, especially in emerging markets prone to having greater UIP deviations (higher Γ).

6 Conclusion

We introduce heterogeneous households into an otherwise standard New-Keynesian open economy model. Our model matches both the size and the heterogeneity in MPCs observed empirically. We show that this is critical to understand the effects of capital flows and monetary policy. Depreciations due to sudden capital outflows raise the prices of imported goods, leading high-MPC households to cut back on spending significantly. This in turn causes a decline in aggregate consumption, resolving the Backus-Smith puzzle. When, in addition, expenditure switching is small or delayed, this real income channel can be sufficiently strong to cause a short-run contraction in output. These effects are also active when the depreciation is due to domestic monetary easing. They weaken the expansionary effects of monetary policy, and cause it to "steal demand from the future".

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