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Consumption heterogeneity and monetary policy in an open economy[☆]

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ABSTRACT

We incorporate two types of agents (Ricardian versus Keynesian) into a standard open economy macro model. We find that consumption heterogeneity has major implications for the impact of monetary policy shocks, the international transmission mechanism, and the design of optimal monetary policy. With sticky prices, the existence of Keynesian agents causes a spillover of shocks across countries, and leads to the interdependence of optimal monetary targeting rules. In the case of local currency pricing, consumer heterogeneity leads an optimal monetary policy to generate currency misalignment and deviations from the law of one price. Theoretically, there are ranges of household heterogeneity in which monetary policy becomes ineffective, but this depends sensitively on the interaction of aggregate demand and relative price effects.

1. Introduction

This paper studies the positive and normative effects of monetary policy in an open economy model in the presence of within-country heterogeneity. Using a baseline open economy framework as in [Clarida et al. \(2002\)](#) or [Engel \(2011\)](#), we show that consumer heterogeneity has important consequences for the impacts of monetary policy shocks, the spillovers of monetary policy, and the design of the optimal monetary policy.

Our paper is motivated by observations on income inequality and heterogeneous financial inclusion across the world. Over the last few decades, income inequality has increased in many countries. For example, the US Census Bureau reports that the Gini coefficient in the United States was 0.49 in 2021, rising from 0.4 in 1980. Likewise, according to the World Inequality Database, the share of the top 1 percent of US income earners went from 10 percent in 1980 to 19 percent in 2021. Similar trends have been seen in other OECD countries.¹ While World Bank (2022) estimates of the share of the population of who saved in high-income countries rose from 70 to 76 percent between 2011 and 2021, it still suggests that a substantial minority of the population is effectively ‘hand to mouth’ households

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¹ Data for Canada and the UK indicate a rise from 9 to 14 percent and 10 to 14 percent over a similar period. For France and Italy, the rise was more modest, moving from around 7 to 10 percent. See <https://wid.world/data/>.

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(see also [Kaplan et al., 2014](#)).

Our model is a version of a Two-Agent New Keynesian model (TANK) as in [Debortili and Gali \(2018\)](#). We allow for two types of households, namely, “Ricardian” and “Keynesian”. Ricardian consumers can smooth consumption over time by borrowing and lending freely in financial markets, as in the standard New Keynesian model and have full ability to engage in international financial risk-sharing. Keynesian consumers however are hand-to-mouth agents who can only consume their disposable labor income every period.

While the TANK model lacks some of the detailed heterogeneity features in the recent Heterogeneous Agent New Keynesian (HANK) literature,² an advantage is that it allows for a simple analytical exploration of the interaction of consumer heterogeneity with monetary policy, a clear illustration of how heterogeneity affects the international transmission of monetary policy shocks, and an exact analytical description of the optimal monetary policy in the presence of heterogeneity.

One central ingredient of our model is the interrelationship between measures of the output gap and consumer heterogeneity. In the absence of price stickiness, heterogeneity in our model is irrelevant.³

A rise in the output gap implies that Keynesian households consume more than Ricardian households. But with fully flexible prices, the output gap is closed, and therefore there is no consumption heterogeneity in the efficient flexible price equilibrium.

With sticky prices, monetary shocks will open an output gap, which leads to heterogeneous consumption responses both within and across countries. In our baseline, assuming producer currency pricing (PCP), monetary shocks operate through aggregate consumption (expenditure changing) effects and terms of trade (expenditure switching) effects. But the strength of these effects is dependent on the degree of consumer heterogeneity. Up to a critical threshold, the aggregate impact of monetary policy shocks is increasing in the fraction of Keynesian households in a given country. In this region, an interest rate cut stimulates the consumption of Ricardian households, but there is a magnified effect on the consumption of Keynesian households, leading to a larger impact on the output gap.

If the share of Keynesian agents is large enough, our model implies that there is the possibility of perverse effects of monetary policy, implying that expansionary monetary policy would lead to a fall in the country’s output gap. This is similar to the ‘inverted aggregate demand’ effect described by [Bilbiie \(2008\)](#). But in the open economy, we find the region of inverted aggregate demand is reduced by the presence of terms of trade adjustment.

Consumer heterogeneity has an important implication for the cross-country spillovers of monetary policy shocks. In our baseline model, there are no spillover effects at all in the absence of Keynesian consumers. While an interest rate cut has an expenditure changing effect - directly increasing spending on foreign goods, this is exactly offset by the expenditure switching effects of an appreciation of the foreign currency. But with consumer heterogeneity, monetary policy shocks have positive spillover effects. This is because heterogeneity leads to a magnification of the direct spending (expenditure changing) effects due to the high marginal propensity to consume of Keynesian consumers, but it leaves the terms of trade response (expenditure switching) unchanged, relative to the model without heterogeneity. Thus consumer heterogeneity acts so as to propagate monetary policy shocks across borders, and the overall effects depend on heterogeneity in both the source and receiving countries. But crucially, international transmission requires consumer heterogeneity in the source country.

We extend the analysis to that of a small economy. Without heterogeneity, this would not affect the results at all - economic size is irrelevant to the results, and there would be no spillover effects of policy shocks to or from the small economy. With heterogeneity, the effects of monetary shocks in the small economy are smaller than in the symmetric two-country model, and the effects of shocks in the rest of the world are larger, so long as there is consumer heterogeneity in the outside world economy.⁴

The implications for optimal monetary policy depend on the composition of shocks. Assuming only productivity shocks a monetary rule which stabilizes the PPI in each country ensures that the output gap is closed, and full risk sharing within and across countries is achieved simultaneously. But when we extend the model to allow for cost-push shocks, consumer heterogeneity plays a key role in optimal policy design. With Keynesian consumers, due to inefficient risk sharing across countries, optimal targeting rules are interdependent, and a domestic inflationary shock is transmitted to foreign inflation and output gaps.

The analysis easily extends to the alternative of local currency pricing (LCP). But with LCP, there is always a cross country spillover of monetary policy shocks, even in the absence of Keynesian consumers. But again, the spillover is magnified in the presence of consumer heterogeneity.

The presence of Keynesian consumers also affects the optimal monetary policy under LCP. When all consumers are Ricardian, optimal monetary policy rule under LCP should stabilize the CPI, and to eliminate any currency misalignment (or deviations from the law of one price), as in [Engel \(2011\)](#). But with Keynesian consumers, due to the absence of within and across country risk-sharing, an optimal monetary policy allows for currency misalignment following a country-specific productivity shock. In response to a home country productivity shock, an optimal rule allows for a real exchange rate depreciation in the home country to stimulate higher consumption of Keynesian consumers.

1.1. Related literature

Here we mention briefly some related literature. A more complete literature survey is presented in Section 11 of the online

² See, for example, [Kaplan et al. \(2018\)](#).

³ The consumption heterogeneity in this paper means the heterogeneity in consumption response, rather than in the level of consumption.

⁴ The small-open economy setup mutes the spillovers from the small to the large economy and this is what drives the difference relative to the large-open economies model.

Technical Appendix. Our paper is closely related to three strands of literature. The first is the work on new Keynesian open-economy macroeconomic models. Two papers are considered as benchmarks for comparison [Clarida et al. \(2002\)](#), hereafter CGG develops the canonical model for open-economy monetary policy analysis in a Keynesian framework. They show that if price setting is based on PCP, the central bank should target producer inflation (PPi). [Engel \(2011\)](#) examines optimal monetary policy under LCP and shows that to eliminate currency misalignment, an optimal policy requires CPI targeting.

The second relevant literature is the Heterogeneous Agent New Keynesian (HANK) literature, which allows for endogenous time varying wealth distributions (e.g. [Kaplan et al., 2018](#)). [Debortili and Gali \(2018\)](#) and [Bilbiie \(2008\)](#) develop simpler models based on two type of agents with differential access to financial markets, namely the Two Agents New Keynesian (TANK).

The study of the heterogeneous agent model in an open economy is still relatively new. This literature is fast-growing and here we only highlight a few of them.⁵ [Auclert et al. \(2021\)](#) find that heterogeneity amplifies the real income channel of exchange rates. [de Ferra et al. \(2020\)](#) study the role of heterogeneity in an economy that experiences a current account reversal. [Guo et al. \(2022\)](#) explore the distributional consequences of sudden stops. [Oskolkov \(2022\)](#) studies the role of exchange rate regimes in shaping the distributional effects of monetary shocks.

These papers, however, are based on a small open economy model, and do not explicitly investigate the role of heterogeneity in the optimal monetary problem in such a setting. In contrast, our paper is concerned with a third strand of literature focusing on optimal monetary policy in a multi-country setting, such as that of [Corsetti et al. \(2010\)](#).

The rest of the paper is organized as follows. [Section 2](#) lays out the basic model and defines an equilibrium. [Section 3](#) analyzes the transmission of monetary shocks under PCP with alternative assumptions about consumer heterogeneity. [Section 4](#) derives an optimal policy under PCP. [Section 5](#) examines the case of LCP strategy in the presence of consumer heterogeneity. Conclusions are in [Section 6](#).

2. A two-country model with household heterogeneity

The benchmark model extends the existing New Open Economy Macroeconomics (NOEM) literature by introducing household heterogeneity. The baseline model is similar to the classic CGG two-country model, which assumes producer currency pricing. The only difference is that we model two types of agents in each country. Following [Bilbiie \(2008\)](#) and [Debortili and Gali \(2018\)](#), we adopt a Two-Agent New Keynesian (TANK) model.

2.1. Household

There is a continuum of households in the home country $[0,1]$, all having the same utility function. A constant measure $1 - n$ of households is labeled Ricardian and has unconstrained access to financial markets, while measure n , referred to as Keynesian, just consume their labor income and lump-sum transfers each period.

Let $s \in \{R, K\}$ specify the household type (Ricardian and Keynesian). Utility is

$$E \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t^s) - \eta \frac{(L_t^s)^{1+\omega}}{1+\omega} \right] \quad (1)$$

where $C_t^s = [C_{ht}^s]^\nu [C_{ft}^s]^{1-\nu}$ is the aggregate consumption of home and foreign goods with home bias $\nu \geq 1$, which is assumed to be identical in both types of agent.⁶ This implies that $P_t^s = P_t$, so the consumption price index is identical for both types of households. So we omit the superscript “R” or “K” for the price variables.

2.1.1. Ricardian households

Ricardian households have access to both state-contingent bonds in the domestic market and foreign market. They are also equity holders who claim the ownership of firms. Their period budget constraint is

$$\begin{aligned} P_t^R C_t^R + B_{t+1} + Q_t^e B_t^e + \sum_{\zeta^{t+1} \in Z_{t+1}} Q(\zeta^{t+1} | \zeta^t) D_{hh}(\zeta^{t+1}) + S_t \sum_{\zeta^{t+1} \in Z_{t+1}} Q^*(\zeta^{t+1} | \zeta^t) D_{hf}^*(\zeta^{t+1}) \\ = W_t L_t^R + (1 + i_{t-1}) B_t + (D_t^e + Q_t^e) B_{t-1}^e + D_{hh}(\zeta^t) + S_t D_{hf}^*(\zeta^t) \end{aligned} \quad (2)$$

where B_{t+1} and B_t^e are the holdings of domestic non-state-contingent bonds and equity. Q_t^e and D_t^e are the price and dividend of the equity. i_{t-1} is the domestic bond’s nominal interest rate. S_t is the nominal exchange rate, defined as the price of 1 unit of foreign currency in terms of domestic currency. $D_{hh}(\zeta^{t+1})$ and $D_{hf}^*(\zeta^{t+1})$ are home’s holding of the state-contingent domestic and foreign securities. Here we are assuming complete international financial markets for Ricardian agents. L_t^R is the labor supplied by the Ricardian household and $W_t L_t^R$ is wage income.

Let Λ_t represent the Lagrangian multiplier associated with the flow budget constraint, then the stochastic discount factor between t

⁵ For example, see [Prasad and Zhang \(2015\)](#), [Cugat \(2019\)](#), [Hong \(2020\)](#), and [Zhou \(2022\)](#).

⁶ The case of asymmetric home bias is explored in Technical Appendix Section 8.

and $t + i$ is $\tilde{\Lambda}_{t,t+i} = \beta^i \frac{\Lambda_{t+i}}{\Lambda_t} = \beta \left(\frac{C_t^R}{C_{t+i}^R} \right)^{-1} \frac{P_t}{P_{t+i}}$. From the first order conditions of the Ricardian households,⁷ we have: $\frac{1}{1+i_t} = E_t \tilde{\Lambda}_{t,t+1}$ and $W_t \frac{1}{C_t^R P_t} = \eta (L_t^R)^\omega$. In equilibrium, we also have the risk-sharing condition as follows: $\frac{C_t^R}{C_t^*} = e_t$, where $e_t = \frac{S_t P_t^*}{P_t}$ is the real exchange rate, C_t^{R*} and P_t^* represent the consumption and price level of foreign Ricardian households.

2.1.2. Keynesian households

Keynesian households simply consume their labor income each period. The budget constraint is $P_t C_t^K = W_t L_t^K$, where C_t^K and L_t^K denote consumption and labor supply for Keynesian households. We abstract away from idiosyncratic shocks as in Bilbiie (2008) and Debortili and Gali (2018). Optimal labor supply by Keynesian households is given by $W_t \frac{1}{C_t^K P_t} = \eta (L_t^K)^\omega$. Using the budget constraint and optimal labor supply, we can solve for Keynesian household's labor supply $L_t^K = \eta^{-\frac{1}{1+\omega}}$, showing that Keynesian households have constant labor supply given the form of preferences assumed in (1).

2.1.3. Demand for goods

Given the aggregate consumption $C_t^s = [C_{ht}^s]^{\frac{v}{2}} [C_{ft}^s]^{1-\frac{v}{2}}$, the demand for the home and Foreign good is

$$C_{ht}^s = \frac{v}{2} \frac{P_t C_t^s}{P_{hh}}, \quad C_{ft}^s = \left(1 - \frac{v}{2}\right) \frac{P_t C_t^s}{P_{fh}} \quad (3)$$

where $P_t = \bar{\Theta} [P_{hh}]^{\frac{v}{2}} [P_{fh}]^{1-\frac{v}{2}}$, and P_{hh} and P_{fh} are the prices of domestic and foreign goods sold in the Home market, respectively. $\bar{\Theta} \equiv \left(\frac{v}{2}\right)^{\frac{v}{2}} \left(1 - \frac{v}{2}\right)^{1-\frac{v}{2}}$ is a constant. Given the demand structure $C_{ht}^s = \left[\int_0^1 C_{ht}^s(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$ and $C_{ft}^s = \left[\int_0^1 C_{ft}^s(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$, we solve for the demand for varieties, which are reported in Technical Appendix Section 1.2.

2.1.4. Consumption heterogeneity

Aggregate consumption is $C_t = (1-n)C_t^R + nC_t^K$. We define the index of heterogeneity between the Ricardian and Keynesian households, $H_t \equiv \frac{C_t^R}{C_t} = \left(1 - n + n \frac{C_t^K}{C_t^R}\right)^{-1}$. When $C_t^R = C_t^K$, $H_t = 1$, there is no consumption heterogeneity.

With this, we can rewrite the Euler equation of Ricardian households and the risk-sharing condition in terms of aggregate consumption.

$$\frac{1}{1+i_t} = \beta E_t \left(\frac{C_{t+1}^R}{C_t^R} \right)^{-1} \frac{P_t}{P_{t+1}} = \beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-1} \left(\frac{H_{t+1}}{H_t} \right)^{-1} \frac{P_t}{P_{t+1}} \quad (4)$$

$$\frac{(C_t H_t)^{-1}}{P_t} = \frac{(C_t^* H_t^*)^{-1}}{S_t P_t^*} \quad (5)$$

2.2. Firms, price setting, and equilibrium

Each firm i in the home economy has the production technology, $Y_t(i) = Z_t L_t(i)$, where $Z_t = \exp(\theta_t)$ is a country-specific productivity shock, and θ_t is distributed with mean zero and variance σ_θ^2 .

Firms adjust prices following a standard Calvo mechanism. In the home country, a firm may reset its prices with probability $1 - \kappa$ each period. In the baseline analysis, we limit discussion to a producer currency pricing (PCP) strategy. The optimization problem of firms is standard and is defined in Technical Appendix Section 1.1.1.

The terms of trade is defined as the relative price of foreign to home goods $Q_t = \frac{S_t P_t^*}{P_{hh}}$.

The goods market clearing condition for the home good is:

$$Y_t = \frac{v}{2} \frac{P_t C_t}{P_{hh}} \Delta_{hh,t} + \left(1 - \frac{v}{2}\right) \frac{P_t^* C_t^*}{P_{fh}^*} \Delta_{hf,t}^* \quad (6)$$

where $\Delta_{hh,t} = \int \left(\frac{P_{hh}(i)}{P_{hh}} \right)^{-\epsilon} di$ and $\Delta_{hf,t}^* = \int \left(\frac{P_{fh}^*(i)}{P_{fh}^*} \right)^{-\epsilon} di$ are price dispersion terms.

The labor market clearing condition of home is:

$$L_t = (1-n)L_t^R + nL_t^K \quad (7)$$

Markets for domestic non state-contingent bonds, state-contingent bonds, and equities are cleared in the model. Details are given in the Technical Appendix Section 1.2. Monetary authorities use a nominal interest rate as the policy instrument. The policy rule will be specified below.

⁷ First-order conditions with respect to equity are reported in the Technical Appendix Section 1.2.

Definition. Given the stochastic process of the productivity shocks and monetary policy rules and monetary shocks, an equilibrium is characterized by a sequence of consumptions, hours worked, bond holdings, equity holdings, securities holdings, $\{C_t^R, C_t^{*R}, L_t^R, L_t^{*R}, C_t^{*K}, C_t^K, L_t^K, L_t^{*K}, B_t, B_t^*, B_t^e, B_t^{*e}, D_{hht}, D_{hft}^*, D_{fft}^*, D_{fht}\}$, and goods prices, exchange rate, interest rates, equity prices, and securities prices $\{P_{h,t}, P_{f,t}^*, S_t, i_t, i_t^*, Q_t, Q_t^*, Q(\zeta^{t+1}|\zeta^t), Q^*(\zeta^{t+1}|\zeta^t)\}$, such that: (a) Ricardian households optimally choose consumption, state-contingent assets, domestic non-state-contingent bonds, equity and labor supply; (b) Keynesian households optimally choose consumption and labor supply; (c) Firms set their prices to maximize profits; (d) Home and Foreign goods markets, labor markets, and financial markets all clear.

3. Transmission mechanism of monetary shocks

3.1. The flexible price equilibrium

To highlight the role of monetary policy, we first illustrate the flexible price equilibrium where money is neutral. Since there is no monopoly distortion in the model,⁸ the flexible price allocation is efficient if it can assure full risk-sharing between Keynesian and Ricardian consumers.

We normalize the wage, marginal cost, prices and dividend by the CPI price level in the relevant country. The normalized variables are labeled as lower case letters. That is, $w_t = \frac{W_t}{P_t}, mc_t = \frac{MC_t}{P_t}, p_{hht} = \frac{P_{hht}}{P_t}$, and $d_t^e = \frac{D_t^e}{P_t}$. In our notation, variables with hat refer to the deviation of the log of corresponding variables from steady state, and variables with a superscript “fb” are defined as variables in flexible price equilibrium. The solution to the flexible price equilibrium is summarized in Proposition 1.

Proposition 1. *With household heterogeneity ($n > 0, n^* > 0$), the solution to the flexible price equilibrium is identical to the efficient equilibrium in the standard New Keynesian open macro model (i.e., CGG).*

$$\begin{aligned} \hat{H}_t^{fb} &= \hat{H}_t^{fb,*} = 0, & \hat{q}_t^{fb} &= (\theta_t - \theta_t^*), & \hat{Y}_t^{fb} &= \theta_t, & \hat{Y}_t^{fb*} &= \theta_t^* \\ \hat{C}_t^{fb} &= \hat{C}_t^{R,fb} = \hat{C}_t^{K,fb} = \frac{v}{2}\theta_t + \frac{2-v}{2}\theta_t^*, & \hat{C}_t^{*,fb} &= \hat{C}_t^{R*,fb} = \hat{C}_t^{K*,fb} = \frac{v}{2}\theta_t^* + \frac{2-v}{2}\theta_t \end{aligned}$$

The proof is presented in the Technical Appendix Section 1.4. The proposition says that if prices are fully flexible, given the model specification as described, heterogeneity is irrelevant. The intuition comes from the fact that heterogeneity in consumption across groups is tied to heterogeneity in labor supply since both groups receive the same real wage in each country. We have shown that labor supply for the Keynesian consumers is constant, given their hand-to-mouth status. But in the flexible price equilibrium driven only by productivity shocks, the same outcome applies to Ricardian consumers. We can show this as follows. First, guess that $L_t^R = L_t^K$ so that equilibrium labor supply is equal across groups. Then from the risk-sharing condition for Ricardian consumers and the goods market equilibrium conditions, the terms of trade in the flexible price economy is simply proportional to relative output levels, $Q_t = \frac{S_t P_{f,t}^*}{P_{h,t}} = \frac{Z_t L_t^*}{Z_t^* L_t^*}$. Given this, consumption of Ricardian agents is given by $C_t^R = \bar{\Theta} (Z_t L_t^*)^{\frac{v}{2}} (Z_t^* L_t^*)^{1-\frac{v}{2}}$.

Then since prices are fully flexible, the home firm’s price is equal to marginal cost, which, by the labor supply condition of Ricardian agents gives us $P_{h,t} = \frac{W_t}{Z_t} = \eta \frac{P_t C_t^R L_t^{R\omega}}{Z_t}$. Using then the definition of the Home country CPI, we get

$$\left(\frac{P_{h,t}}{S_t P_{f,t}^*} \right)^{1-\frac{v}{2}} \bar{\Theta} = \left(\frac{Z_t^* L_t^*}{Z_t L_t} \right)^{1-\frac{v}{2}} \bar{\Theta} = \eta \frac{C_t^R L_t^{R\omega}}{Z_t}$$

Substituting in for C_t^R above, we arrive at Ricardian labor supply equal to $L_t^R = \eta^{\frac{1}{1-\omega}}$, identical to Keynesian agent’s labor supply, confirming the guess. But then Keynesian and Ricardian agents have identical consumption levels, which achieves full cross-country risk-sharing. Hence, given the form of preferences, technology, and productivity shocks, the flexible price economy has no equilibrium heterogeneity in consumption. For both Keynesian and Ricardian agents, with flexible prices, productivity shocks lead to changes in real wages and the terms of trade such that substitution and income effects exactly cancel out and labor supply is constant in equilibrium. Moreover, since the endogenous terms of trade in the flexible price economy achieves full risk sharing, there is no need for Ricardian agents to use international capital markets. In equilibrium they consume current income just the same as Keynesian agents.

When prices are sticky however, labor supply of Ricardian and Keynesian agents will differ. In the model, the heterogeneity of Ricardian to Keynesian consumption depends critically on their difference in labor supplies, which is negatively related to the country’s output gap. In particular, using labor supply equations for both Ricardian and Keynesian households, Eq. (7), and the analogous conditions for the foreign country, we can show

$$\hat{H}_t = \frac{-n\omega}{1-n} (\hat{Y}_t - \theta_t), \tag{8}$$

⁸ The markup is eliminated by constant production subsidy and the dividend is zero in the flexible price equilibrium, so households are indifferent as to their asset holdings.

$$\widehat{H}_t^* = \frac{-n^* \omega}{1-n^*} (\widehat{Y}_t - \theta_t^*) \quad (9)$$

An increase in the output gap in either country must be associated with a rise in the relative consumption of Keynesian households. A rise in the output gap $\widehat{Y}_t - \theta_t$ means an increase in hours worked for Ricardian households, this implies a lower consumption response than Keynesian households, whose labor supply is constant. But in the flexible price equilibrium, as we have just shown, labor supply of Ricardian households is also constant, due to exactly offsetting income and substitution effects, so that consumption responses are identical for both households.

We note that conditions (8) and (9) are derived from the household side, independent of the firm's pricing policy, whether prices are sticky or not. The only difference is that the right hand side is zero in the fully flexible price case.

3.2. Monetary policy shocks and spillovers under PCP

We now discuss the PCP case with sticky prices. To highlight the key mechanisms that channel consumer heterogeneity, we first focus on a symmetric case where $n = n^*$, and assume symmetric preferences without home bias (so that $\nu = 1$).

Without home bias, under PCP, purchasing power parity holds, so that the real exchange rate is constant, i.e. $\widehat{e}_t = 0$, and the risk-sharing condition implies that Ricardian households have equal consumption responses; $\widehat{C}_t^R = \widehat{C}_t^{*,R}$. Then goods market clearing conditions in the home and foreign countries can be rewritten as:

$$\widehat{Y}_t = \widehat{C}_t + \frac{1}{2} (\widehat{q}_t + \widehat{H}_t - \widehat{H}_t^*) = \widehat{C}_t^R - \widehat{H}_t + \frac{1}{2} (\widehat{q}_t + \widehat{H}_t - \widehat{H}_t^*) \quad (10)$$

$$\widehat{Y}_t^* = \widehat{C}_t^* - \frac{1}{2} (\widehat{q}_t + \widehat{H}_t - \widehat{H}_t^*) = \widehat{C}_t^{*,R} - \widehat{H}_t^* - \frac{1}{2} (\widehat{q}_t + \widehat{H}_t - \widehat{H}_t^*) \quad (11)$$

Eqs. (10) and (11) indicate that home and foreign GDP are driven by changes in demand by Ricardian households, changes in the terms of trade, and changes in consumption heterogeneity among home and foreign consumers. Holding constant the terms of trade and Ricardian consumption, a rise in Keynesian consumption in either country (a fall in \widehat{H}_t or \widehat{H}_t^*), will raise demand in both countries. But by (8) and (9), \widehat{H}_t and \widehat{H}_t^* are themselves driven directly by changes in the output gap. For a positive monetary shock (an interest rate cut) that raises demand, Eqs. (10) and (11) then illustrate how for a given relative price response the presence of Keynesian consumers leads to a magnification of the aggregate spending effects of the shock, and enhances the spillovers across borders.

Eqs. (10) and (11) together yield $\widehat{q}_t = \widehat{Y}_t - \widehat{Y}_t^*$, which implies that the terms of trade under PCP is simply determined by relative output levels. The terms of trade does not directly depend on the presence of consumer heterogeneity. This feature of the model is important for understanding how heterogeneity leads to cross country spillovers. Moreover, this property continues to hold even in the case of home bias in consumption, as shown in the Technical Appendix Section 2.1.3.

Following CGG, we define the PPI-based real interest rates in the home and foreign countries as $\widehat{r}_t = \widehat{i}_t - E_t \pi_{hh,t+1}$ and $\widehat{r}_t^* = \widehat{i}_t^* - E_t \pi_{ff,t+1}^*$. Then taking a log linearization of Ricardian household's Euler equation, we obtain the home country Euler equation:⁹

$$\widehat{C}_t^R = E_t (\widehat{C}_{t+1}^R) - \left[\widehat{r}_t - \frac{1}{2} E_t \Delta \widehat{q}_{t+1} \right] \quad (12)$$

where we define $\Delta x_t = x_t - x_{t-1}$ as the first difference of a variable x_t .

Using (12), (10) and (11), along with the two equations of consumption heterogeneity (8) and (9) we get the following intuitive characterization for the dynamics of home and foreign output in terms of real interest rate and productivity shocks.

$$\widehat{Y}_t = E_t \widehat{Y}_{t+1} - \frac{1+\delta}{2\delta} \widehat{r}_t - \frac{1-\delta}{2\delta} \widehat{r}_t^* + \frac{1-\delta}{2\delta} (E_t \Delta \theta_{t+1} + E_t \Delta \theta_{t+1}^*) \quad (13)$$

$$\widehat{Y}_t^* = E_t \widehat{Y}_{t+1}^* - \frac{1+\delta}{2\delta} \widehat{r}_t^* - \frac{1-\delta}{2\delta} \widehat{r}_t + \frac{1-\delta}{2\delta} (E_t \Delta \theta_{t+1} + E_t \Delta \theta_{t+1}^*) \quad (14)$$

where $\delta = 1 - \frac{n\omega}{1-n}$ is a term controlling the degree of household heterogeneity, with $\delta = 1$ representing a fully Ricardian economy, and δ falls as the measure of Keynesian consumers rises. Moreover, $\delta < 0$ for $n > \frac{1}{1+\omega}$.

From the Euler equation in the flexible price equilibrium, we define the domestic natural interest rate as: $\widehat{r}_t^{fb} = E_t (\widehat{Y}_{t+1}^{fb}) - \widehat{Y}_t^{fb} = E_t \Delta \theta_{t+1}$. Therefore, we can rewrite (13) and (14) in terms of deviations from the flexible price equilibrium:

⁹ The dynamics of CPI inflation and PPI inflation are determined by

$$\pi_t = \pi_{hh,t} + \frac{1}{2} \Delta \widehat{q}_t; \quad \pi_t^* = \pi_{ff,t}^* - \frac{1}{2} \Delta \widehat{q}_t$$

$$\widehat{Y}_t - \widehat{Y}_t^{fb} = E_t(\widehat{Y}_{t+1} - \widehat{Y}_{t+1}^{fb}) - \frac{1+\delta}{2\delta}(\widehat{r}_t - \widehat{r}_t^{fb}) - \frac{1-\delta}{2\delta}(\widehat{r}_t^* - \widehat{r}_t^{*fb}) \quad (15)$$

$$\widehat{Y}_t^* - \widehat{Y}_t^{fb*} = E_t(\widehat{Y}_{t+1}^* - \widehat{Y}_{t+1}^{fb*}) - \frac{1+\delta}{2\delta}(\widehat{r}_t^* - \widehat{r}_t^{*fb}) - \frac{1-\delta}{2\delta}(\widehat{r}_t - \widehat{r}_t^{fb}) \quad (16)$$

In order to highlight the role of heterogeneity in the response to money shocks, we abstract away from dynamics by assuming the monetary authorities in both countries follow a rule whereby the expected PPI based real interest rate is constant (a similar assumption is made in Auclert et al., 2021, and in a closed economy context by Woodford, 2011). Thus, we assume that the real interest rates equal their natural rate plus a monetary shock. $\widehat{r}_t = E_t \pi_{hh,t+1} + u_t + \widehat{r}_t^{fb}$, $\widehat{r}_t^* = E_t \pi_{ff,t+1}^* + u_t^* + \widehat{r}_t^{*fb}$ where monetary shocks u_t, u_t^* are i.i.d. This assumption ensures that the expected effects of monetary policy are purely transitory, and the expected real interest rate is constant. We can then solve for the equilibrium allocations under PCP as follows:

$$\begin{aligned} \widehat{Y}_t - \widehat{Y}_t^{fb} &= -\frac{1+\delta}{2\delta}u_t - \frac{1-\delta}{2\delta}u_t^*, & \widehat{Y}_t^* - \widehat{Y}_t^{fb*} &= -\frac{1+\delta}{2\delta}u_t^* - \frac{1-\delta}{2\delta}u_t \\ \widehat{q}_t &= \widehat{Y}_t - \widehat{Y}_t^* = \widehat{Y}_t^{fb} - \widehat{Y}_t^{fb*} + u_t^* - u_t \\ \widehat{C}_t^R &= \widehat{C}_t^{R*} = -\frac{1}{2}(u_t + u_t^*) + \frac{1}{2}E_t(\widehat{Y}_t^{fb} + \widehat{Y}_t^{fb*}) \end{aligned} \quad (17)$$

We first summarize these results in the following proposition, and then provide an intuitive discussion.

Proposition 2. a) For $\delta = 1$, a domestic monetary expansion (interest rate cut) increases the output gap one for one, and has zero spillover effects on the foreign output gap.

b) For $1 > \delta > 0$, a domestic monetary expansion increases the output gap by more than one for one, and has a positive spillover to the foreign output gap.

c) For $0 > \delta > -1$, a domestic monetary expansion has a negative effect on the domestic and foreign output gaps.

d) When $-1 > \delta$, a domestic monetary expansion raises the domestic output gap, but reduces the foreign output gap.

Proof: See Eq. (17), which is derived in Technical Appendix Section 2.1.2.

We first discuss cases a) and b) of the Proposition, which we argue below is the presumptive case. The key intuition is that the presence of Keynesian consumers increases the demand effects of an interest rate cut (the expenditure changing effect), but has no effect on the terms of trade (the expenditure switching) response. In the model without consumer heterogeneity, an interest rate cut increases the home and foreign country consumption one for one, as there is full risk sharing and all agents are Ricardian. At the same time, the home terms of trade deteriorates, which leads to an expenditure switching away from foreign goods and towards home goods. Then without heterogeneity the combination of the positive demand effect and the negative relative price effect exactly cancels out for the foreign country, leaving the foreign output gap unchanged.¹⁰

In the model with Keynesian consumers, there is a magnification effect on aggregate demand, as the rise in the output gap following the interest rate cut leads (through conditions (8) and (9)) to a more than proportional rise in the consumption of Keynesian agents. This raises the home output gap by more than proportionately, but also spills over into higher demand for the foreign good, leading to a further magnification effect. But since the response of the terms of trade is the same as in the full Ricardian model, the demand effect (expenditure changing) exceeds the relative price effect (expenditure switching) and the foreign output gap rises. This leads to a second round effect on home demand, as a ‘spillback’ term, and the final outcome is that both home and foreign output rise by more than in the model without heterogeneity.

A clear illustration of the magnification of the expenditure changing effect of consumer heterogeneity is provided in the above Eqs. (10) and (11). These equations can be rewritten more succinctly in the following way (assuming no productivity shocks)

$$\widehat{Y}_t = \frac{1}{\delta}\widehat{C}_t^R + \frac{1}{2}\widehat{q}_t = \frac{\frac{1-n}{1+\omega}}{\frac{1}{1+\omega}-n}\widehat{C}_t^R + \frac{1}{2}\widehat{q}_t \quad (18)$$

$$\widehat{Y}_t^* = \frac{1}{\delta}\widehat{C}_t^{R*} - \frac{1}{2}\widehat{q}_t = \frac{\frac{1-n}{1+\omega}}{\frac{1}{1+\omega}-n}\widehat{C}_t^{R*} - \frac{1}{2}\widehat{q}_t \quad (19)$$

The first term on the right hand side of (18) relates to the aggregate consumption, or expenditure changing effect. As shown in the equilibrium solution, both \widehat{C}_t^R and the terms of trade \widehat{q}_t are independent of consumer heterogeneity and increase in response to a domestic interest rate cut. Specifically, if we assume no productivity shocks or foreign monetary shocks, we have $\widehat{C}_t^{R*} = \widehat{C}_t^R = -\frac{\mu}{2}$ and $\widehat{q}_t = -\mu_t$. The term $0 < \delta < 1$ thus imposes a magnification effect on home output. That is, the response of output is amplified by the presence of Keynesian consumers ($0 < n < \frac{1}{1+\omega}$). Likewise, Eq. (19) is written in the same way, but the terms of trade effect is negative.

¹⁰ We note that the absence of spillover effects of monetary policy shocks in the model without heterogeneity is a special property of the baseline model, arising due to the unit elasticity of substitution between home and foreign goods, and unit inter-temporal elasticity of substitution in consumption. We maintain this assumption in the baseline model so as to more clearly emphasize the special role of consumption heterogeneity in monetary spillovers.

When $0 < \delta < 1$, the spillovers to foreign output must be positive.

Cases c) and d) of the proposition are associated with a feature of the TANK model first highlighted by Bilbiie (2008) whereby if the share of Keynesian agents rises above a threshold, there is no finite equilibrium in which a cut in interest rates can raise output, since the second round demand effects from Keynesian agents will always exceed the first round output gap. Bilbiie (2008) identifies this as a situation of ‘inverted aggregate demand’, and technically, it implies an interest rate cut should reduce both home and foreign output when $0 > \delta > -1$ (case c). From Eq. (18), the first term is negative and would dominate the positive terms of trade effect. By contrast, under case d), where $-1 > \delta$ the interest rate cut should raise home output, but have a negative spillover to foreign output. In this case, the (negative) impact on consumption demand from (18) is offset by the positive impact from the terms of trade deterioration, and since the terms of trade deterioration reduces foreign demand, the foreign output gap falls.

Section 3 of Technical Appendix discusses the case c) and d) of the Proposition in further detail, and provides a graphical illustration of the determination of the output gap in the two countries in cases a-d). But we also show that cases c) and d) are likely to exhibit indeterminacy of equilibrium under a standard monetary policy rule. Moreover, we argue that these cases rely on empirically implausible values for the share of Keynesian agents in the economy. In particular, for an expansionary monetary policy to have a contractionary effect, the share of Keynesian consumers should range from $\frac{1}{\omega+1}$ to $\frac{1}{\frac{\omega}{2}+1}$. The value for ω , the inverse elasticity of labour supply, is usually set at unity. In this case, the range for perverse effects of monetary policy is from 0.5 to 0.67. The consensus in the literature suggests that the share of Keynesian households in the economy is much less than 0.5.¹¹ Thus, we view the possibility of an inverse relationship between monetary expansion and aggregate demand in the open economy model as of limited empirical relevance. As a result, in what follows we discuss only the results where $\delta > 0$, and the extension of this condition to the case of differences in country heterogeneity.

The analysis can be easily extended to allow for asymmetric household heterogeneity, where $n \neq n^*$. In Technical Appendix Section 2.1.1, we show that for $n < \frac{1}{1+\omega}$ and $n < \frac{1}{1+\omega}$ that the response of output and the spillover effects of an interest rate cut is increasing in the share of Keynesian households in both countries, but what is crucial is the presence of Keynesian households in the source country. Absent Keynesian households in the source country, there are no magnification effects resulting from the source country monetary shocks, and no spillovers to the other country.

3.3. Country size and spillovers

Some recent papers analyzing heterogeneous agent open economy models focus on small open economies (see e.g. Auclert et al., 2021; Guo et al., 2022). In this subsection, we allow asymmetries in country size in the two-country model setting. Due to the heterogeneity in size, it is also of interest to allow for differences in heterogeneity across countries, so we allow for $n \neq n^*$. We normalize the foreign country size (population) as 1 and denote $0 \leq \kappa \leq 1$ as home’s country size relative to foreign’s. Following Sutherland (2005) and De Paoli (2009), the consumption aggregators in both the home and foreign countries are given by

$$C_t^s = [C_{ht}^s]^{\frac{1}{2}} [C_{ft}^s]^{\frac{1}{2}}, \quad C_t^{s,*} = [C_{ht}^{s,*}]^{\frac{\kappa}{2}} [C_{ft}^{s,*}]^{1-\frac{\kappa}{2}}$$

When $\kappa = 1$, our model will be the benchmark two-country setting, but when $\kappa \rightarrow 0$, the two-country model reduces to a small open economy model.¹²

Technical Appendix Section 7 describes the solution for the two-country model with asymmetric country size. Following the same steps as before, we express the dynamics of domestic and foreign output as a function of home and foreign interest rate shocks in the following way.

$$\widehat{Y}_t - \widehat{Y}_t^{fb} = E_t(\widehat{Y}_{t+1} - \widehat{Y}_{t+1}^{fb}) - \frac{2\delta^* - (\delta^* - 1)\kappa}{\Delta_1} (\widehat{r}_t - \widehat{r}_t^{fb}) - \frac{1 - \delta^*}{\Delta_1} (\widehat{r}_t^* - \widehat{r}_t^{fb*}) \quad (20)$$

$$\widehat{Y}_t^* - \widehat{Y}_t^{fb*} = E_t(\widehat{Y}_{t+1}^* - \widehat{Y}_{t+1}^{fb*}) - \frac{\kappa(\delta - 1)}{\Delta_1} (\widehat{r}_t - \widehat{r}_t^{fb}) - \frac{1 + \delta}{\Delta_1} (\widehat{r}_t^* - \widehat{r}_t^{fb*}) \quad (21)$$

where $\Delta_1 = \delta^*(1 + \delta) + \kappa\delta(1 - \delta^*)$, $\delta^* = 1 - \frac{n^*\omega}{1-n^*}$ and for $\kappa = 1$, and $n^* = n$, we arrive at the same expressions as Eqs. (15) and (16) above.

¹¹ For example, Debortili and Gali (2018) argue that about 21%-27% of households are financially constrained, while Kaplan et al. (2014) estimate that the share of hand-to-mouth households was 30%. This accords well with the data on the fraction of the population who engage in savings reported by the World Bank, as cited in the Introduction.

¹² There are two reasons that the home consumption structure is assumed to be unchanged with country size. First, it allows home preferences to be the same in both the two-country model and the small open economy model. Secondly, if the home consumption also depended on country size, then when $\kappa = 0$ we would need to allow for other home bias parameters to guarantee that home goods are demanded.

In the small economy case, the condition that monetary policy has a presumptive impact on output is different than the case for Proposition 2 and requires that $n < \frac{1}{\frac{\alpha}{2}+1}$. We assume this condition holds in what follows.¹³

Proposition 3. (a) In the absence of consumer heterogeneity, the response of the output gap and the terms of trade to a domestic or foreign country monetary shock is identical to that of the two country model and independent of the size of each country.

(b) For a given degree of heterogeneity, the output response to a domestic interest rate cut is smaller in the small open economy (when $\kappa = 0$) than in the two country world economy.

(c) In the small open economy, the output response to a domestic interest rate cut is independent of the share of Keynesian households in the foreign economy.

(d) The output response to a foreign interest rate cut is greater in the small open economy than in the two country world economy.

(e) The response of the terms of trade to an interest rate shock in either country in the small open economy is identical to that in the two country world economy.

Proof: These statements follow directly from Eqs. (20) and (21), given the definitions of δ , δ^* and κ . See Technical Appendix Section 7.5.1 for more details.

Part (a) of the Proposition reflects standard results indicating that the size of the economy does not affect the responses to monetary policy shocks. But size becomes important in the presence of consumer heterogeneity. First, as before, in the small economy, the impact of an interest rate cut is magnified by the presence of Keynesian households. But when $\kappa = 0$, there are no spillover effects to the foreign economy, as established by Eq. (21), hence no ‘spillover’ to the small economy that enhances the response to the interest rate cut, reducing the overall size of the expansion, thus accounting for part (b). Then part (c) of the Proposition must follow, since the amplification of output in the small economy depends only on domestic Keynesian households. By contrast, part (d) of the Proposition says the spillover response to a foreign interest cut is greater in the small economy than in the two country world economy. The intuition comes from the fact that the foreign economy expands more, since the terms of trade has no effect on the large foreign economy, so the consumer real interest rate $\tilde{r}_t^* + \frac{\alpha}{2}E_t\Delta\hat{q}_{t+1}$ responds by the full amount of the interest rate shock, i.e. \tilde{r}_t^* , when $\kappa = 0$. Since the movement of home Ricardian consumption and the terms of trade are the same in the $\kappa = 0$ and $\kappa = 1$ case, this means that home output must expand by more in the case of the small open economy. Finally, the explanation behind part (e) of the Proposition comes from the combination of the risk-sharing condition $\hat{C}_t^R - \hat{C}_t^{R,*} = \hat{e}_t = \frac{1-\kappa}{2}\hat{q}_t$ and the response of \hat{C}_t^R and $\hat{C}_t^{R,*}$ to interest rate shocks, which in the case of temporary shocks, the difference can be derived as $-(\tilde{r}_t - \tilde{r}_t^*) - \frac{1-\kappa}{2}\hat{q}_t$. Putting these together, we arrive at the response $\hat{q}_t = -(\tilde{r}_t - \tilde{r}_t^*)$, as before.

4. Optimal monetary policy

In this section, we explore the implications for optimal monetary policy under PCP. To compare with Engel (2011), we assume a cooperative optimal monetary policy designed to maximize world welfare, but allowing for separate home and foreign monetary policy targets, and incorporating within-country heterogeneity.¹⁴

In Technical Appendix Section 4.4, we derive the global planner’s objective function in the presence of household heterogeneity. The global planner’s problem is:

$$L_0 = \left\{ \begin{aligned} & \frac{1+\omega}{2}(\hat{Y}_t - \theta_t)^2 + \frac{1+\omega}{2}(\hat{Y}_t^* - \theta_t^*)^2 + \frac{1-n}{2n}\frac{1}{\omega}\hat{H}_t^2 + \frac{1-n^*}{2n^*}\frac{1}{\omega}(\hat{H}_t^*)^2 \\ & + \frac{v(2-v)}{4}(\hat{H}_t^* - \hat{H}_t)^2 + \frac{\varepsilon}{2\bar{\kappa}}\pi_{rh,t}^2 + \frac{\varepsilon}{2\bar{\kappa}}\pi_{ff,t}^{*2} \end{aligned} \right\} \quad (22)$$

where $\bar{\kappa} = \frac{(1-\beta\kappa)(1-\kappa)}{\kappa}$. Heterogeneity matters to the planner in itself, both individual country heterogeneity as well as heterogeneity differences across countries, in addition to the standard loss from output gaps and inflation. Heterogeneity matters for two reasons. The presence of consumption heterogeneity in the first line in the expression (22) captures the loss associated with the deviation of output

¹³ Also note that in contrast to the two country case, from conditions (20) and (21), in the small open economy, there is no upper threshold for the value of n in which the impact of expansionary monetary policy moves from negative to positive, analogous to part (d) of Proposition 2. The reason is tied to the fact there is no spillover from the home country monetary policy to the rest of the world (see below). This means that for $\delta < 0$, the negative impact of a monetary expansion on consumption always offsets the terms of trade response, as in part (c) of Proposition 2.

¹⁴ Here we are characterizing an optimal monetary policy problem that abstracts away from strategic interaction between monetary authorities. In this, we are following the approach of the literature (see e.g. Benigno and Benigno, 2003; Benigno and Benigno, 2006; Corsetti et al., 2010; Corsetti et al., 2020; Engel, 2011, and others) The cooperative approach involves each country abstaining from attempting to manipulate interest rates or terms of trade in its favour. A full analysis of the strategic interaction in the monetary policy framework would involve a significant expansion of the state space and account for the manipulation of goods and financial market prices that would complicate the analysis considerably. Engel (2016) provides an extensive discussion of the issues involved. He notes that in setting up the non-cooperative policy-makers second-order approximated loss function, it is necessary to characterize an ‘optimal tariff’ which removes the pre-existing ‘distortion’ that exists because each policy-maker is not exploiting its market power over the terms of trade. He is able to characterize non-cooperative monetary policy in an environment of complete financial markets (which we have for Ricardian agents), but only in a static model with no price rigidity.

from its efficient level in the home and foreign country due to heterogeneity. But in addition, the difference in consumption heterogeneity, shown in the second line in Eq. (22), represents the loss in cross-country risk sharing, since only Ricardian consumers can directly share risk across countries. If there are no Keynesian consumers, so that $n = 0$, the loss function collapses to the standard PCP loss function evaluated by Engel (2011).

Despite that heterogeneity enters the loss function directly in the planner's problem, the solution to the optimal monetary policy problem under PCP still exhibits the 'divine coincidence' of the standard new Keynesian model. In the absence of cost-push shocks, the optimal policy stabilizes producer price inflation, and this closes all output gaps. Intuitively, this follows from Proposition 1 and the fact that we can replace \widehat{H}_t and \widehat{H}_t^* using the definitions of heterogeneity (i.e., Eqs. (8) and (9)).

Proposition 4. *The solution to the global planner's problem under PCP restores the economy to the flexible price equilibrium. PPI inflation stabilization can close both the output gap and eliminate the consumption heterogeneity even when $n \neq n^*$.*

See Section 5 of the Technical Appendix for proof.

4.1. Cost-Push shocks and targeting rules

We can describe policy in the form of monetary targeting rules. The targeting rule is represented by the first order conditions implied by the global planner's problem of minimizing the loss function (22) subject to the following inflation equations

$$\pi_{hh,t} = \bar{\kappa} \left[(1 + \omega) \widehat{Y}_t - (1 + \omega) \theta_t + \frac{2 - \nu}{2} (\widehat{H}_t^* - \widehat{H}_t) \right] + \beta E_t \pi_{hh,t+1} + \nu_t \quad (23)$$

$$\pi_{ff,t}^* = \bar{\kappa} \left[(1 + \omega) \widehat{Y}_t^* - (1 + \omega) \theta_t^* - \frac{2 - \nu}{2} (\widehat{H}_t^* - \widehat{H}_t) \right] + \beta E_t \pi_{ff,t+1}^* + \nu_t^* \quad (24)$$

Here, we allow for the possibility of temporary markup or cost-push shocks in each country, represented by the variables ν_t and ν_t^* .¹⁵ With markup shocks, it is well known that monetary policy faces a trade off between stabilizing the output gap and stabilizing inflation. Let ξ_t and ξ_t^* to be the shadow prices of (23) and (24). Assuming the 'timeless perspective' for the planner, the optimal monetary policy is characterized by the following first-order conditions:

$$(1 + \omega)(\widehat{Y}_t - \theta_t) - \widehat{H}_t - \nu \bar{\delta} (\widehat{H}_t - \widehat{H}_t^*) + (1 + \omega + \bar{\delta}) \bar{\kappa} \xi_t - \bar{\delta} \bar{\kappa} \xi_t^* = 0 \quad (25)$$

$$(1 + \omega)(\widehat{Y}_t^* - \theta_t^*) - \widehat{H}_t^* - \nu \bar{\delta}^* (\widehat{H}_t^* - \widehat{H}_t) + (1 + \omega + \bar{\delta}^*) \bar{\kappa} \xi_t^* - \bar{\delta}^* \bar{\kappa} \xi_t = 0 \quad (26)$$

$$\frac{\varepsilon}{\bar{\kappa}} \pi_{hh,t} + \xi_{t-1} - \xi_t = 0 \quad (27)$$

$$\frac{\varepsilon}{\bar{\kappa}} \pi_{ff,t}^* + \xi_{t-1}^* - \xi_t^* = 0 \quad (28)$$

Where $\bar{\delta} = \frac{2 - \nu}{2} (1 - \delta)$ and $\bar{\delta}^* = \frac{2 - \nu}{2} (1 - \delta^*)$. The targeting rules involve an interaction between domestic and foreign output gaps, inflation rates and heterogeneity variables. In the absence of consumer heterogeneity, (25)–(28) collapse to the standard targeting rules which are independent across countries and involve only a trade-off between a domestic output gap and domestic PPI inflation:

$$(\widehat{Y}_t - \theta_t) - (\widehat{Y}_{t-1} - \theta_{t-1}) + \varepsilon \pi_{hh,t} = 0 \quad (29)$$

$$(\widehat{Y}_t^* - \theta_t^*) - (\widehat{Y}_{t-1}^* - \theta_{t-1}^*) + \varepsilon \pi_{ff,t}^* = 0 \quad (30)$$

With Keynesian consumers, however, the optimal targeting rules are interdependent. The key insight is due to inefficient risk sharing, captured by the term in heterogeneity differences in the welfare function (22). Since a cost-push shock must lead to a fall in the output gap and an increase in heterogeneous consumption responses within a country, it leads to inefficient risk sharing across countries and requires a concomitant response in the partner country.

Fig. 1 illustrates the response to a home country cost-push shock in the case with and without consumer heterogeneity. The calibrated parameters are presented in Table 1.¹⁶ The labor supply elasticity parameter is set to be one. As shown in Kaplan et al. (2014), a reasonable estimate for n in the United States is 0.3. We will follow their estimates for our benchmark model. A higher value of $n = 0.45$ is also considered for sensitivity analysis.

As shown in Fig. 1, in the absence of Keynesian consumers, an inflation shock leads to a fall in the home output gap and a rise

¹⁵ Following Engel (2011), it is easy to show that these shocks can be modeled as temporary shocks to the elasticity of substitution across varieties.

¹⁶ We follow Engel (2011) and Fujiwara and Wang (2017) in choosing the basic value of parameters. We assume that each period is one quarter; The discount factor is 0.99, while the preference weight on labor disutility is 2. The degree of price stickiness is 0.75 so that the average duration of price change is 4 quarters, the elasticity of substitution across individual goods is 11 so that the markup is 10%, the home bias parameter ν is 1.5, the persistence of the productivity shock is 0.95.

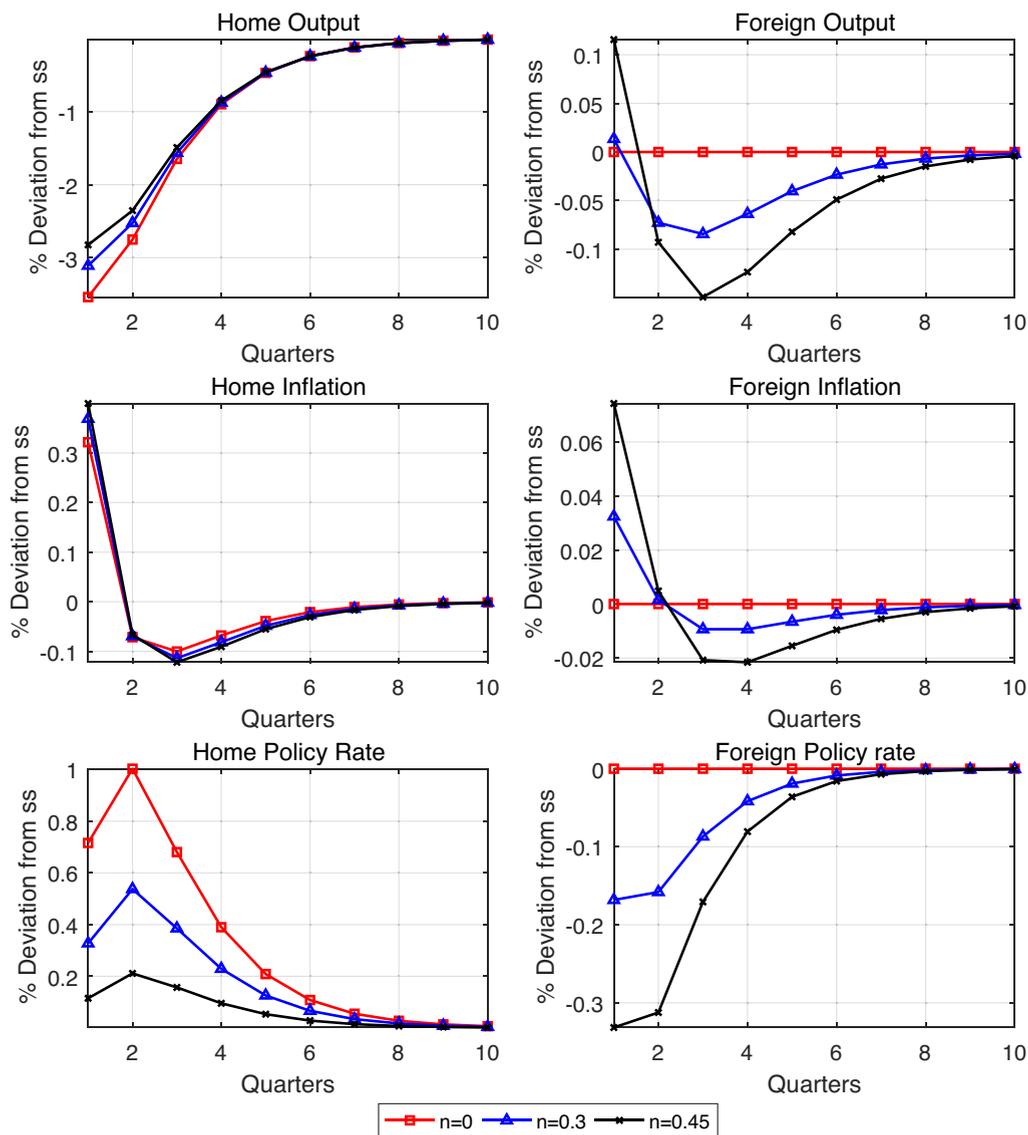


Fig. 1. Impulse Response Functions for Home Cost-Push Shock.

Table 1
Parameter values (Baseline).

Parameter	Description	Value
β	discount factor	0.99
η	preference weight on labor	2
ω	Inverse of the Frische elasticity in Labor supply	1
κ	degree of price stickiness	0.75
ε	elasticity of substitution across individual goods	11
ν	home bias	1.5
n	the fraction of household whose is “hand-to-mouth”	0.3
ρ_θ	persistence of productivity shock	0.95
ρ_ν	persistence of cost-push shock	0.5
σ	productivity shock size	0.01

inflation, and a rise in the home policy rate, but has no implications for the foreign country. But when $n = n^* > 0$, there is a spillover to the foreign country - the foreign policy rate falls, the both the foreign output gap and foreign inflation rate rises. The spillover acts so as to partly ameliorate the impact of the shock in the home country, as the home policy rate rises by less, and the output gap falls by a

smaller amount than in the model without consumer heterogeneity.

5. An alternative pricing strategy: LCP

The role of heterogeneity for the spillovers of monetary policy shocks is dependent on the currency of pricing. We now explore the model identical to that above except assuming that firms follow a local currency pricing strategy (LCP), so that exported goods prices are set in the currency of the buyer. As in the PCP case, a firm may reset its prices with probability $1 - \kappa$ each period. But now the firm sets two prices, $P_{hht}^o(i)$ in home currency for sales in the home market, and $P_{hft}^o(i)$ in foreign currency for sales in the foreign market. The optimization problem of firms is defined in Technical Appendix section 1.1.2.

Under LCP, the terms of trade is $Q_t = \frac{P_{hft}}{S_t P_{hht}^*}$. The deviations from the law of one price (LOOP) for the home and foreign good are $d_t = \frac{S_t P_{hft}^*}{P_{hht}^*}$ and $d_t^* = \frac{P_{hft}}{S_t P_{hft}^*}$.

5.1. Transmission mechanism of monetary shocks

The household side of the model under LCP is identical to the PCP case. We still have the Eqs. (8) and (9) in the LCP case. We rely on the Euler equations as well as the goods market clearing condition to analyze the effect of monetary policy shocks. In the LCP case however, the deviation from LOOP influences the equilibrium allocation. Therefore, we need to use the Phillips curves to characterize the dynamics of deviations from LOOP. This differs from the PCP case and complicates the solution. We first consider the symmetric case ($n = n^*$) with no home bias ($\nu = 1$) and keep our discussion closely related to Engel (2011), but we highlight the role of household heterogeneity. The more general case is treated in the Technical Appendix Section 2.

In the LCP setting, the law of one price does not hold and the real exchange rate is variable, even when $\nu = 1$, so that $\hat{e}_t \neq 0$. Then the risk-sharing condition for Ricardian consumers is $\hat{C}_t^R = \hat{C}_t^{R*} + \hat{e}_t$. The movement in the real exchange rate creates a gap between home and foreign Ricardian consumption. This will lead to different transmission mechanism of monetary shocks under LCP than that under PCP.

Log-linearizing the deviation from the law of one price, terms of trade, and the real exchange rate, we obtain

$$\begin{aligned} \hat{d}_t &= \hat{p}_{hft}^* + \hat{e}_t - \hat{p}_{hht}, \hat{d}_t^* = \hat{p}_{hft} - \hat{e}_t - \hat{p}_{hft}^* \\ \hat{q}_t &= \hat{p}_{hft} - \hat{p}_{hft}^* - \hat{e}_t, m_t = \frac{1}{2}(\hat{d}_t - \hat{d}_t^*) = \hat{e}_t \end{aligned}$$

where m_t is the average currency misalignment in the global economy, which is a key variable for optimal monetary policy.

The log-linearized goods market clearing is similar to that of (10) under PCP. In the symmetric case with $\nu = 1$, we can use the home and foreign goods market conditions to express the within-country terms of trade as the output difference between Home and Foreign countries. $\hat{q}_t + \hat{e}_t = \hat{Y}_t - \hat{Y}_t^*$, where $\hat{q}_t + \hat{e}_t$ equals the average of the relative prices of foreign to home goods in both home and foreign markets.¹⁷ In the LCP case, the relative prices include two components: the terms of trade and the real exchange rate. Moreover, as shown in the Technical Appendix Section 2.2.1, $\hat{Y}_t - \hat{Y}_t^* = 0 + t.i.p$, and $\hat{d}_t + \hat{d}_t^* = 0 + t.i.p$ where t.i.p is a function of productivity shocks but independent of monetary policy shocks. Intuitively, because this represents a relative price expressed in the same currency, it cannot be manipulated by monetary policy in either country.

Now we can use the Euler equations to solve for the effect of monetary shocks on output

$$\hat{C}_t^R = E_t(\hat{C}_{t+1}^R) - \left[\hat{r}_t - \frac{1}{2}E_t\Delta\hat{q}_{t+1} - \frac{1}{2}E_t\Delta\hat{d}_{t+1} \right] \quad (31)$$

where $\hat{r}_t = \hat{i}_t - E_t\pi_{nh,t+1}$ is the real interest rate. The response of home output to monetary shocks and productivity shocks are given by,

$$\hat{Y}_t = E_t(\hat{Y}_{t+1}) - \frac{1}{2\delta}\hat{r}_t - \frac{1}{2\delta}\hat{r}_t^* + \Theta \quad (32)$$

where Θ is a function of productivity terms. Using the interest rate rules specified in the PCP case, we have

$$\hat{Y}_t - \hat{Y}_t^{fb} = E_t(\hat{Y}_{t+1} - \hat{Y}_{t+1}^{fb}) - \frac{1}{2\delta}\hat{u}_t - \frac{1}{2\delta}\hat{u}_t^* + \Theta \quad (33)$$

Proposition 5. *With household heterogeneity, under LCP an expansionary monetary shock in the home or foreign country will increase home and foreign output equally as long as $n < \frac{1}{w+1}$.*

¹⁷ In particular, $\hat{q}_t + \hat{e}_t = \hat{p}_{hht} - \hat{p}_{hft,t}^*$, where we recall that each expression on the right hand side represents the price normalized by the local CPI. Note also that the relative price of foreign to home goods in the same currency is identical in the home and foreign country. This equivalence holds up to a first order approximation.

Proof: See Eq. (33), and Technical Appendix Section 2.2.1 for a full proof.

As in the case of PCP, there is an upper limit on the size of the Keynesian sector in order for a monetary expansion to have positive effects on output.¹⁸

Just as in the case of PCP, the effect of heterogeneity is to magnify the impact of a monetary shock due to its effect on the demand of Keynesian consumers. But now the impact is uniform across countries. To see this, we may use the following relationship that is derived from the home goods market clearing condition,

$$\hat{Y}_t = \frac{1}{\delta} \left(\hat{C}_t^R - \frac{1}{2} \hat{e}_t \right) + \frac{1}{2} (\hat{q}_t + \hat{e}_t) \quad (34)$$

In face of an interest rate cut in the home country, domestic Ricardian consumption increases. However, in the LCP case, foreign Ricardian consumption increases less than Home Ricardian consumption due to the real exchange rate depreciation. Here, $\hat{C}_t^R - \frac{1}{2} \hat{e}_t$ captures the total change in global Ricardian consumption and $\frac{1}{\delta}$ measures the response of aggregate consumption to Ricardian consumption.

Unlike the PCP case, the second term in the right hand side of (34) indicates that the relative price impact on demand involves changes in both terms of trade and the real exchange rate. But as we have just noted, the term $\hat{q}_t + \hat{e}_t$ is independent of monetary policy. The relative price effect is shut down in the LCP case.

5.2. Optimal monetary policy under LCP

Unlike the case with PCP, the monetary policy under LCP pricing cannot achieve the first best allocation, even in the absence of consumer heterogeneity. But as we show, the presence of Keynesian consumers has important implications for the optimal coordinated monetary policy under LCP. Again we focus on the case with symmetric household heterogeneity ($n = n^*$). It is convenient to define the planner's loss function in terms of global averages and global differences. Following Engel (2011), we define the "relative" and "world" value for output, heterogeneity and inflation. For variable \hat{X}_t , \hat{X}_t^* , define $\hat{X}_t^d = \frac{1}{2}(\hat{X}_t - \hat{X}_t^*)$ and $\hat{X}_t^W = \frac{1}{2}(\hat{X}_t + \hat{X}_t^*)$.

We can then define the global planner's loss function with household heterogeneity under LCP is given by:

$$L_0 = \left\{ \begin{aligned} & (1 + \omega) (\hat{Y}_t^d - \hat{Y}_t^{d,fb})^2 + (1 + \omega) (\hat{Y}_t^W - \hat{Y}_t^{W,fb})^2 + \frac{1-n}{\omega} \left(\frac{1}{n} \right) [(\hat{H}_t^d)^2 + (\hat{H}_t^W)^2] \\ & + \frac{v(2-v)}{4} (\hat{m}_t - 2\hat{H}_t^d)^2 + \frac{\varepsilon}{\bar{\kappa}} (\pi_t^d)^2 + \frac{\varepsilon}{\bar{\kappa}} (\pi_t^W)^2 \\ & + \frac{\varepsilon}{2\bar{\kappa}} \frac{v(2-v)}{2} [2(\hat{Y}_t^d - \hat{Y}_t^{d,fb}) + (v-1)2\hat{H}_t^d + (\theta_t - \theta_t^*) + (1-v)\hat{m}_t]^2 \end{aligned} \right\} \quad (35)$$

Here, $\hat{Y}_t^{d,fb} = \frac{1}{2}(\theta_t - \theta_t^*)$ and $\hat{Y}_t^{W,fb} = \frac{1}{2}(\theta_t + \theta_t^*)$ represent the efficient relative and world value for output in the flexible price equilibrium. The loss function (35) indicates that the planner is concerned with average world inflation and the average output gap, as well as the differential in inflation and the output gap across countries, but also, as in Engel (2011), the deviation from the law of one price \hat{m}_t , which causes a deviation from efficient risk sharing. As in the case of PCP pricing, consumption inequality, represented by \hat{H}_t and \hat{H}_t^* , is also costly, both because it is associated with deviations of the output gap from the efficient level, but also because, given that only Ricardian consumers can engage in cross country risk sharing, consumption inequality leads to a deviation from efficient risk sharing across countries.

The constraints can also be rewritten as below:

$$\pi_t^d = (v-1)\bar{\kappa}B(\hat{Y}_t^d - \hat{Y}_t^{d,fb}) + \bar{\kappa} \frac{v(2-v)}{2} \hat{m}_t + \beta E_t \pi_{t+1}^d \quad (36)$$

$$\pi_t^W = \bar{\kappa}(1+\omega)(\hat{Y}_t^W - \hat{Y}_t^{W,fb}) + \beta E_t \pi_{t+1}^W \quad (37)$$

$$\begin{aligned} & A(\Delta \hat{Y}_t^d - \Delta \hat{Y}_t^{d,fb}) - \frac{(v-1)}{2} \Delta \hat{m}_t + \frac{1}{2} (\Delta \theta_t - \Delta \theta_t^*) \\ & = \bar{\kappa} \left[-B(\hat{Y}_t^d - \hat{Y}_t^{d,fb}) + \frac{(v-1)}{2} \hat{m}_t \right] \\ & + \beta E_t \left[A(\Delta \hat{Y}_{t+1}^d - \Delta \hat{Y}_{t+1}^{d,fb}) - \frac{(v-1)}{2} \Delta \hat{m}_{t+1} + \frac{1}{2} (\Delta \theta_{t+1} - \Delta \theta_{t+1}^*) \right] \end{aligned} \quad (38)$$

¹⁸ Unlike Proposition 2, due to the absence of relative price effects, there is no upper region where the aggregate demand relationship reverts as n rises further.

where $A = 1 - (\nu - 1)(1 - \delta)$, $B = 1 + \omega + (2 - \nu)(1 - \delta)$. Eq. (37) indicates that the world output gap drives world inflation, and is equivalent to the standard closed economy representation. But from Eqs. (36) and (38), we see that output gap and inflation differences interact with \hat{m}_t , the deviations of the law of one price.

To highlight the intuition, we focus on the special case without home bias ($\nu = 1$).¹⁹ Then Equation (38) shows \hat{Y}_t^d is independent of monetary policy. Under LCP with $\nu = 1$, monetary policy can only influence the average world output gap, and cannot affect the division of the output gap between the Home and Foreign country. Then we can show from (38) that a positive relative productivity shock in the home country will lead the relative home output gap to fall. With sticky prices and LCP, the absence of expenditure switching means that after a home productivity shock, the home output response is less than is fully efficient.

Since \hat{H}_t^d and \hat{H}_t^W are functions of output gaps, the choice variables for the global planner are $\{\hat{Y}_t^W - \hat{Y}_t^{W,fb}, \pi_t^d, \pi_t^W, \hat{m}_t\}$. The first-order conditions to characterize the optimal monetary policy are in Technical Appendix Section 6.1.

We first note the following

Proposition 6. *If $n = 0$, then the optimal policy implies $\pi_t^W = \pi_t^d = \hat{m}_t = 0$.*

This is an application of Engel (2011), and proved in Technical Appendix Section 6.2. Intuitively, although the planner cannot correct individual output gaps, the world output gap is closed, and an optimal policy means that monetary policy targets the CPI in each country, and eliminates all deviations from the law of one price.²⁰

In the general case where $n > 0$, this property no longer holds. We establish the following Proposition on the optimal monetary policy under LCP based on the solution in Technical Appendix Section 6.1.

Proposition 7. *In the model with LCP, when there is household heterogeneity ($n > 0$) but with no home bias ($\nu = 1$):*

- (a) *Optimal monetary policy stabilizes the world average output gap and world average CPI.*
- (b) *A home (foreign) relative productivity shock leads to a rise (fall) in relative home CPI inflation π_t^d .*
- (c) *A home (foreign) relative productivity shock leads to a positive (negative) deviation from the law of one price $\hat{m}_t > 0, (< 0)$.*

Proof: See Section 6.1 of Technical Appendix for proof.

To illustrate the nature of the optimal policy under LCP, use the simplifying notation for the \hat{H}_t^d process, noting that when $\nu = 1$, \hat{H}_t^d is independent of monetary policy. Let $\hat{H}_t^d = \rho \hat{H}_{t-1}^d + \eta_t$ where $E_{t-1} \eta_t = 0$, and η_t represents unanticipated shocks to relative productivity, and ρ represents the persistent of the shock.

Then, using assumption, (36), the FOC w.r.t to π_t^d and the FOC w.r.t to \hat{m}_t , the optimal monetary policy is characterized by a persistent process for \hat{m}_t that satisfies

$$\hat{m}_t = \lambda \hat{m}_{t-1} + \gamma_0 \hat{H}_{t-1}^d + \gamma_1 \eta_t \tag{39}$$

where $1 > \lambda > 0$, and γ_0 and γ_1 are constant coefficients. In particular,

$$\gamma_0 = \frac{2(\beta\rho^2 - \beta\rho - \rho + 1)}{\beta\lambda + \beta\rho - \varepsilon\bar{\kappa} - \beta - 1} < 0, \gamma_1 = -\frac{\beta\gamma_0 - 2\beta\rho + 2\beta + 2}{\beta\lambda - \varepsilon\bar{\kappa} - \beta - 1} > 0$$

Eq. (39) implies that in response to a positive home relative productivity shock, the relative home output gap falls below zero. Because Keynesian agents cannot share risk across countries, there is a failure of cross-country risk sharing. The planner allows the home country a positive deviation from the law of one price, which generates a real exchange rate depreciation and a rise in relative home consumption.

Given (39), using the FOC w.r.t to π_t^d and the FOC w.r.t to \hat{m}_t , the world relative inflation rate π_t^d takes on the same dynamic process as \hat{m}_t . A positive home relative productivity shock is associated with a persistent positive relative CPI inflation rate as part of the optimal monetary policy response.

6. Conclusions

There has been an extensive debate about the question of whether central banks should be concerned with distributional effects of monetary policy. We extend this debate into the open economy in a simple but tractable model in which there is consumer heterogeneity due to the inability of a group of consumers to access financial markets. Consumer heterogeneity has important effects on the outcome of monetary policy shocks and the transmission of monetary shocks across countries. Optimal monetary policy rule should take account of consumer heterogeneity, and with heterogeneity, optimal monetary targeting rules become interdependent. In the situation of local currency pricing, an optimal monetary policy actively allows for deviations from the law of one price as a second best policy in face of consumer heterogeneity.

¹⁹ The more general case with home bias is reported in Section 6.3 of the Technical Appendix

²⁰ In Engel (2011), optimal monetary policy targets the CPI in each country when $\omega = 0$ (linear disutility of labor), even when $\nu \geq 1$. Here we show that the same property holds when $\omega > 0$ so long as $\nu = 1$, without consumer heterogeneity.

An interesting follow-up from our results would be to investigate the empirical evidence for magnified spillovers of monetary policy shocks depending on the degree of heterogeneity within countries. We leave this exploration for further research.

CRedit authorship contribution statement

Sihao Chen: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Michael B. Devereux:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Kang Shi:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Juanyi Xu:** Conceptualization, Methodology, Formal analysis, Writing – original draft.

Data availability

No data was used for the research described in the article.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at [10.1016/j.jmoneco.2023.07.001](https://doi.org/10.1016/j.jmoneco.2023.07.001)

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