Fiscal funding, convenience yields and the real exchange rate*

Marco Graziano† Maria Pia Lombardo‡ Maxime Phillot§

January 14, 2026

Abstract

This paper introduces a new mechanism to reconcile the empirical evidence of real exchange rate depreciation in response to fiscal shocks for the United States with models of open economies with sticky prices and complete markets. The mechanism hinges on the convenience yield of U.S. Treasuries and on the fraction of government spending financed by debt. In a model with fixed real rates, a fiscal shock financed at least in part by debt causes a drop in the convenience yield and a substitution towards higher consumption, resulting in a real exchange rate depreciation through international risk sharing. On the other hand, when the real interest rate is not fixed, the interactions between fiscal and monetary policy matter. Under fiscal dominance, the real exchange rate depreciates, but the convenience yield rises. Under monetary dominance, debt-funded fiscal shocks deliver a drop in the convenience yield, and a real depreciation as long as the nominal rate does not react too strongly to inflation. The paper also provides evidence that in the U.S. tax-financed fiscal shocks lead to an appreciation of the exchange rate and a higher convenience yield; while debt-financed shocks lead to a depreciation and lower convenience yield, consistently with the model.

JEL Classification: E63, F31, F41

Keywords: exchange rates, convenience yields, fiscal-monetary interactions, fiscal shocks, safe assets.

---

*The views expressed in this paper are those of the authors and do not necessarily reflect those of the Swiss National Bank. We are grateful to Philippe Bacchetta, Ryan Banerjee, Gianluca Benigno, Kenza Benhima, Paolo Cavallino, Ambrogio Cesa-Bianchi, Aurélien Eyquem, Laurent Ferrara, Jordi Galí, Oleg Itskhoki, Dmitry Mukhin, Erica Perego, Giacomo Porcellotti, Emiliano Santoro, Daniele Siena, Carolin Spallek, and Pascal St-Amour for their valuable feedback. We also thank seminar participants at the University of Lausanne and the University of Basel, as well as participants and discussants at the 14th PhD Student Workshop on International Macroeconomics, for their helpful comments and suggestions. This paper supersedes an earlier draft, entitled "Convenience yields and the exchange rate appreciation puzzle".

†University of Basel. marco.graziano@unibas.ch

‡University of Lausanne. mariapia.lombardo@unil.ch

§Swiss National Bank. maxime.phillot@snb.ch

1 Introduction

In times of large and volatile government spending, as exemplified by the unprecedented fiscal stimulus in response to the Covid-19 pandemic and the rapid build-up of military expenditure in Europe following the Russian invasion of Ukraine, the question of how fiscal shocks affect the economy is growing ever more urgent. In an open-economy context, the real exchange rate merits particular attention due to its direct implications for welfare (De Paoli, 2009; Corsetti et al., 2010). Yet, our understanding of how the real exchange rate responds to fiscal shocks has long been plagued by a strident discrepancy between theory and empirical evidence.

A large class of DSGE models with flexible (Backus et al., 1994; Engel, 2002) or sticky (Corsetti and Pesenti, 2001) prices predicts that an expansionary fiscal shock should cause a real appreciation. As government spending increases, forward-looking households expect higher future taxation to fund the expenditure, which lowers their permanent income. As a result, they consume less and the real exchange rate appreciates through the international risk sharing condition implied by market completeness. Contrary to these predictions, a vast empirical literature has found that fiscal shocks induce an increase in consumption and a depreciation of the real exchange rate, with particularly robust evidence for the United States (Kim and Roubini, 2008; Monacelli and Perotti, 2010; Ravn et al., 2012).

This discrepancy, dubbed the "exchange rate appreciation puzzle", has encountered several candidate solutions ranging from alternative utility functions to market incompleteness and spending reversals. In this paper, we bring attention to the hitherto neglected role of the funding composition of government spending shocks.

Under Ricardian equivalence, the degree to which taxes or deficits contemporaneously fund new expenditure should be irrelevant, provided that the intertemporal budget constraint of the government is ultimately satisfied through higher future taxation. However, the empirical literature on fiscal multipliers shows that the source of immediate funding matters (Ilzetzki et al., 2010; Chodorow-Reich, 2017; Ramey, 2019). Likewise, several theoretical mechanisms can break Ricardian equivalence, including finitely-lived agents (Blanchard, 1985) and household heterogeneity (Brinca et al., 2016). For example, Galí et al. (2007) demonstrates how, in a model where hand-to-mouth households consume their current income, a debt-funded government spending shock raises aggregate consumption, while a tax-funded one lowers it. However, in this framework the exchange rate appreciation puzzle persists because assets are priced by the Euler equation of optimising households.

We focus on the convenience yield of U.S. Treasuries as a mechanism that can break Ricardian equivalence. U.S. Treasuries trade as a premium with respect to similarly safe domestic securities (Krishnamurthy and Vissing-Jorgensen, 2012) and foreign government bonds (Du et al., 2018) due to their liquidity, dollar denomination, and role as the premier global safe asset. These non-pecuniary benefits are robustly negatively correlated with the amount of debt outstanding (Jiang et al., 2024), and the literature commonly models this feature as a term in households' utility function that is increasing and concave in real debt holdings (Krishnamurthy and Vissing-Jorgensen, 2012; Jiang et al., 2021, 2023). In this framework, an increase in the supply of government debt resulting from a debt-funded fiscal expansion lowers the marginal utility of real debt holdings and the convenience yield. As a result, consumption increases *ceteris paribus* through an intratemporal substitution effect. Under complete markets, the real exchange rate then depreciates in accordance with the empirical evidence.

This theoretical link is apparent in the data through a strong negative correlation between real dollar appreciation and the convenience yield of U.S. Treasuries , shown in Figure 1. This relationship mirrors the tight correlation between convenience yields and the nominal dollar exchange rate highlighted by the literature (Valchev, 2021; Engel and Wu, 2023).

We start by embedding this mechanism in a simple New-Keynesian open-economy model with complete markets and a fiscal rule allowing the government to choose the mix of taxation or debt that contemporaneously finances new expenditure. We posit that the central bank keeps the real interest rate fixed, so that the intertemporal substitution mechanism of consumption is shut down, and there is no possibility of government debt revaluation through surprise inflation. Importantly, this feature allows us to bring the core mechanism of the convenience yield into stark relief, and distinguish its effects on the real exchange rate from those arising in a model of the fiscal theory of the price level where the government budget constraint is satisfied by inflating debt away (Jiang, 2022).

Under the fixed real interest rate assumption, we derive an analytical solution of the model in terms of consumption and real government debt. For a sufficiently low fraction of tax funding, an expansionary fiscal shock leads to an increase in consumption and a real depreciation. On the contrary, a tax-funded shock implies a drop in consumption and an appreciation as in the standard New-Keynesian open-economy model. Therefore, the degree of debt financing is a crucial sufficient statistic for the effects of fiscal policy on the real exchange rate.

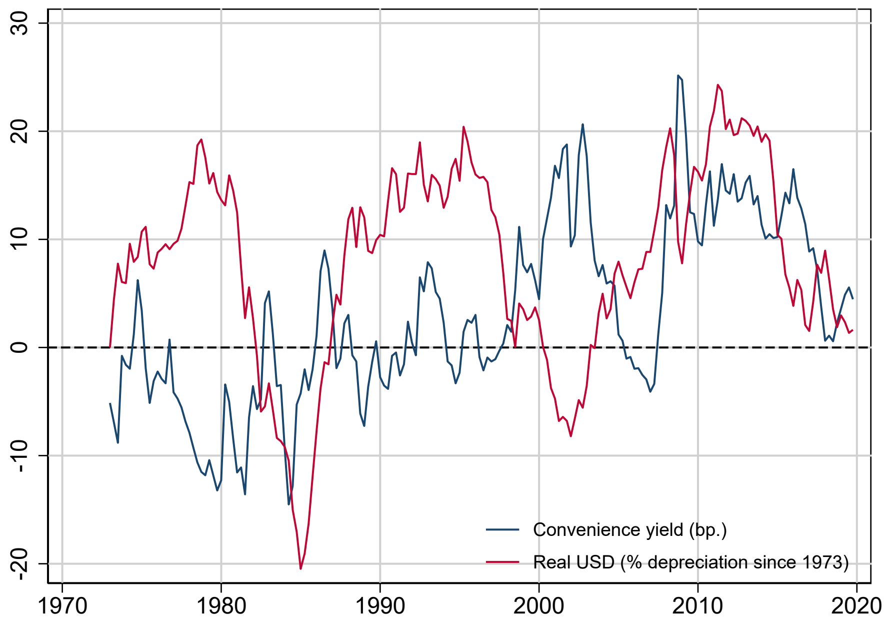


Figure 1: Correlation between exchange rate appreciation and convenience yield

In the baseline calibration, the tax financing threshold below which a depreciation ensues sits at a very high 95%, implying that a very small percentage of debt financing suffices to reconcile the appreciation puzzle through the convenience yield mechanism. The reaction of the convenience yield itself to a fiscal shock depends crucially on the speed of fiscal adjustment. If taxes increase only weakly in response to debt accumulation, the convenience yield rises on impact after a debt-funded fiscal shock , and remains above steady-state for about a year before decreasing. On the other hand, if the higher debt brought about by the spending shock is repaid relatively quickly through taxes, the convenience yield drops on impact and remains persistently lower, consistently with the empirical evidence. This result suggests that the strength of fiscal adjustment is crucial in delivering an empirically-consistent response of both the real exchange rate and the convenience yield to fiscal shocks. It also hints that models in which debt is not repaid through taxation could have trouble explaining both the real depreciation and the drop in the convenience yield in response to debt-funded fiscal expansions.

We then relax the assumptions of a fixed real rate and of debt repayment solely through future taxation to understand the effects of the convenience yield mechanism in a richer environment. This model also micro-founds the convenience yield by explicitly modelling the liquidity benefits of U.S. Treasuries as facilitating transactions (Bansal and Coleman, 1996), rather than assuming that government debt enters consumers' utility function directly. Thanks to this framework, we develop further the intuition that both the contemporaneous source of funding and the degree of intertemporal fiscal backing matter for matching the empirical responses of the real exchange rate and the convenience yield to fiscal shocks.

We build a model where the central bank follows a CPI-inflation Taylor rule and study two types of determinate and unique equilibria: one in which the central bank sets the nominal rate to achieve its inflation target and fiscal policy adjusts taxation to satisfy the government budget constraint; and one in which fiscal policy is not beholden to repaying government debt through higher future taxes because the central bank allows inflation to rise unexpectedly to reduce the real value of debt. We refer to these equilibria as "monetary dominance" and "fiscal dominance", respectively, following the nomenclature in Leeper (1991) and in the literature on monetary-fiscal interactions.

Under fiscal dominance, a debt-funded fiscal shock results in higher inflation on impact as the central bank accommodates the fiscal expansion by raising the nominal rate only weakly. As a consequence, the real interest rate falls and consumption rises through an intertemporal substitution effect. This mechanism, first examined by Jiang (2022), can deliver a real depreciation with complete markets. However, in this regime the convenience yield actually *increases* as nominal outstanding debt increases, in contrast with empirical evidence. This behaviour arises because the real value of government debt drops as the central bank allows it to be inflated away to satisfy the government budget constraint.

Under monetary dominance, the central bank reacts to the inflationary pressure of a debt-funded fiscal shock by raising the nominal interest rate enough for the real rate to rise as well, according to the Taylor principle. As a result, consumption drops and the real exchange rate must appreciate *ceteris paribus* due to the Backus-Smith condition. Under most Taylor rule parameters, this intertemporal substitution mechanism dominates, resulting in the prediciton of a real appreciation as in the standard open-economy New Keynesian model. However, there is a narrow range of Taylor rule parameter for which the central bank reacts strongly enough to inflation to ensure determinacy, but not strongly enough to overturn the increase in consumption due to the higher debt supply. In this part of the parameter space, the intratemporal substitution effect of the convenience yield dominates, leading to an increase in consumption and a real depreciation. In both cases, the convenience yield drops in response to the debt-funded shock, as the amount of real debt outstanding rises in tandem with its nominal counterpart, and households require a higher monetary return to hold an increasing quantity of Treasuries. Therefore, a monetary dominance equilibrium with relatively lax inflation targeting can reconcile the empirical response of both the real exchange rate and the convenience yield to a fiscal shock. Notably, a tax-financed fiscal shock predicts a counterfactual appreciation of the real exchange rate under both fiscal and monetary dominance, underscoring the crucial role of the contemporaneous financing source regardless of the monetary-fiscal regime.

We also provide empirical evidence on the importance of the funding composition for the response of the real exchange rate to fiscal shocks. Using data for the United States in the post-Bretton Woods era of flexible exchange rates, we classify the military spending news events in Ramey (2016), a popular source of fiscal shocks, into a debt-financed and a (partly) tax-financed regime. The former encompasses cases in which the shock is associated with an increase in deficit but no change in taxation, while the latter includes all other possible combinations of changes in deficit and taxes. In the debt-financed regime, a fiscal expansion leads to a large exchange rate depreciation accompanied by a modest fall of the convenience yield of U.S. Treasuries, while in the tax-financed one the real exchange rate displays a weak appreciation and the convenience yield rises sharply. Such results are consistent with the predictions of both the fixed real rate model and the Taylor rule model under monetary dominance with lax inflation targeting. On the other hand, the contemporaneous real depreciation and drop in the convenience yield under debt financing speaks against models of fiscal dominance.

This paper is related to the literature on the exchange rate appreciation puzzle. A set of papers focuses on alternative specifications of households' utility function, including non-separability of consumption and leisure (Monacelli and Perotti, 2010) and deep habits (Ravn et al., 2012). Other studies show how departing from the typical assumption of unproductive government spending (Di Giorgio et al., 2018) or introducing government spending in the utility function (Bouakez and Rebei, 2007) can deliver a real depreciation in reaction to a fiscal expansion. An alternative explanation relies on spending reversals (Corsetti et al., 2012): in a Ricardian setting, a real depreciation can follow a positive fiscal shock if households expect a systematic future decrease in spending. The authors do find this pattern in the data, but interestingly our empirical methodology shows no signs of reversals. Yet another strand of the literature relaxes the complete markets assumptions to break the link between consumption and the real exchange rate (Kollmann, 2010; Bouakez and Eyquem, 2015). In particular, Bouakez and Eyquem (2015) introduces a wedge in the Uncovered Interst Parity (UIP) condition through a reduced-form interest rate premium increasing in the amount of debt outstanding. We show how concave preferences for non-pecuniary benefits of U.S. Treasuries can generate an isomorphic wedge in a complete-market setting.

In the broader picture of the exchange rate appreciation puzzle literature, our key contribution lies in proposing a mechanism that, by relying on the uniqueness of U.S. Treasuries as a global safe asset, can explain why the empirical result that a fiscal shock causes a real depreciation is particularly robust for the United States, while it is questionable for both the European Union (Beetsma et al., 2008; Benetrix and Lane, 2013) and emerging markets (Miyamoto et al., 2019).

In this area, the closest paper is Jiang (2022), which uses a fiscal theory of the price level model where the real interest rate adjusts automatically to satisfy the government debt valuation equation. In response to an expansionary government spending shock, implicitly funded by debt, the real rate drops through higher inflation and so consumption rises, resulting in a real depreciation through international risk sharing. We contribute by extending the analysis to a richer environment in which monetary policy can affect the real rate and fiscal policy can control the degree of contemporaneous debt funding; and by studying the interaction of fiscal backing with the convenience yield of government debt. Our paper presents a clear challenge to the predictive power of fiscal theory models in an open economy context. While they can explain the evidence of real depreciation, we show how the core mechanism of erosion in the real value of government debt stands at odds with the behaviour of the convenience yield.

We also offer a new perspective on the empirical discriminants of the relationship between the real exchange rate and government spending. The existing empirical literature proposes a large host of factors, including the distinction between news and surprise shocks (Forni and Gambetti, 2016; Auerbach and Gorodnichenko, 2016), the specific identification strategy (Ferrara et al., 2021), the nominal exchange rate regime (Born et al., 2013, 2019; Lambertini and Proebsting, 2023), the composition of spending between consumption and investment (Boehm, 2020), and country characteristics such as openness and the stage of economic development (Kim, 2015; Miyamoto et al., 2019). Instead, our approach highlights how different responses of the real exchange rate can be interpreted through the lens of the funding source of government spending. In investigating the role of fiscal funding, we follow the example of Mountford and Uhlig (2009), which tackled the question in a closed-economy setting.

Another related area of research studies the implications of the convenience yield of U.S. Treasuries for asset markets and the macroeconomy. Several papers establish that the convenience yield accounts for a number of properties of the nominal exchange rate. Valchev (2021) builds a model with preferences for government bonds and slowly-adjusting tax policy that can explain the oscillatory dynamics of the exchange rate and the associated short-term failure of the UIP condition with a reversal at longer horizons. Jiang et al. (2024) shows how a simple incomplete-market model with demand for the non-pecuniary benefits of U.S. Treasuries rationalises a plethora of exchange rate puzzles including volatility, disconnect, and UIP deviations. More generally, Jiang et al. (2021) tightly links the dynamics of the nominal dollar exchange rate with movements in the convenience yield. We contribute to this growing literature by demonstrating how convenience yields can help explain the dynamics of the real exchange rate too.

Convenience yields have broader implications for large quantitative models as well. Bodenstein et al. (2023) builds a large-scale two-country model augmented with time-varying preferences for dollar-denominated government bonds, finding that shocks to safe-asset demand are the most important quantitative driver of global business cycles. Similarly, Georgiadis et al. (2023) demonstrates that a model with dollar dominance in safe assets, trade invoicing, and international credit can match the dynamics of the global financial cycle. In the context of macroeconomic models with convenience yields, our framework can be seen as an open-economy extension of Bonam (2020), which shows how a domestic notion of the convenience yield eases constraints on fiscal policy sustainability and makes countercyclical fiscal policy more effective at stabilising business cycles.

Finally, our paper also touches on the topic of monetary-fiscal interactions, and in particular on its open-economy implications (Dupor, 2000; Lombardo and Sutherland, 2004; Leith and Wren-Lewis, 2008; Ding and Jiang, 2024; Witheridge, 2024). The sharply different implications of monetary and fiscal dominance for the joint empirical behaviour of the real exchange rate and the convenience yield call into question the suitability of models solved under extreme policy regimes for investigating the open-economy effects of fiscal shocks, adding to the appeal of recently-developed models of partial fiscal backing (Cochrane, 2022; Bianchi et al., 2023).

The rest of the paper is structured as follows. Section 2 develops a simple analytical model showing how a debt-funded fiscal shock delivers a real depreciation in an environment with a convenience yield for government debt. Section 3 presents a model with a Taylor rule and analyses the implications of monetary and fiscal dominance regimes for the exchange rate appreciation puzzle. Section 4 shows evidence that the funding composition of government spending matters for the reaction of the real exchange rate and convenience yield to fiscal shocks. Section 5 concludes.

2 Analytical model

In this section, we present a stylized version of the model that delivers analytical results and clearly illustrates the core mechanism. The framework builds on the standard New Keynesian small open economy model of Galí (2015), in which households have access to complete international asset markets, and firms operate a production technology using labor as the sole input. The global economy consists of a small open economy — referred to as the home country — and a large foreign country representing the rest of the world. Each country is populated by a continuum of identical, infinitely-lived households, and features a continuum of monopolistically competitive firms producing differentiated final goods. The number of households and firms is normalized to one. Firms do not price discriminate across markets, ensuring that the law of one price holds for all goods.

To capture the role of safe assets, we introduce fiscal authorities in both the home and foreign countries, each issuing nominal government bonds and levying lump-sum taxes to finance public spending. Following Krishnamurthy and Vissing-Jorgensen (2012), we adopt a "bonds-in-the-utility" approach to capture the non-pecuniary convenience benefits investors derive from holding home-issued nominal bonds. Moreover, both countries exhibit a symmetric preference for bonds issued by the home country, following Jiang et al. (2021). This assumption reflects the unique global role of U.S. Treasuries as safe assets, which command a premium over other sovereign bonds with similar risk and return profiles (Du et al., 2018; Jiang et al., 2021; Jiang, 2023).

At first glance, the coexistence of complete markets and nominal government bonds may appear counterintuitive. However, these features serve distinct purposes: complete markets ensure full consumption risk-sharing and equalization of marginal utility of consumption across countries, while nominal bonds enable monetary policy implementation and generate deviations from uncovered interest parity (UIP) through convenience yields. In this framework, government bonds are valued not only for their pecuniary return, but also for their superior liquidity, safety, and role as collateral. This setup highlights how the presence of a convenience yield on government bonds can lead to persistent interest rate differentials, even under full risk-sharing.

In our model, the small open economy represents the United States. While this is a strong and stylized assumption, it serves as a useful benchmark for understanding the role of the convenience yield in addressing the exchange rate appreciation puzzle. A number of other studies adopt a similar assumption even when comparing the model with evidence based on U.S. data, and demonstrate that adopting a two-country framework does not meaningfully alter the core mechanisms that give rise to the exchange rate appreciation puzzle (Monacelli and Perotti, 2010; Bouakez and Eyquem, 2015). In what follows, we describe the small open economy and use an asterisk to denote variables associated with the rest of the world. Throughout the paper, variables without time subscripts denote steady-state values. Further details on the analytical model are provided in Appendix A.

2.1 The household

The representative household in the home country maximizes its expected lifetime utility.

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} + \chi \frac{(\frac{B_{Ht}}{P_t})^{1-\psi}}{1-\psi} \right) \tag{1}$$

subject to the budget constraint

$$P_t C_t + \mathbb{E}_t \Lambda_{t,t+1} D_{t+1} + B_{Ht} + \mathcal{E}_t B_{Ft} = D_t + W_t N_t - T_t + B_{Ht-1}(1+i_{t-1}) + \mathcal{E}_t B_{Ft-1}(1+i_{t-1}^*) \tag{2}$$

and to the appropriate no-Ponzi-game conditions. In the utility function (1), the parameters $0 < \beta < 1$ and φ are, respectively, the subjective discount factor and the inverse of Frisch elasticity of labor supply. The convenience yield on home-issued government bonds depends on real bond holdings, $\frac{B_{Ht}}{P_t}$, the preference weight for home bonds, χ, and the curvature parameter, ψ. The assumption $\psi > 0$ ensures that the marginal utility from real government bond holdings is decreasing and concave. This parameter restriction ensures that in equilibrium the convenience yield is decreasing in the real amount of bond holdings, in accordance with empirical evidence. C_t is a composite consumption index and N_t denotes hours of labor supplied to the firms. In equation (2), B_{Ht} and B_{Ft} are the household's nominal holdings of, respectively, foreign and domestic government bonds; D_{t+1} is the nominal payoff in period $t+1$ of the portfolio of Arrow securities held at the end of period t (including shares in firms); $\Lambda_{t,t+1}$ is the stochastic discount factor for one-period-ahead nominal payoffs relevant to the domestic household; $\mathcal{E}_t$ is the nominal exchange rate, defined as the price of a unit of foreign currency in terms of the domestic currency; W_t is the nominal hourly wage; i_t and i_t^* are the nominal interest rates paid on, respectively, domestic and foreign government bonds.

We log-linearize the model around a zero-inflation steady state. Denote by b_{ht} the real home-issued government bond holdings, by q_t the real exchange rate and by c_t^* foreign level of consumption. Then, the household's log-linearized optimality conditions[1] are given by:

$$\sigma c_t + \varphi n_t = w_t - p_t \tag{3}$$

$$\sigma \mathbb{E}_t \Delta c_{t+1} + \mathbb{E}_t \pi_{t+1} - i_t = \frac{1-\beta(1+i)}{\beta(1+i)}(\sigma c_t - \psi b_{ht}) \tag{4}$$

$$\sigma \mathbb{E}_t \Delta c_{t+1} + \mathbb{E}_t \pi_{t+1} - i_t^* - \mathbb{E}_t \Delta e_{t+1} = 0 \tag{5}$$

[1] Lowercase variables denote log-linearized values.

$$q_t = \sigma(c_t - c_t^*) \tag{6}$$

and the usual transversality conditions. Equation (3) represents the standard intra-temporal optimality condition, which balances consumption and hours worked. Equation (6) is the international risk-sharing condition, which asserts that, in a model with complete asset markets, the marginal utilities of consumption between the home and foreign economies are equalized.

Equations (4) and (5) are the optimality conditions with respect to the real holdings of domestic and foreign government bonds, respectively. From (4), we observe that the convenience yield—defined as the marginal rate of substitution between real domestic government bond holdings and consumption—is a decreasing function of the real bond holdings.

By combining equations (4) and (5), we derive the Uncovered Interest Parity (UIP) condition for the domestic economy:

$$i_t^* + \mathbb{E}_t \Delta e_{t+1} - i_t = \frac{1 - \beta(1+i)}{\beta(1+i)}(\sigma c_t - \psi b_{ht}) \tag{7}$$

The convenience yield introduces a wedge in the UIP condition, implying that the difference between the domestic interest rate, i_t, and the foreign interest rate, i_t^*, is not fully compensated by movements in the nominal exchange rate. The modified UIP condition also implies that in the steady state the domestic interest rate is lower than the foreign interest rate.

In other words, the Complete Asset Markets ensure international consumption risk-sharing (6), while UIP deviations (7) arise from the non-pecuniary value of domestic government bonds, which affect the pricing of nominal assets. The two mechanisms operate in separate margins: the former over consumption allocations, the latter over bond returns. This separation allows for full international risk-sharing alongside interest rate differentials driven by convenience yields.

By examining the optimality conditions above, we can already identify how the core mechanism of our model addresses the exchange rate appreciation puzzle in partial equilibrium. Specifically, holding $c_t^*, i_t^*, i_t, \mathbb{E}_t \pi_{t+1}$ constant, when a government spending shock is partially financed through debt, the increased supply of government bonds reduces the convenience yield. A lower convenience yield then leads to higher current consumption (and lower consumption growth), as reflected in Euler equation (4). In turn, the rise in current consumption results in a depreciation of the real exchange rate *ceteris paribus*, as indicated by the Backus-Smith condition (6); and in an immediate depreciation and/or a future appreciation of the nominal exchange rate, as shown by the Modified UIP condition (7).

The key insight is the substitution towards consumption resulting from the lower marginal utility of holding government debt, which offsets the negative wealth effect of government expenditure. In contrast, in the standard complete asset market DSGE model without a convenience yield a positive fiscal shock results in a negative wealth effect that generates to the exchange rate appreciation puzzle.

2.2 The firms

Now we turn to the supply side of the economy. We adopt an entirely standard approach in the New Keynesian literature by positing that monopolistically competitive firms produce differentiated goods and set prices à la Calvo (1983), so that each period a fraction θ of firms cannot change their prices. Further details are provided in Appendix A.3.

The solution of the firms' optimization problem results in a Phillips curve expressed in terms of domestic PPI inflation. The log-linearized Phillips curve is

$$\pi_{ht} = \beta \mathbb{E}_t \pi_{ht+1} + \lambda \Theta mc_t, \tag{8}$$

where π_{ht} represents domestic PPI inflation, mc_t denotes the marginal cost of production, and the parameter λ is equal to $\frac{(1-\beta\theta)(1-\theta)}{\theta}$.

The parameter Θ is defined as:

$$\frac{1-\alpha_p}{1-\alpha_p+\epsilon_p\alpha_p}$$

where $\alpha_p \in (0,1)$ denotes the output elasticity with respect to labor and $\epsilon_p > 1$ the elasticity of substitution across differentiated goods.

2.3 Fiscal policy

Given that households derive utility from holding U.S. government bonds, Ricardian Equivalence does not hold. Therefore, the composition of government financing through taxes or deficits affects real variables, including consumption, by changing the equilibrium real amount of domestic government debt. We then specify fiscal policy in a way that allows us to study the effect of funding composition by varying policy parameters.

The government budget constraint is:

$$B_t + T_t = (1 + i_{t-1})B_{t-1} + G_t \tag{9}$$

where B_t denotes the nominal value of government bonds and G_t the nominal level of government expenditure. Similarly to Galí et al. (2007), we assume a fiscal policy rule of the form

$$t_t = \phi_b b_{t-1} + \phi_g g_t \tag{10}$$

where ϕ_b and ϕ_g are positive constants. ϕ_g is of primary interest in our model, as it distinguishes between debt-funded government expenditure shocks. The extreme cases are $\phi_g = 0$, corresponding to an entirely debt-funded fiscal shock; and $\phi_g = 1$, corresponding to an entirely tax-funded fiscal shock. The model also allows for a range of partially debt-funded shocks. Importantly, the notion of funding we describe here is purely *contemporaneous*. The parameter ϕ_b regulates the degree to which debt shocks are funded by future taxation. In the simplified version of the model, we restrict our attention to equilibria in which the fiscal authority sets taxes so that all deficits are eventually repaid by means of a high enough ϕ_b. These equilibria correspond to the notion of monetary dominance in the fiscal-monetary interaction literature (Leeper, 1991). In section **??**, we extend our analysis to cases of fiscal dominance in which the central bank stabilises debt by accommodating deficits through higher inflation.

Finally, government purchases are assumed to evolve exogenously according to a first order autoregressive process

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \tag{11}$$

where $0 < \rho_g < 1$ and ε_t^g is a serially uncorrelated disturbance with zero mean.

This formulation allows us to analyze the macroeconomic effects of government spending shocks under different fiscal financing plans.

2.4 Monetary policy

To obtain analytical results, we assume that the monetary authority adjusts the nominal interest rate one-for-one with expected inflation. This implies that both the short- and long-term real interest rates remain constant in every period, i.e.

$$i_t - \mathbb{E}_t \pi_{t+1} = \sum_{s=0}^{\infty} (i_{t+s} - \mathbb{E}_t \pi_{t+1+s}) = 0 \quad \forall t$$

As a consequence, intertemporal substitution is shut down, which allows us to isolate the wealth effect and convenience yield mechanisms. Importantly, a fixed real rate also prevents debt revaluation through unexpected jumps in inflation. Combined with debt repayment through future taxation ensured by a high enough ϕ_b , this feature rules out solutions of the appreciation puzzle through a lower real interest rate and higher consumption as in the fiscal theory of the price level model in Jiang (2022).

2.5 Equilibrium dynamics

To solve the model, we log-linearize its equilibrium conditions around a zero-inflation steady state where all prices are equal to one, which ensures that the steady-state real exchange rate is also equal to one. [2] We assume that all foreign variables remain at their steady state values ($c_t^* = 0$, $i_t^* = 0$, $\pi_t^* = 0$, $g_t^* = 0$), with the sole exception of real domestic government bond holdings by foreign countries, normalized by domestic prices (b_{ht}^*). Since foreign households also derive utility from holding domestic government bonds, we can solve for b_{ht}^* and express the equilibrium conditions solely in terms of total domestic government debt, i.e. b_t. Further details are provided in Appendix A.6.

In the absence of intertemporal substitution, due to the constancy of the real interest rate, the model simplifies to a system of two equations with two endogenous dynamic variables, c_t and b_{t-1}, and one exogenous state variable, g_t. The equations in the dynamic system are

$$b_t = \frac{G}{B}\left[(1+i)\frac{B}{G} - (i\frac{B}{G}+1)\phi_b\right] b_{t-1} + \frac{G}{B}\left[1 - (i\frac{B}{G}+1)\phi_g\right] g_t \tag{12}$$

$$\mathbb{E}_t c_{t+1} = -\frac{1-\beta(1+i)}{\beta(1+i)}\frac{\psi}{\sigma} b_t + \left[1 + \frac{1-\beta(1+i)}{\beta(1+i)}\left(\psi\frac{B_H^*}{B} + \frac{B_H}{B}\right)\right] c_t, \tag{13}$$

where home-issued real government bonds, b_{t-1}, and the real government expenditure shock, g_t, are the only two state variables. The terms $\frac{G}{B}$ represents the steady state government expenditure-to-home government debt ratio, $\frac{B_H^*}{B}$ denotes the steady state ratio of home government debt held by foreign investors to home government debt and $\frac{B_H}{B}$ represents the steady state ratio of home government debt held domestically to home government debt.

[2] Appendix A.5 characterizes the steady state in further detail.

The stability and determinacy of the solution depend only on fiscal policy, ensuring bounded government debt dynamics. This requires:

$$\phi_b \in \left[\frac{i\frac{B}{G}}{1+i\frac{B}{G}}, \frac{(2+i)\frac{B}{G}}{1+i\frac{B}{G}}\right]$$

.

The lower bound ensures that taxes adjust strongly enough to debt so as to eventually repay it, preventing it from diverging to infinity. The upper bound ensures that taxes do not react so strongly as to induce explosive oscillatory dynamics. These stability conditions ensure that all debt is repaid through taxation in the future regardless of the contemporary source of funding. Therefore, they rule out the mechanism of debt stabilisation through surprise inflation typical of fiscal theory of the price level models.

Applying the method of undetermined coefficients, we conjecture that the policy function for consumption, c_t, takes the following form:

$$c_t = \chi_c b_{t-1} + \chi_g g_t \tag{14}$$

Given the Backus-Smith condition in Eq.(6), i.e. $q_t = \sigma(c_t - c_t^*)$, the exchange rate appreciation puzzle is resolved only when domestic consumption increases.

The coefficients χ_c and χ_g that satisfy the conjectured policy function are:

$$\chi_c = \frac{\frac{1-\beta(1+i)}{\beta(1+i)}\frac{\psi}{\sigma}\frac{G}{B}\left[(1+i)\frac{B}{G} - (i\frac{B}{G}+1)\phi_b\right]}{\Gamma - \frac{G}{B}\left[(1+i)\frac{B}{G} - (i\frac{B}{G}+1)\phi_b\right]} \tag{15}$$

$$\chi_g = \frac{\frac{\psi}{\sigma}\frac{1-\beta(1+i)}{\beta(1+i)}\Gamma\frac{G}{B}\left[1 - (i\frac{B}{G}+1)\phi_g\right]}{\left(\Gamma - \frac{G}{B}\left((1+i)\frac{B}{G} - (i\frac{B}{G}+1)\phi_b\right)\right)(\Gamma - \rho_g)} \tag{16}$$

where $\Gamma = 1 + \frac{1-\beta(1+i)}{\beta(1+i)}\left(\psi\frac{B_H^*}{B} + \frac{B_H}{B}\right)$.

Notably, when the parameter ψ is equal to zero, Ricardian Equivalence holds, implying that consumption remains unaffected by the amount of debt, i.e. $\chi_g = 0$ and $\chi_c = 0$. Consumption responds positively to an increase in government spending, ensuring $\chi_g > 0$, when $\psi > 0$ and $\phi_g < 1/(1+i\frac{B}{G})$. The degree of concavity in the demand for real government bond holdings, $\psi > 0$, plays a crucial role in affecting the real economy. In this case, the marginal utility of holding government bonds decreases as the supply of government debt increases, prompting households to substitute bond holdings with higher consumption. The threshold $\phi_g < 1/(1 + i\frac{B}{G})$ implies that a sufficiently high level of government spending is required for government spending to have a positive impact on consumption. We calibrate the model to study the regions of the $\{\psi, \phi_g, \phi_b\}$ parameter space that feature a positive response of consumption.

2.6 Calibration

We calibrate the model at a quarterly frequency, drawing on empirical data and insights from relevant macroeconomic literature. Our primary target is the annual average real interest rate on U.S. Treasury securities from January 1973 to April 2024, chosen to exclude the Bretton Woods period. This results in a calibrated value of $i = 0.0138$. The discount factor β is set considering an appropriate annualized convenience yield, estimated from the spread between U.S. Treasury securities and AAA U.S. corporate bonds, leading to $\beta = 0.9837$. Alternatively, the convenience yield can be calibrated using the interest rate differential between U.S. Treasuries and foreign government bonds. The model accommodates both approaches, as in steady state, the return on foreign government bonds equals the return on Arrow securities.

The Calvo price-setting probability is set to $\theta = 0.75$, following Galí (2015). The risk aversion parameter σ is set to 1. The inverse Frisch elasticity of labor supply is set to $\varphi = 2$ and the labor elasticity to $\alpha_p = 1/3$ in line with the macroeconomic literature.

Trade openness is captured by $\epsilon_b = 0.3$, while the elasticity of substitution between domestic and foreign goods is set to $\epsilon_h = 1.5$, in line with macroeconomic literature. The elasticity of substitution across varieties within a country is set to $\epsilon_p = 6$, as in Galí (2015).

The calibration of government debt to GDP (B/Y), foreign holdings of government debt to GDP (B_H^*/Y), and government spending to GDP (G/Y) are based on Federal Reserve Economic Data (FRED), aligning with the time horizon used for the annualized U.S. Treasury interest rate. Given the structure of the model, we calibrate C/Y explicitly, as symmetry between the home country and the rest of the world cannot be assumed.

In our analysis, we explore the interactions between the parameters ψ, ϕ_b and ϕ_g, by testing various combinations. Specifically, we examine three values for the curvature parameter $\psi \in \{0.5, 1.0, 1.5\}$. Given a particular choice of ψ, the utility weight of government bonds χ is determined at the steady state as:

$$\chi = [1 - \beta(1 + i)] \frac{B^\psi}{C^\sigma}$$

For the debt dynamics parameter ϕ_b, we focus on smooth paths, restricting the choice to $\phi_b \in \{0.05, 3\}$. The government expenditure response parameter, ϕ_g, is allowed to vary continuously within the interval $\phi_g \in [0, 1]$. For the autocorrelation coefficient of the government spending process, we pick $\rho_g = 0.8$ to match the persistency of US government expenditure.

Table 1 summarizes our parameter calibration.

Table 1: Analytical Model - Parameter Calibration and Values

Parameter	Description	Value
β	Discount factor	0.9837
i	Quarterly average real interest rate on U.S. Treasuries	0.0138
θ	Calvo probability of not changing prices	0.75
α_p	Output elasticity with respect to labor	1/3
σ	Risk aversion parameter	1
φ	Inverse Frisch elasticity of labor supply	2
ϵ_b	Trade openness	0.3
ϵ_h	Elasticity of substitution between domestic and foreign goods	1.5
ϵ_p	Elasticity of substitution across varieties	6
B/Y	Steady-state government debt to GDP ratio	0.66
BH^*/Y	Steady-state foreign holdings of Treasuries to GDP ratio	0.15
C/Y	Steady-state consumption to GDP ratio	0.65
G/Y	Steady-state government expenditure to GDP ratio	0.20
ρ_g	Persistency of government expenditure shocks	0.8
ψ	Curvature Parameter	$\{0.5, 1.0, 1.5\}$
ϕ_b	Parameter related to debt dynamics	$\{0.05, 3\}$
ϕ_g	Parameter for government expenditure response dynamics	$[0, 1]$

2.7 Impulse response functions

In this section, we examine the impulse response functions following both tax-funded and debt-funded government expenditure shocks. Additionally, we analyze the sensitivity of the impulse responses to variations in the fiscal policy parameter ϕ_g, which determines the extent to which government spending is financed through lump-sum taxation rather than debt issuance.

2.7.1 Tax-funded government expenditure shock

In Figure 2, we present the impulse response functions following a tax-funded government expenditure shock. In this case, the exchange rate appreciation puzzle is not resolved for all combinations of ψ and ϕ_b. Households anticipate higher future taxes, which prompts them to increase savings and reduce their consumption. This reduction in consumption leads to a decrease in the real exchange rate (an appreciation), as explained by the Backus-Smith condition (Eq. 6).

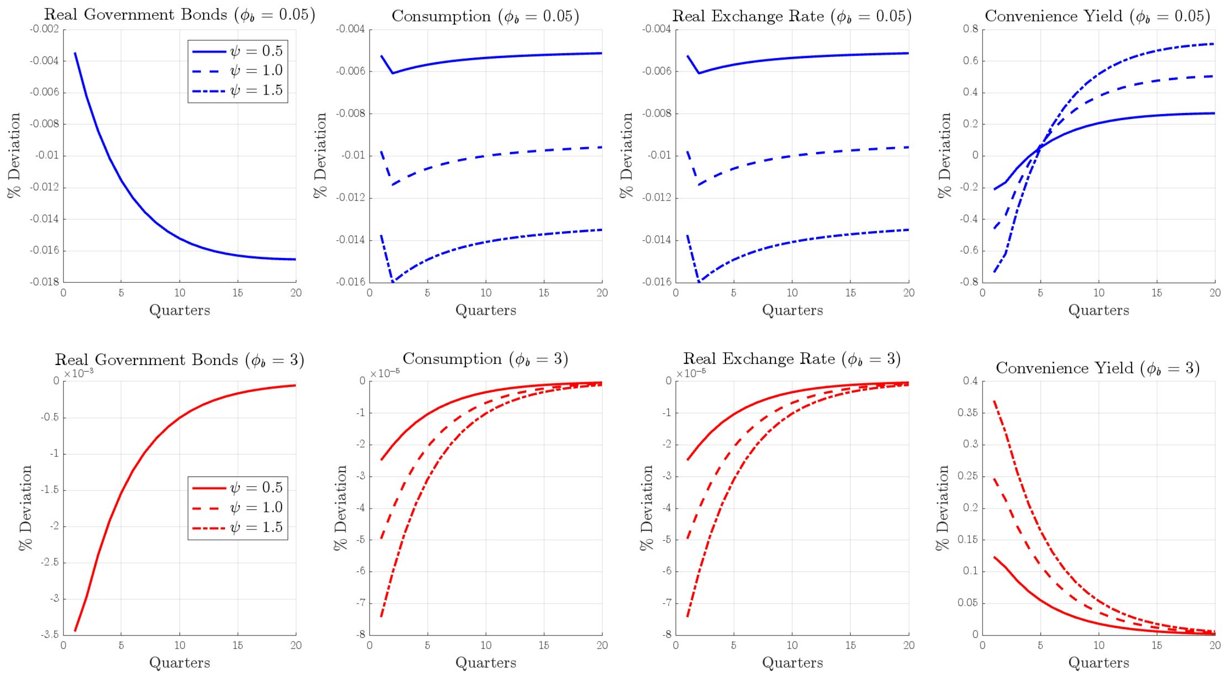


Figure 2: IRF following 0.25% tax-funded government expenditure shock, $\phi_g = 1$

2.7.2 Debt-funded government expenditure shock

In Figure 3, we present the impulse response functions following a debt-funded government expenditure shock. From Equation 4, we observe that the value of the convenience yield is influenced by the intra-temporal substitution between real government bond holdings and consumption. Since the real government expenditure shock is entirely financed through an increase in the real value of government debt, households substitute real government bonds for consumption. This substitution effect is more pronounced as the curvature of the utility from bonds, ψ, increases. As is typical in models with international risk sharing, the increase in domestic consumption leads to a depreciation of the real exchange rate (Eq. 6). Furthermore, the increase in consumption is weaker as the fiscal parameter governing stable real debt dynamics, ϕ_b, increases. This can be explained by the fact that a larger ϕ_b implies a more rigid fiscal policy, where the fiscal authority is required to maintain the real value of government debt stable. As a result, the authority's constraint limits the extent to which consumption can increase in response to the debt-funded government expenditure shock.

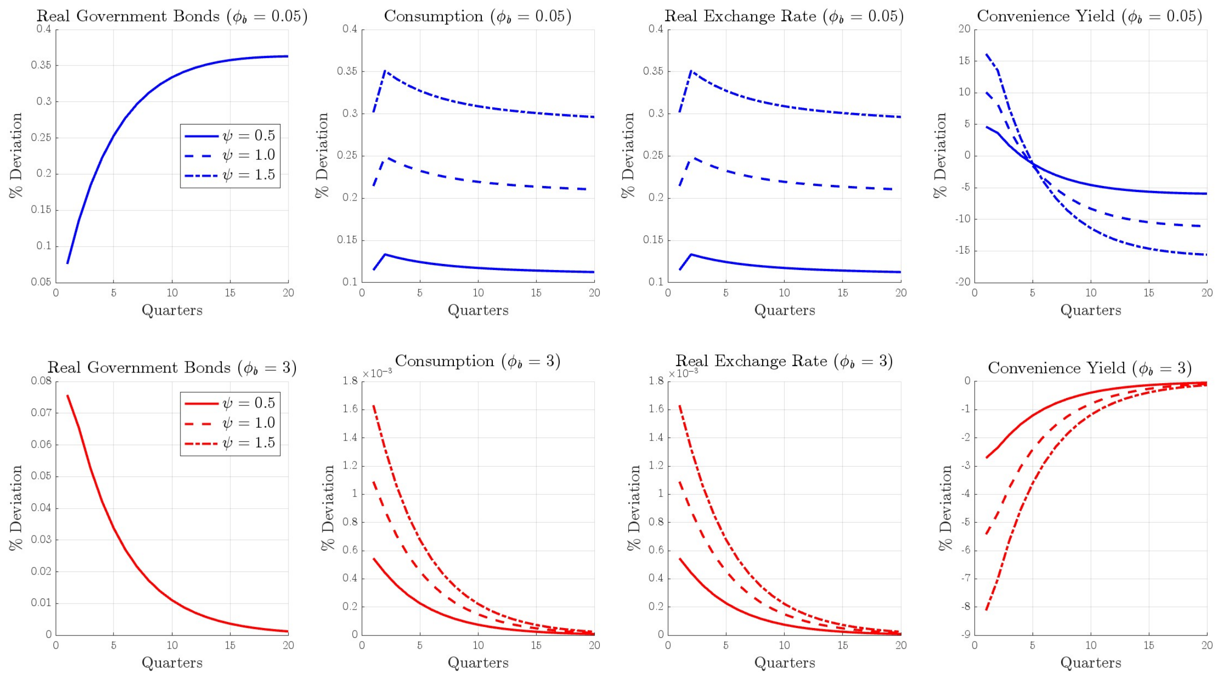


Figure 3: IRF following 0.25% debt-funded government expenditure shock, $\phi_g = 0$

2.7.3 Sensitivity to variations in the fiscal policy parameter ϕ_g

Figure 4 highlights the crucial role played by the parameter ϕ_g in addressing the exchange rate appreciation puzzle. Lower values of ϕ_g indicate that the government expenditure shock is primarily funded through debt, which has a positive effect on consumption and leads to a depreciation of the real exchange rate. Furthermore, for low values of ϕ_b, representing rigidity in fiscal behavior, the model fails to generate the correct direction for the convenience yield. The empirical literature, such as Graziano and Phillot (2024), Du et al. (2018) and Jiang et al. (2024), provides substantial evidence that an increase in the supply of government bonds should lead to a reduction in the convenience yield. This finding suggests that a more stringent fiscal authority is needed to correct both the direction of the real exchange rate and the convenience yield, reinforcing the importance of fiscal policy in these dynamics.

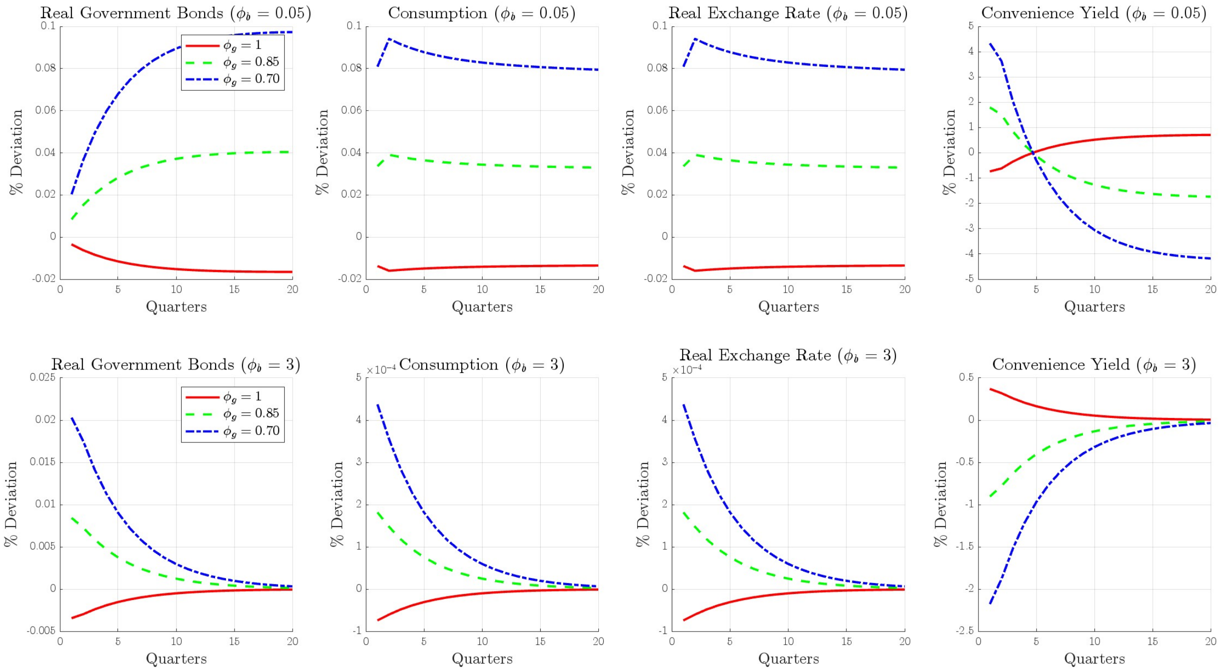


Figure 4: Sensitivity of IRF to ϕ_g

3 Quantitative model

In this section, we extend the analytical model presented in Section 2 by incorporating a more realistic specification for the convenience yield and the conduct of monetary policy. Further details on the quantitative model are provided in Appendix B.

3.1 The household

The representative household in the home country maximizes its expected lifetime utility.

$$\mathbb{E}_t \sum_{t=0}^{\infty} \left(\beta^t \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right) \tag{17}$$

subject to the intertemporal budget constraint

$$P_tC_t + \mathbb{E}_t\Lambda_{t,t+1}D_{t+1} + B_{Ht} + \mathcal{E}_tB_{Ft} + P_t\chi C_t^{\alpha}\left(\frac{B_{Ht}}{P_t}\right)^{1-\alpha} = \\ = D_t + W_tN_t - T_t + B_{Ht-1}(1+i_{t-1}) + \mathcal{E}_tB_{Ft-1}(1+i^*_{t-1}) \qquad (18)$$

along with the usual no-Ponzi-game conditions. Further details on the optimality conditions are provided in Appendix B.1.

Compared to the analytical model, the hey innovation lies in the treatment of the convenience yield. Specifically, we move from the standard "bonds-in-the-utility-function" framework to a transaction technology approach, represented by the term:

$$P_t\chi C_t^{\alpha}\left(\frac{B_{Ht}}{P_t}\right)^{1-\alpha}$$

where $\alpha > 1$ governs how steeply transaction costs increase as liquidity deteriorates and χ is a scale parameter for the transaction cost function. In this setup, the strength of the convenience yield is governed by the parameter α. When the parameter restriction on α is satisfied, a higher α implies that liquidity shortages (i.e. low bond holdings) lead to rapidly increasing transaction costs, thereby emphasizing the role of bonds as a liquidity-providing asset.

Despite the functional equivalence between these two modeling strategies—originally demonstrated by Feenstra (1986)—the transaction cost approach offers a deeper microeconomic foundation for the role of government bonds. In this specification, households do not derive utility directly from holding bonds (as in reduced-form utility models), but rather benefit from their ability to lower transaction costs.

This more structural modeling choice aligns better with the empirical features of government bonds: they are more liquid than other assets, often serve as collateral, and can be readily liquidated in times of stress. This micro-founded rationale is widely adopted in the quantitative macro-finance literature (see, for instance, Valchev (2020) and Bansal and Coleman (1996)).

3.2 Monetary Policy

Compared to the analytical model, instead of maintaining a constant real interest rate, the monetary authority now follows a CPI-based Taylor Rule, given by:

$$i_t = \phi_\pi \pi_t$$

As a result, fiscal policy can no longer be considered independent of monetary policy. The interaction between these two policies introduces an intertemporal substitution mechanism that links real government bond holdings to the consumption path. Furthermore, this extended framework introduces a new parameter, ϕ_π, which was not present in the original analytical model. In the following analysis, we examine the stability and determinacy properties of this new setup, along with the corresponding impulse response functions.

3.3 Equilibrium

Given the introduction of a new parameter, ϕ_π, we now analyze the interaction between ϕ_π, ϕ_b, and α, and their impact on the stability and determinacy properties of equilibrium dynamics. Specifically, we consider three different values of $\alpha \in \{15, 20, 25\}$ and define a parameter grid for $\phi_\pi \in [0, 2]$ and $\phi_b \in [-1, 1.5]$. Notably, the fiscal parameter ϕ_b is not constrained to be strictly positive, as the debt burden can be mitigated through inflation dynamics, allowing the fiscal authority to implement pro-cyclical fiscal policies.

Figure 5 illustrates that, for each value of α, the combinations of ϕ_π and ϕ_b exhibit similar patterns, delineating two distinct regimes. The lower-left quadrant represents the Fiscal Dominance Region, characterized by low values of ϕ_b and ϕ_π, where fiscal policy is active and monetary policy is passive. Conversely, the upper-right quadrant corresponds to the Monetary Dominance Region, where both ϕ_b and ϕ_π are high, leading to an active monetary policy alongside a passive fiscal policy.

In Figure 6, in addition to analyzing the interactions between ϕ_π, ϕ_b, and α, we allow the parameter ϕ_g to vary within the interval $[0, 1]$. This allows us to identify the minimum proportion of debt financing necessary to resolve the exchange rate appreciation puzzle. As ϕ_g increases, a smaller share of government expenditure must be financed through debt issuance. Our results indicate that the puzzle is resolved under both the Fiscal Dominance regime and the (weak) Monetary Dominance regime.

Figure 7 presents a comparative exercise in which the same model is solved both without and with a convenience yield. The findings show that the exchange rate appreciation puzzle is resolved under the Fiscal Dominance regime in both cases. However, under the Monetary Dominance regime, the puzzle is resolved only when the convenience yield is introduced.

Appendix C presents the results obtained using a monetary policy rule that includes an interest rate smoothing parameter.

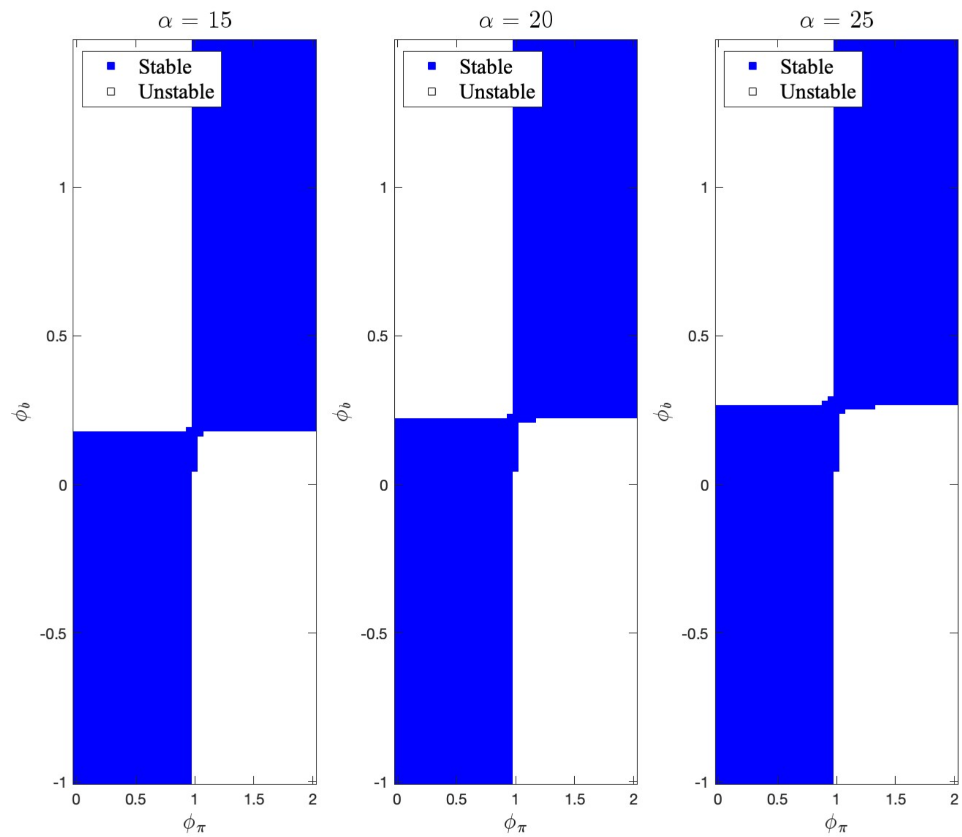


Figure 5: Stability Regions

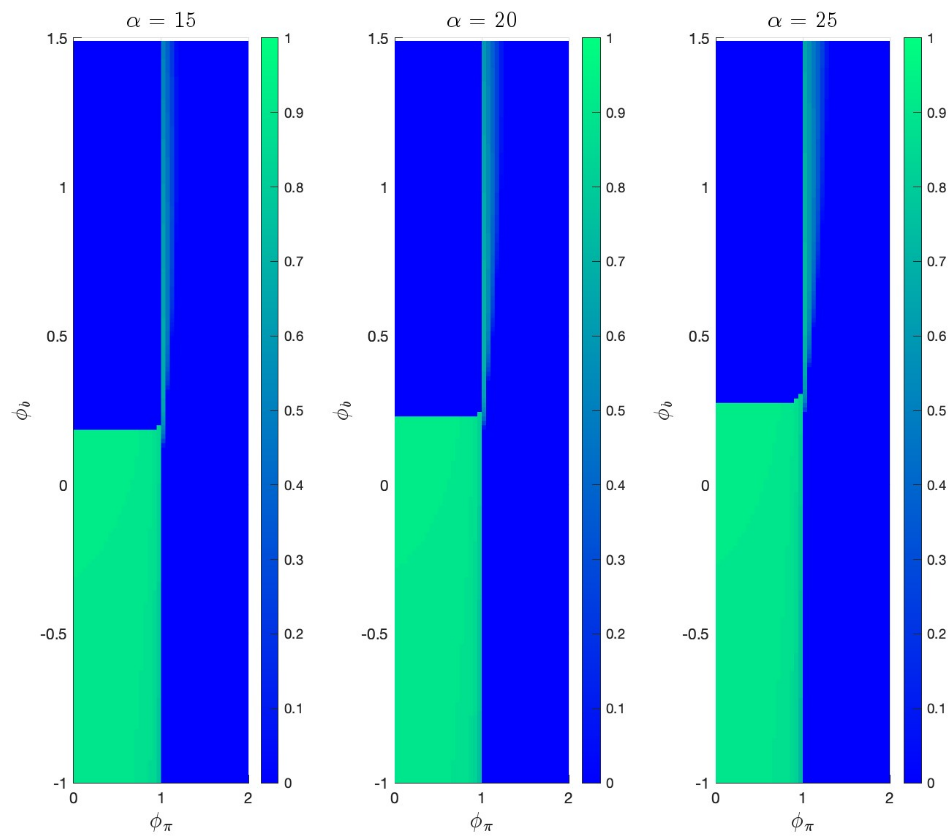
3.4 Impulse response functions

In the following analysis, we present the impulse response functions for both the Fiscal Dominance and Monetary Dominance regimes in response to government expenditure shocks, distinguishing between tax-funded and debt-funded scenarios.

3.4.1 Fiscal dominance regime

As expected, in response to a tax-funded government expenditure shock under Fiscal Dominance, households anticipate higher future taxation, prompting them to reduce consumption. This decline in consumption, through the Backus-Smith condition (Eq. 6), leads to an appreciation of the real

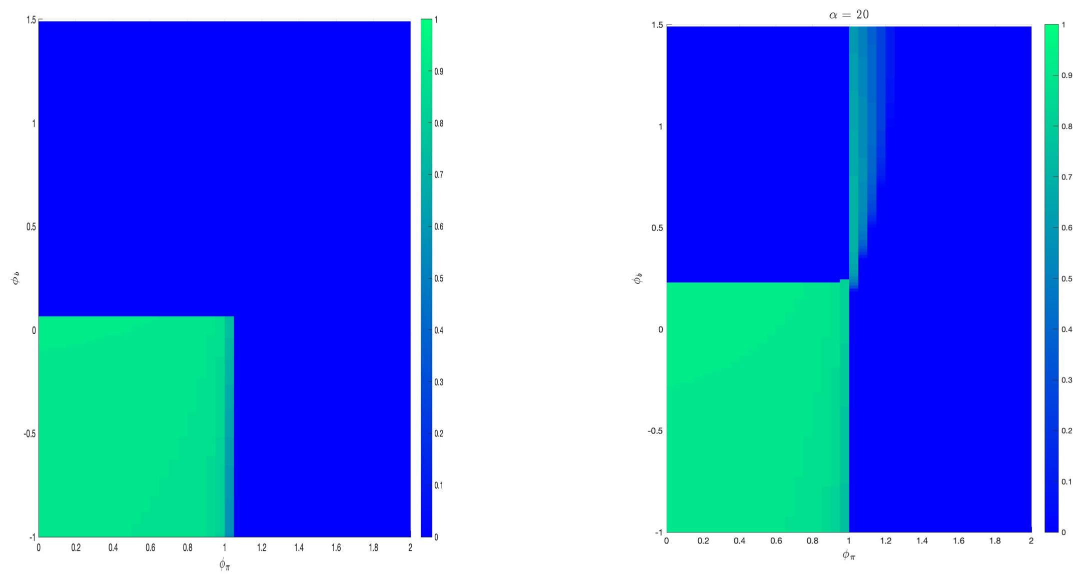
Figure 6: On-impact depreciation regions



exchange rate.

In a Fiscal Dominance regime, the monetary authority lacks full control over inflation dynamics, which are influenced by the government expenditure shock through the Phillips Curve. This can be observed by combining Equations 3, 8, and 39. Consequently, following a debt-funded government expenditure shock, the real interest rate declines. A lower real interest rate reduces the opportunity cost of consumption, encouraging households to increase their consumption levels — an effect driven by intertemporal substitution arising from the interaction between monetary and fiscal policy. Additionally, higher inflation erodes the real value of government bond holdings. Through

Figure 7: Model results for various ϕ_g under alternative assumptions about the convenience yield.



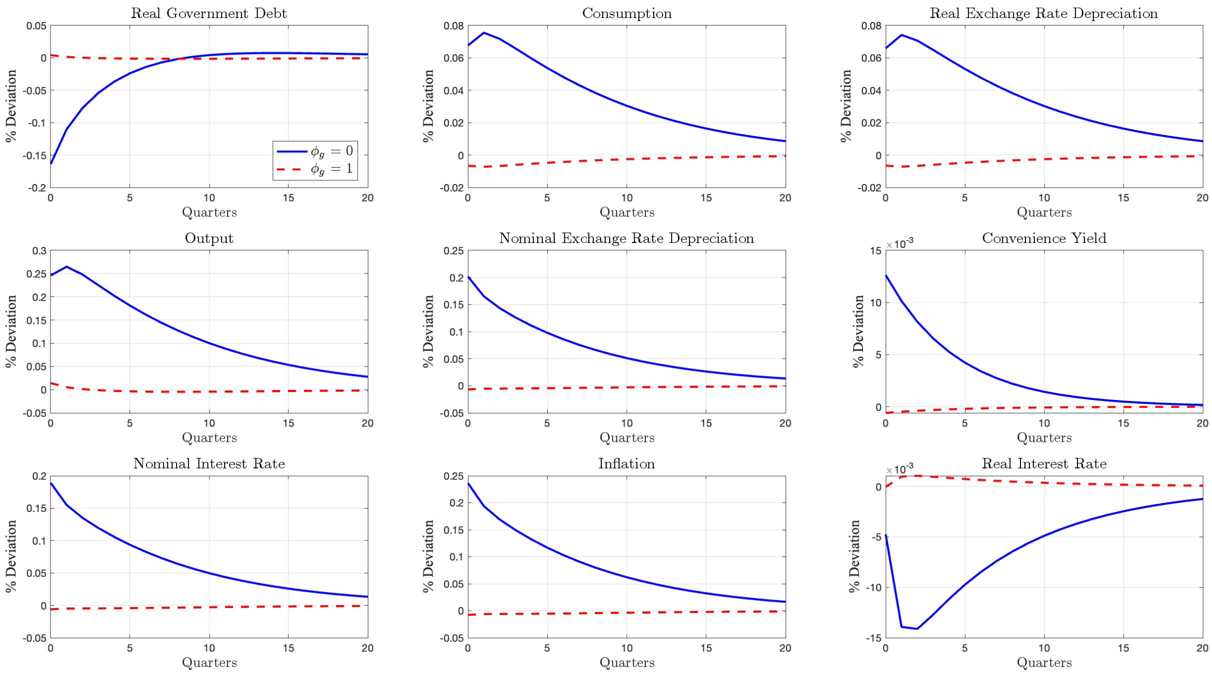
No Convenience Yield

With Convenience Yield

the convenience yield mechanism, as captured in Eq. 4, households may opt to save rather than consume, substituting current consumption with increased government bond holdings via intratemporal substitution.

Figure 8 illustrates that the intertemporal substitution effect outweighs the intratemporal substitution effect, ultimately leading to higher consumption. As a result, in accordance with the Backus-Smith condition (Eq. 6), the increase in consumption induces a depreciation of the real exchange rate, thereby resolving the exchange rate appreciation puzzle. However, contrary to empirical evidence, the convenience yield rises. Empirical studies show that an increased supply of government debt typically leads to a decrease in the convenience yield. This result becomes particularly interesting when compared to the analysis in Jiang (2022), which demonstrates that under the fiscal theory of the price level—a case of extreme Fiscal Dominance—the exchange rate appreciation puzzle is resolved. Based on our findings, we conclude that fiscal dominance alone does not provide a complete explanation, as it fails to match the observed negative relationship between the supply of government debt and the convenience yield.

Figure 8: IRF to a 0.25% percent increase in government expenditure under Fiscal Dominance



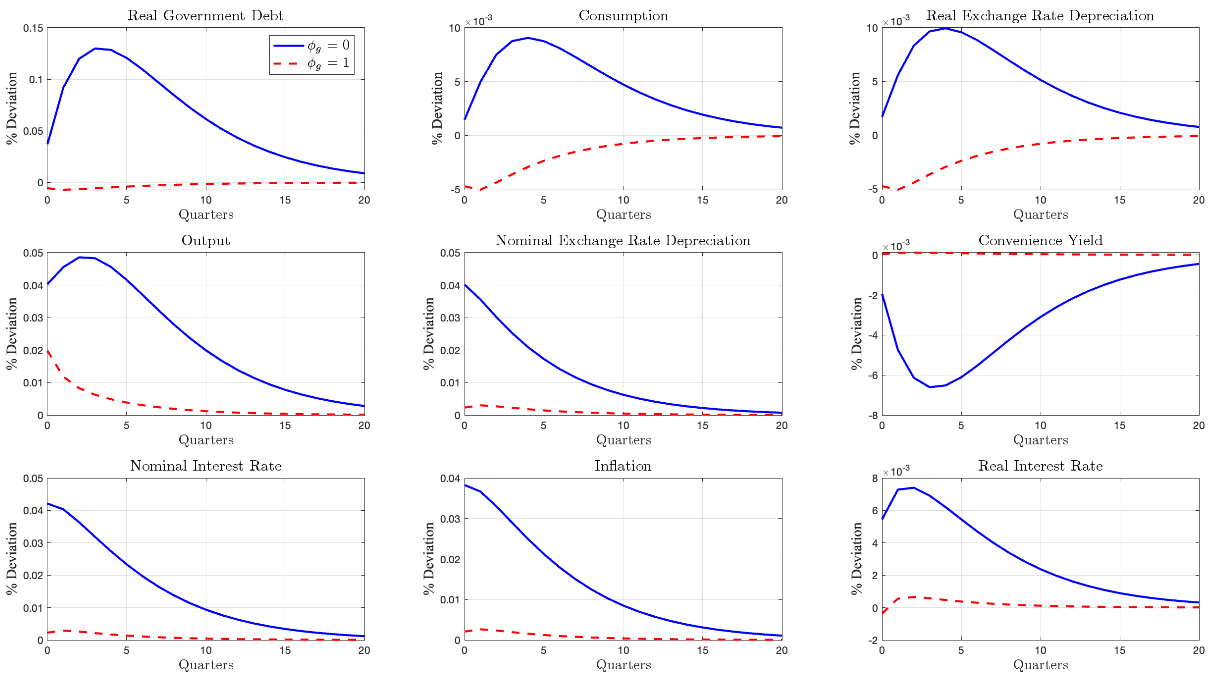
$\phi_b = 0$, $\phi_\pi = 0.8$, and $\alpha = 20$

3.4.2 Monetary dominance regime

In a Monetary Dominance regime, the monetary authority has full control over inflation, which results in an increase in the real interest rate, thereby raising the opportunity cost of consumption. This represents the intertemporal substitution effect. Following a debt-funded government expenditure shock, the real level of government bond holdings increases. This increase in real bond holdings encourages households to substitute a higher level of consumption for greater government bond holdings, through intratemporal substitution.

Figure 9 illustrates that, under a weakly active monetary policy, the intratemporal substitution effect dominates the intertemporal one, leading to an increase in consumption. As a result, the exchange rate appreciation puzzle is resolved under a weak Monetary Dominance regime. This outcome implies that Monetary Dominance is consistent with both the correct sign of the convenience yield and the observed direction of the change in consumption. These findings underscore the relevance of our mechanism, as it extends the solution to the puzzle beyond what is achieved in the model without a convenience yield (as shown in Figure 7) under Monetary Dominance.

Figure 9: IRF to a 0.25% percent increase in government expenditure under Monetary Dominance



$\phi_b = 1$, $\phi_\pi = 1.1$, and $\alpha = 20$

4 Empirical evidence

In this section, we investigate whether the financing composition of government spending, determined by ϕ_g in the model, matters empirically for the reaction of the real exchange rate to government spending shocks. As in the model, we focus on the source of *contemporaneous* funding for government expenditures, remaining agnostic on whether the intertemporal budget constraints of the government ultimately adjusts through future tax increases, corresponding to a monetary-led regime in the model; or through surprise inflation, corresponding to a fiscal-led regime.

Distinguishing between monetary and fiscal dominance in the data is notoriously challenging (Cochrane, 1999; Leeper and Walker, 2012), but our approach allows us to test the predictions of the two regimes by comparing the joint reaction of the real exchange rate and the relative convenience yield of U.S. Treasuries in response to a debt- of tax-financed fiscal shock.

4.1 Methodology

4.1.1 Estimating equation

We estimate a state-dependent local projection (Ramey and Zubairy, 2018; Cloyne et al., 2023) of real exchange rates, relative convenience yield and other relevant variables on government spending, with two states that represent different regimes for the funding of government spending. The estimating equation is

$$y_{t+h} - y_{t-1} = \alpha^h + \mathbb{I}_t \left[\beta_D^h \Delta G_t\right] + (1 - \mathbb{I}_t) \left[\beta_T^h \Delta G_t\right] + \varepsilon_t^h, \quad h = \{1, ..., H\}, \tag{19}$$

where y_t is either the trade-weighted real dollar index, government spending, the relative convenience yield of U.S. Treasuries, deficits, or tax receipts. An increase in the trade-weighted real dollar index corresponds to a real dollar depreciation. All these variables are in real terms and calculated as a ratio to potential GDP. ΔG_t is the quarterly change in real government spending. $\mathbb{I}_t$ is an indicator variable that defines the funding regime of government spending. It takes value 1 when deficit increases and taxes simultaneously do not increase in quarter t . Therefore, the β_D^h coefficient measures the h-period ahead response of y_t to a one percentage point increase of government spending funded entirely by debt, while β_T^h measures the response to government spending funded at least partially by taxes. The former coefficient maps directly to $\phi_g = 0$ in the model, while the latter encompasses a large set of values for ϕ_g, ranging from full to partial tax funding.

One limitation of the current definition of states is that it does not allow to precisely disentangle fully debt-funded and fully tax-funded spending, nor does it capture the continuous nature of ϕ_g. This approach trades off precision in the definition of the funding regime with simplicity in limiting the number of states to two; and sample size in including a wider range of fiscal episodes than it would be otherwise possible with a stricter definition of states. We estimate this equation on quarterly data from the United States from 1973 Q2 to 2015 Q4. The beginning of the sample coincides with the effective end of the Bretton Woods arrangement, which ushered in the era of flexible exchange rates; while the end reflects data availability.

4.1.2 Identification strategy

The estimation of Equation 19 by OLS would clearly suffer from endogeneity. For example, the cyclical fluctuations of government spending through automatic stabilisers systematically correlate with macroeconomic aggregates such as consumption, which in turn affect the real exchange rate.

To overcome this issue, we instrument changes in government spending ΔG_t with the Ramey (2016) military news shocks. The shock series is built by extracting public expectations on the size of newly-announced military spending from newspaper articles and historical accounts. The exclusion restriction requires that new military expenditures be unrelated to the any macroeconomic development that affects the dependent variables. Since the shocks are constructed from news articles, they capture announcements of government spending that may happen in the future. Therefore, they should be understood as "news" shocks in the context of the government spending anticipation literature (Susan Yang, 2005; Mertens and Ravn, 2010; Leeper et al., 2013).

Formally, we adopt a two-stage least squares approach, where the first stage is

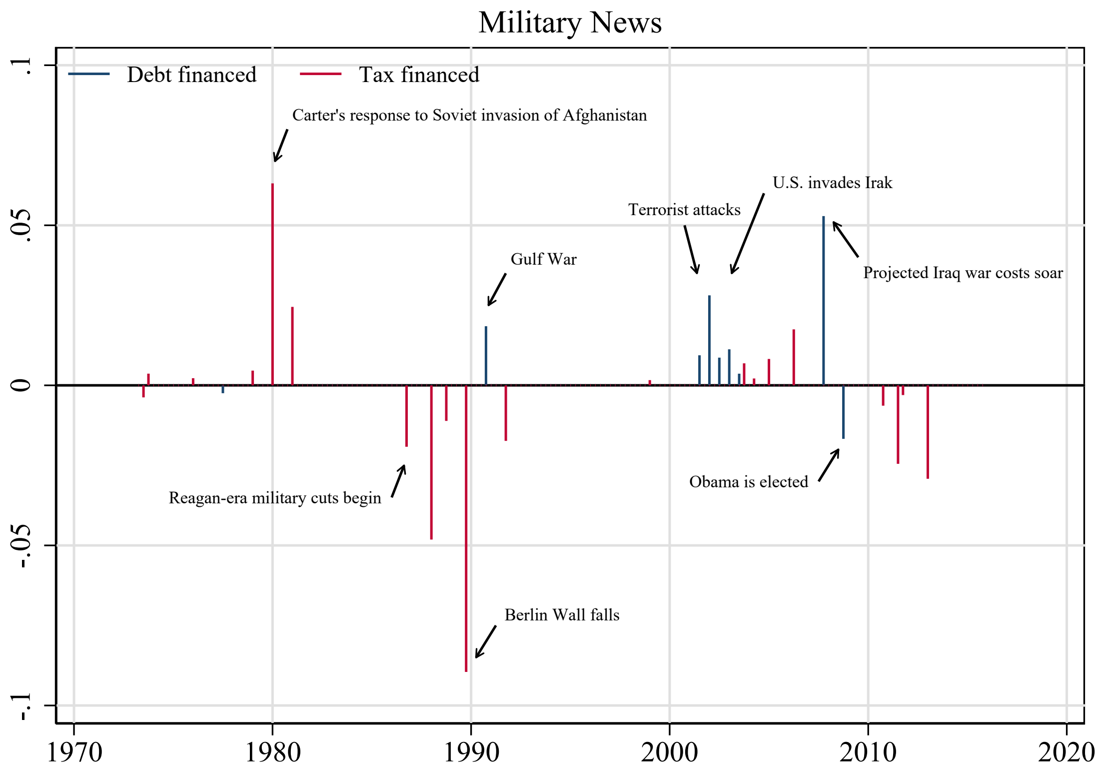
$$\Delta G_t = a + b \cdot \text{News}_t + e_t. \tag{20}$$

We then use the fitted values $\Delta\tilde{G}_t$ as an instrument for ΔG_t to estimate Equation 19 in the second stage.

Figure 10 depicts the shock series and marks some specific events that generated the military spending news. The blue bars denote episodes in which deficits rose and taxes did not, while red bars denote other episodes. There is substantial variety both in the sign of the shocks and in the source of contemporaneous funding, even though we restrict our attention to news about military expenditure only. For example, the fall of the Berlin Wall was associated with expectations of lower military spending by almost 10% of potential GDP, accompanied by a drop in tax receipts. On the other hand, the start of the Gulf War led to expectations of higher government spending by roughly 2% of potential GDP financed by a higher deficit.

The entire series comprises 29 episodes. The dearth of available events justifies our approach in the definition of funding regimes, as any stricter classification would have resulted in insufficient variation in the shocks, resulting in instrument weakness.

Figure 10: Military spending news shocks



Military news shock series from Ramey (2016) as a ratio of potential real GDP. The blue bars correspond to events under the debt-financed regime with $\mathbb{I}_t = 1$, while red bars correspond to events under the tax-financed regime with $\mathbb{I}_t = 0$.

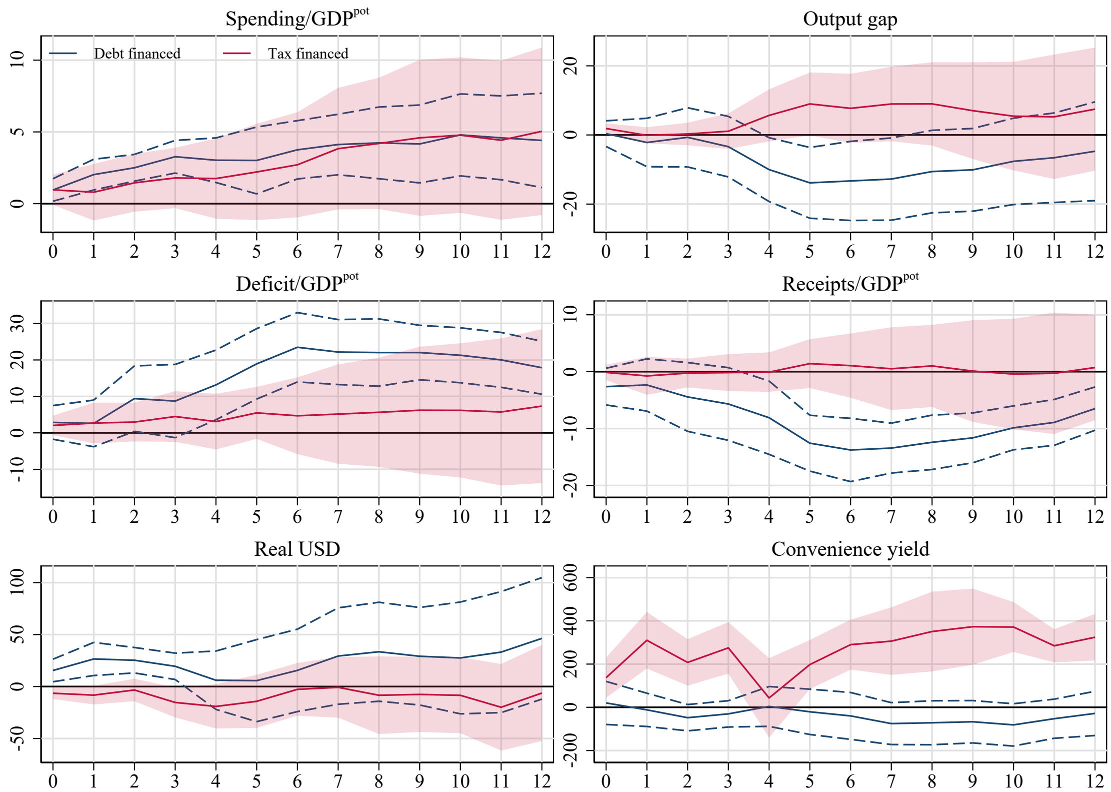
4.2 Results

Figure 11 displays the impulse response functions of the real exchange rate to government spending shocks. The blue lines represent the responses in the debt-financed regime, while the red lines those in the tax-funded regime.

Government spending over potential GDP increases by one percent on impact by construction in both regimes, and it remains persistently high for up to 3 years. Interestingly, the dynamics of government spending do not show any sign of reversal, which Corsetti et al. (2012) proposes as a solution for the exchange rate appreciation puzzle.

Deficit over potential GDP rises by around 2 percentage points on impact and remains persistently

Figure 11: Impulse responses to government spending shocks



Impulse response functions from a 2SLS estimation of Equation (19). Blue lines report results under the debt-financed regime with $\mathbb{I}_t = 1$, while red lines report results under the tax-financed regime with $\mathbb{I}_t = 0$. The blue dashed lines and the red shaded areas depict 90% confidence bands based on Newey and West (1987) standard errors. All variables are in percentage points, except for the Real USD index and the convenience yield, which are in basis points. The x-axis represents quarters from the initial shock.

high in the debt-funded regime. It rises in the tax-funded regime as well, although the reaction is smaller and not very statistically significant. The increase of deficit in the tax-funded regime is not surprising, given that we define the latter as the complement of episodes that feature an increase in deficit without an increase in taxes. This definition encompasses cases of partial tax funding in which both deficits and taxes rise. On the other hand, tax receipts over potential GDP rise slightly in the tax-funded regime, while they fall by up to 12 percentage points over time in the debt-funded regime. The joint behaviour of deficits and tax receipts react in a manner consistent with deficit and tax financing in the respective states, lending credibility to the regime definition procedure.

The real exchange rate displays a clearly different behaviour in the two regimes. In the debt-financed regime, it depreciates by roughly 10% on impact, and the depreciation persists for up to 3 years. On the contrary, in the tax-funded regime it appreciates by around 2.5% on impact and it remains appreciated up to 3 years. These results are qualitatively consistent with the predictions of the model: debt financing delivers an exchange rate depreciation, while tax financing results in an appreciation.[3] Therefore, the standard prediction of a real appreciation in response to an increase in government spending, typical of a wide range of complete-market models, does appear to have empirical support if the fiscal shock is financed at least in part by higher taxation. However, the source of funding matters and a fully debt-financed spending shock recovers the depreciation usually found in the empirical literature.

The distinction between debt- and tax-financed fiscal shocks helps frame some results on the open-economy effects of government spending. Forni and Gambetti (2016) identifies both news and surprise shocks in an open-economy VAR, finding that the former triggers an increase in government surplus and a real appreciation, while the latter a drop in surpolus and a real depreciation. Through the lens of our approach, the difference between the two can be attributed to the implied source of financing, rather than only to the anticipation features of the fiscal shock itself. On the other hand, our results stand in stark contrast with the findings in Ferrara et al. (2021), which reports a combination of lower tax revenue and an appreciated exchange rate in response to a fiscal expansion identified with Ramey (2016) news shocks in a proxy SVAR.

Importantly, the real exchange rate depreciation in response to a debt-funded fiscal expansion is by itself consistent with both the convenience yield mechanism articulated in our model, and with the adjustment through inflation and lower real debt first introduced by Jiang (2022) and at work here in the fiscal dominance regime of the full model. The prediction of a higher convenience yield implicit in the fiscal dominance regime is however at odds with the well-established findings of a drop in the convenience yield in response to higher nominal government debt.

The empirical behaviour of the convenience yield allows us to discriminate between these two competing explanations. A debt-funded shock leads to a small but persistent drop in the relative convenience yield of U.S. Treasuries, while a tax-funded shock causes a very large and persistent increase of up to 4 percentage points. These responses are qualitatively consistent with the predictions of both the analytical model, and the full model under monetary dominance. However, they stand at odds with models of fiscal dominance that predict an increase in the convenience yield due to the fall of real government debt after a fiscal shock.

[3] Although qualitatively consistent, the estimated reaction of the exchange rate is much larger than in the model simulation.

5 Conclusion

This paper establishes two main implications of the convenience yield of U.S. Treasuries for the reaction of the real exchange rate to fiscal shocks.

First, if households value the liquidity of government bonds, the real amount of debt becomes a key variable in equilibrium, directly affecting consumption through a substitution margin. As a consequence, the *contemporaneous* composition of funding for government spending assumes a crucial role for the behaviour of the real exchange rate under complete markets. In a simple New-Keynesian open-economy model with a fixed real rate, this mechanism suffices to overturn the usual real appreciation in response to fiscal expansions and delivers the depreciation often found empirically. This result is contingent on expenditures being financed at least in part by the issuance of new debt, as the convenience yield shrinks and households consume more to equate marginal utilities. The importance of the funding source is confirmed by the empirical evidence: in the U.S., a debt-funded fiscal shock leads to a real depreciation and a lower convenience yield, while a tax-funded one results in an appreciation and a higher convenience yield.

Second, in a model where the nominal rate adjusts according to a Taylor rule, the interactions between monetary and fiscal policy regime take centre stage. Under fiscal dominance, a debt-funded fiscal expansion depreciates the real exchange rate consistently with empirical findings, but it also causes the convenience yield to rise counterfactually. Instead, a monetary-led regime predicts empirically-consistent drop in the convenience yield in response to debt-funded fiscal shocks. However, the real exchange rate appreciates under most Taylor rule parameters, introducing once again the central issue afflicting many complete-markets DSGE models. In this setting, the puzzle can be reconciled by a monetary policy rule that reacts relatively weakly to inflation while still respecting the Taylor principle.

In a macroeconomic conjuncture characterised by large and volatile government spending, these results underscore the importance of fiscal financing and monetary-fiscal interactions, as debt- and tax-funded shocks have starkly different implications not only for the domestic economy and the liquidity of its government debt, but also beyond national borders through exchange rates.

References

Auerbach, A. and Y. Gorodnichenko (2016). Effects of fiscal shocks in a globalized world. *IMF Economic Review 64*(1), 177–215.

Backus, D. K., P. J. Kehoe, and F. E. Kydland (1994). Dynamics of the Trade Balance and the Terms of Trade: The J-Curve? *American Economic Review 84*(1), 84–103.

Bansal, R. and W. J. Coleman (1996, December). A Monetary Explanation of the Equity Premium, Term Premium, and Risk-Free Rate Puzzles. *Journal of Political Economy 104*(6), 1135–1171.

Beetsma, R., M. Giuliodori, and F. Klaassen (2008, April). The Effects of Public Spending Shocks on Trade Balances and Budget Deficits in the European Union. *Journal of the European Economic Association 6*(2-3), 414–423.

Benetrix, A. S. and P. R. Lane (2013). Fiscal Shocks and the Real Exchange Rate. *International Journal of Central Banking 9*(3), 32.

Bianchi, F., R. Faccini, and L. Melosi (2023). A Fiscal Theory of Persistent Inflation. *The Quarterly Journal of Economics 138*(4), 2127–2179.

Blanchard, O. J. (1985, April). Debt, Deficits, and Finite Horizons. *Journal of Political Economy 93*(2), 223–247.

Bodenstein, M., P. C. Borda, N. Gornemann, I. Presno, A. Prestipino, A. Queralto, and A. Raffo (2023, October). Global Flight to Safety, Business Cycles, and the Dollar. *International Finance Discussion Paper* (1381), 1–70.

Boehm, C. (2020). Government consumption and investment: Does the composition of purchases affect the multiplier? *Journal of Monetary Economics 115*(C), 80–93.

Bonam, D. (2020). A Convenient Truth: The Convenience Yield, Low Interest Rates and Implications for Fiscal Policy. *SSRN Electronic Journal*.

Born, B., F. D'Ascanio, G. Müller, and J. Pfeifer (2019). The Worst of Both Worlds: Fiscal Policy and Fixed Exchange Rates. Technical report.

Born, B., F. Juessen, and G. J. Müller (2013). Exchange rate regimes and fiscal multipliers. *Journal of Economic Dynamics and Control 37*(2), 446–465.

Bouakez, H. and A. Eyquem (2015, September). Government spending, monetary policy, and the real exchange rate. *Journal of International Money and Finance 56*, 178–201.

Bouakez, H. and N. Rebei (2007, August). Why does private consumption rise after a government spending shock? *Canadian Journal of Economics/Revue canadienne d'économique 40*(3), 954–979.

Brinca, P., H. Holter, P. Krusell, and L. Malafry (2016). Fiscal multipliers in the 21st century. *Journal of Monetary Economics 77*(C), 53–69.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of monetary Economics 12*(3), 383–398.

Chodorow-Reich, G. (2017). Geographic cross-sectional fiscal multipliers: What have we learned? Working paper, Harvard University OpenScholar.

Cloyne, J., Òscar Jordà, and A. M. Taylor (2023, February). State-Dependent Local Projections: Understanding Impulse Response Heterogeneity. NBER Working Papers 30971, National Bureau of Economic Research, Inc.

Cochrane, J. (2022, July). A fiscal theory of monetary policy with partially repaid long-term debt. *Review of Economic Dynamics 45*, 1–21.

Cochrane, J. H. (1999, January). A Frictionless View of US Inflation. In *NBER Macroeconomics Annual 1998, volume 13*, NBER Chapters, pp. 323–421. National Bureau of Economic Research, Inc.

Corsetti, G., L. Dedola, and S. Leduc (2010). Optimal monetary policy in open economies. In B. M. Friedman and M. Woodford (Eds.), *Handbook of Monetary Economics* (1 ed.), Volume 3, Chapter 16, pp. 861–933. Elsevier.

Corsetti, G., A. Meier, and G. J. Müller (2012, November). Fiscal Stimulus with Spending Reversals. *Review of Economics and Statistics 94*(4), 878–895.

Corsetti, G. and P. Pesenti (2001, May). Welfare and Macroeconomic Interdependence. *The Quarterly Journal of Economics 116*(2), 421–445.

De Paoli, B. (2009). Monetary policy and welfare in a small open economy. *Journal of International Economics 77*(1), 11–22.

Di Giorgio, G., S. Nisticò, and G. Traficante (2018, March). Government spending and the exchange rate. *International Review of Economics & Finance 54*, 55–73.

Ding, X. and Z. Jiang (2024). Monetary-fiscal coordination with international hegemon. NBER Working Papers 33123, National Bureau of Economic Research, Inc.

Du, W., J. Im, and J. Schreger (2018, May). The U.S. Treasury Premium. *Journal of International Economics 112*, 167–181.

Du, W., A. Tepper, and A. Verdelhan (2018, June). Deviations from Covered Interest Rate Parity. *The Journal of Finance 73*(3), 915–957.

Dupor, B. (2000, June). Exchange rates and the fiscal theory of the price level. *Journal of Monetary Economics 45*(3), 613–630.

Engel, C. (2002). Expenditure switching and exchange rate policy (Engel 2002).pdf. *NBER Macroeconomics Annual*.

Engel, C. and S. P. Y. Wu (2023, September). Liquidity and Exchange Rates: An Empirical Investigation. *The Review of Economic Studies 90*(5), 2395–2438.

Feenstra, R. C. (1986, March). Functional equivalence between liquidity costs and the utility of money. Technical report, Columbia University, New York, NY 10027, USA.

Ferrara, L., L. Metelli, F. Natoli, and D. Siena (2021, November). Questioning the puzzle: Fiscal policy, real exchange rate and inflation. *Journal of International Economics 133*, 103524.

Forni, M. and L. Gambetti (2016, March). Government spending shocks in open economy VARs. *Journal of International Economics 99*, 68–84.

Galí, J. (2015). Monetary policy, inflation, and the business cycle: An introduction to the new keynesian framework and its applications.

Galí, J., J. D. López-Salido, and J. Vallés (2007, March). Understanding the Effects of Government Spending on Consumption. *Journal of the European Economic Association 5*(1), 227–270.

Georgiadis, G., G. J. Müller, and B. Schumann (2023). Dollar Trinity and the Global Financial Cycle. *SSRN Electronic Journal*.

Graziano, M. and M. Phillot (2024). Debt supply, relative convenience yields and exchange rates.

Ilzetzki, E., E. Mendoza, and C. Vegh (2010). How big (small?) are fiscal multipliers? Cep discussion papers, Centre for Economic Performance, LSE.

Jiang, Z. (2022, February). Fiscal Cyclicality and Currency Risk Premia. *The Review of Financial Studies 35*(3), 1527–1552.

Jiang, Z. (2023). Exorbitant Privilege: A Safe-Asset View. *SSRN Electronic Journal*.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2021, June). Foreign Safe Asset Demand and the Dollar Exchange Rate. *The Journal of Finance 76*(3), 1049–1089.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2023, 11). Dollar safety and the global financial cycle. *The Review of Economic Studies 91*(5), 2878–2915.

Jiang, Z., A. Krishnamurthy, H. Lustig, and J. Sun (2024, January). Convenience Yields and Exchange Rate Puzzles. Technical Report w32092, National Bureau of Economic Research, Cambridge, MA.

Jiang, Z., R. Richmond, and T. Zhang (2024). Convenience Lost.

Kim, S. (2015). Country characteristics and the effects of government consumption shocks on the current account and real exchange rate. *Journal of International Economics 97*(2), 436–447.

Kim, S. and N. Roubini (2008, March). Twin deficit or twin divergence? Fiscal policy, current account, and real exchange rate in the U.S. *Journal of International Economics 74*(2), 362–383.

Kollmann, R. (2010, February). Government Purchases and the Real Exchange Rate. *Open Economies Review 21*(1), 49–64.

Krishnamurthy, A. and A. Vissing-Jorgensen (2012, April). The Aggregate Demand for Treasury Debt. *Journal of Political Economy 120*(2), 233–267.

Lambertini, L. and C. Proebsting (2023, January). Fiscal Policy, Relative Prices, and Net Exports in a Currency Union. *American Economic Journal: Macroeconomics 15*(1), 371–410.

Leeper, E., T. Walker, and S.-C. Yang (2013). Fiscal foresight and information flows. *Econometrica 81*(3), 1115–1145.

Leeper, E. M. (1991, February). Equilibria under 'active' and 'passive' monetary and fiscal policies. *Journal of Monetary Economics 27*(1), 129–147.

Leeper, E. M. and T. B. Walker (2012, January). Perceptions and Misperceptions of Fiscal Inflation. In *Fiscal Policy after the Financial Crisis*, NBER Chapters, pp. 255–299. National Bureau of Economic Research, Inc.

Leith, C. and S. Wren-Lewis (2008). Interactions between monetary and fiscal policy under flexible exchange rates. *Journal of Economic Dynamics and Control 32*(9), 2854–2882.

Lombardo, G. and A. Sutherland (2004). Monetary and fiscal interactions in open economies. *Journal of Macroeconomics 26*(2), 319–347.

Mertens, K. and M. Ravn (2010). Measuring the impact of fiscal policy in the face of anticipation: A structural var approach. *Economic Journal 120*(544), 393–413.

Miyamoto, W., T. L. Nguyen, and V. Sheremirov (2019, January). The effects of government spending on real exchange rates: Evidence from military spending panel data. *Journal of International Economics 116*, 144–157.

Monacelli, T. and R. Perotti (2010, May). Fiscal Policy, the Real Exchange Rate and Traded Goods. *The Economic Journal 120*(544), 437–461.

Mountford, A. and H. Uhlig (2009). What are the effects of fiscal policy shocks? *Journal of Applied Econometrics 24*(6), 960–992.

Newey, W. K. and K. D. West (1987, May). A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica 55*(3), 703–708.

Ramey, V. A. (2016, April). Defense news shocks, 1889 - 2015: Estimates based on news sources. Technical report, University of California, San Diego and National Bureau of Economic Research.

Ramey, V. A. (2019, May). Ten years after the financial crisis: What have we learned from the renaissance in fiscal research? *Journal of Economic Perspectives 33*(2), 89–114.

Ramey, V. A. and S. Zubairy (2018). Government spending multipliers in good times and in bad: evidence from us historical data. *Journal of political economy 126*(2), 850–901.

Ravn, M. O., S. Schmitt-Grohé, and M. Uribe (2012, April). Consumption, government spending, and the real exchange rate. *Journal of Monetary Economics 59*(3), 215–234.

Susan Yang, S.-C. (2005, November). Quantifying tax effects under policy foresight. *Journal of Monetary Economics 52*(8), 1557–1568.

Valchev, R. (2020, April). Bond Convenience Yields and Exchange Rate Dynamics. *American Economic Journal: Macroeconomics 12*(2), 124–166.

Valchev, R. (2021). Bond Convenience Yields and Exchange Rate Dynamics.

Witheridge, W. (2024). Monetary policy and fiscal-led inflation in emerging markets. Working paper, University of Maryland.

A Analytical Framework and Model Derivation

In this appendix, we provide a more detailed exposition of the analytical model introduced in Section 2, clarifying key aspects where additional information is necessary for a full understanding of the model.

A.1 Consumption Index and Optimal Allocation

The consumption index, C_t, is an aggregate of consumption of goods produced in the home country, C_{Ht}, and in the rest of the world, C_{Ft}

$$C_t = \left((1-\epsilon_b)^{\frac{1}{\epsilon_h}} C_{Ht}^{\frac{\epsilon_h-1}{\epsilon_h}} + \epsilon_b^{\frac{1}{\epsilon_h}} C_{Ft}^{\frac{\epsilon_h-1}{\epsilon_h}} \right)^{\frac{\epsilon_h}{\epsilon_h-1}} \tag{21}$$

where the parameter ϵ_b measures the degree of openness in the economy and ϵ_h the substitutability between domestic and foreign goods from the viewpoint of the domestic consumers. The associated CPI is

$$P_t = \left((1-\epsilon_b) P_{Ht}^{1-\epsilon_h} + \epsilon_b P_{Ft}^{1-\epsilon_h} \right)^{\frac{1}{1-\epsilon_h}} \tag{22}$$

where P_{Ht} and P_{Ft} are the price sub-indexes associated with C_{Ht} and C_{Ft}, respectively. The optimal allocation of consumption between home and foreign goods gives rise to the following demand functions:

$$C_{Ht} = (1-\epsilon_b) \left(\frac{P_{Ht}}{P_t} \right)^{-\epsilon_h} C_t \qquad C_{Ft} = \epsilon_b \left(\frac{P_{Ft}}{P_t} \right)^{-\epsilon_h} C_t \tag{23}$$

The consumption sub-indexes C_{Ht} and C_{Ft} are bundles of differentiated varieties produced domestically and abroad

$$C_{Ht} = \left(\int_0^1 C_{Ht}(i)^{\frac{\epsilon_p-1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p-1}} \qquad C_{Ft} = \left(\int_0^1 C_{Ft}(i)^{\frac{\epsilon_p-1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p-1}} \tag{24}$$

where $C_{Ht}(i)$ ($C_{Ft}(i)$) is consumption of a typical variety i in the home country (in the rest of the world) and ϵ_p is the elasticity of substitution between varieties produced in the same country. The price sub-indexes associated with C_{Ht} and C_{Ft} are given by

$$P_{Ht} = \left(\int_0^1 P_{Ht}(i)^{1-\epsilon_p} di \right)^{\frac{1}{1-\epsilon_p}} \qquad P_{Ft} = \left(\int_0^1 P_{Ft}(i)^{1-\epsilon_p} di \right)^{\frac{1}{1-\epsilon_p}} \tag{25}$$

where $P_{Ht}(i)$ ($P_{Ft}(i)$) is the domestic-currency price of a typical variety i produced in the home country (in the rest of the world). The optimal demands for domestically produced and foreign varieties are given by

$$C_{Ht}(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon_p} C_{Ht} \qquad C_{Ft}(i) = \left(\frac{P_{Ft}(i)}{P_{Ft}}\right)^{-\epsilon_h} C_{Ft} \tag{26}$$

Note that the law of one price holds for all goods, thus $P_{Ft}(i) = \mathcal{E}_t P^*_{Ft}(i)\ \forall i$, which implies $P_{Ft} = \mathcal{E}_t P^*_{Ft}$.

Note that the real government expenditure index and its corresponding optimal allocation follow the same preference structure as the household consumption index and its optimal allocation.

A.2 The Foreign Household

The representative household in the rest of the world maximizes its expected lifetime utility.

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \frac{C_t^{*1-\sigma}}{1-\sigma} - \frac{N_t^{*1+\varphi}}{1+\varphi} + \chi^* \frac{(\frac{B^*_{Ht}}{P^*_t})^{1-\psi}}{1-\psi} \tag{27}$$

subject to the budget constraint

$$P^*_t C^*_t + \mathbb{E}_t \Lambda^*_{t,t+1} \mathcal{E}_t^{-1} D^*_{t+1} + \mathcal{E}_t^{-1} B^*_{Ht} + B^*_{Ft} = \mathcal{E}_t^{-1} D^*_t + W^*_t N^*_t - T^*_t + \mathcal{E}_t^{-1} B^*_{Ht-1}(1+i_{t-1}) + B^*_{Ft-1}(1+i^*_{t-1}) \tag{28}$$

and to the appropriate no-Ponzi-game conditions. In equation (28), B^*_{Ht} and B^*_{Ft} are the foreign household's nominal holdings of, respectively, home-issued and foreign-issued government bonds.

Denote by b^*_{ht} the real home-issued government bond holdings held by the rest of the world. The foreign household's log-linearized optimality conditions for real government bond holdings, evaluated around a zero-inflation steady state, are given by:[4]:

$$\sigma \mathbb{E}_t \Delta c^*_{t+1} + \mathbb{E}_t \pi^*_{t+1} + \mathbb{E}_t \Delta e_{t+1} - i_t = \frac{1-\beta(1+i)}{\beta(1+i)} (\sigma c^*_t - \psi b^*_{ht} + \psi q_t) \tag{29}$$

$$\sigma \mathbb{E}_t \Delta c^*_{t+1} + \mathbb{E}_t \pi^*_{t+1} - i^*_t = 0 \tag{30}$$

Equations (29) and (30) are the optimality conditions with respect to the real holdings of home-issued and foreign-issued government bonds, respectively.

[4] Lowercase variables denote log-linearized values.

By combining equations (29) and (30), we derive the Uncovered Interest Parity (UIP) condition for the rest of the world:

$$i_t^* + \mathbb{E}_t \Delta e_{t+1} - i_t = \frac{1-\beta(1+i)}{\beta(1+i)} (\sigma c_t^* - \psi b_{ht}^* + \psi q_t) \tag{31}$$

A.3 The firms - details

Each monopolistically competitive firm produces a unique variety i according to the following production technology:

$$Y_t(i) = N_t(i)^{1-\alpha_p} \tag{32}$$

where the labor, $N_t(i)$, is the sole input and $\alpha_p \in (0,1)$ denotes the output elasticity with respect to labor, implying diminishing marginal returns to scale. We assume that each firm takes the overall business environment, including conditions abroad, as given and, consequently, considers only its own marginal cost when making production decisions. The marginal cost, $MC_t(i)$, is equal to the marginal productivity of labor:

$$MC_t(i) = \frac{W_t/P_{Ht}(i)}{(1-\alpha_p)N_t(i)^{-\alpha_p}} \tag{33}$$

Since firms do not segment markets by country, we have that the export price for each individual firm i, $P_{Ht}^*(i)$, is equal to $P_{Ht}(i)/\mathcal{E}_t$, which implies $P_{Ht}^* = P_{Ht}/\mathcal{E}_t$. Prices are set à la Calvo (1983). Each period t, a fraction of $(1-\theta)$ of firms are randomly selected to adjust their prices, while the remaining fraction θ keeps their prices unchanged.

A firm re-optimizing in period t selects the price $\overline{P}_{Ht}$ that maximizes the current market value of the profits generated while the price remain unchanged. Formally, the firm solves the following maximization problem

$$\max_{\overline{P}_{Ht}} \sum_{k=0}^{\infty} (\beta\theta)^k \mathbb{E}_t \left\{ \Lambda_{t,t+k} \left(\overline{P}_{Ht} Y_{t+k|t} - TC_{t+k} \right) \right\}$$

subject to the sequence of demand constraints:

$$Y_{t+k|t} = \left(\frac{\overline{P}_{Ht}}{P_{Ht+k}} \right)^{-\epsilon_p} \left(\frac{P_{Ht+k}}{P_{t+k}} \right)^{-\epsilon_h} \left\{ (1-\epsilon_b) C_{t+k} + \epsilon_b Q_{t+k}^{\epsilon_h} C_{t+k}^* + (1-\epsilon_b) \frac{G_{t+k}}{P_{t+k}} + \epsilon_b Q_{t+k}^{\epsilon_h} \frac{G_{t+k}^*}{P_{t+k}^*} \right\}$$

for $k = 0, 1, 2, ...$, where $Y_{t+k|t}$ represents domestic output demand in period $t+k$ for a firm that last reset its price in period t, $\Lambda_{t,t+k}$ is the stochastic discount factor of the households and TC_{t+k} are the total cost of production.

As is standard in New Keynesian models, the optimality condition of the firm depends on the individual marginal costs of the firm, which can be approximated by the average marginal cost up to a first-order approximation around the zero-inflation steady state. This result hinges on the fact that the dispersion of prices across firms becomes negligible in such a neighborhood.

We start from the price index definition (25):

$$1 = \int_0^1 \left(\frac{P_{Ht(i)}}{P_{Ht}} \right)^{1-\epsilon_p} di$$

where $P_{Ht(i)}$ denotes the price set by firm i and P_{Ht} is the aggregate price index for home goods.

We then perform a second-order Taylor expansion of the integrand around the zero-inflation steady-state:

$$\begin{aligned} 1 &= \int_0^1 \exp\left\{(1-\epsilon_p)(p_{ht}(i) - p_{ht})\right\} di \\ &\approx \int_0^1 \left\{ 1 + (1-\epsilon_p)(p_{ht}(i) - p_{ht}) + \frac{1}{2}(1-\epsilon_p)^2 (p_{ht}^2(i) - p_{ht}^2) \right\} di \end{aligned}$$

which implies, up to second order:

$$p_{ht} = \mathbb{E}_i\left(p_{ht}(i)\right) + \frac{(1-\epsilon_p)}{2} \mathrm{Var}_i\left(p_{ht}(i)\right)$$

where $\mathbb{E}_i\left(p_{ht}(i)\right) = \int_0^1 p_{ht}(i) di$ is the cross-sectional mean of (log) prices and $\mathrm{Var}_i\left(p_{ht}(i)\right) = \int_0^1 \left\{p_{ht}^2(i) - p_{ht}^2\right\} di$ is the cross-sectional variance.

Next, consider the labor market clearing condition:

$$N_t = \int_0^1 N_t(i) di$$

and the production function at the firm level:

$$N_t(i) = Y_t(i)^{\frac{1}{1-\alpha_p}}.$$

Aggregate output demand per firm is given by:

$$Y_t(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon_p} \left(C_{Ht} + C^*_{Ht} + G_{Ht} + G^*_{Ht}\right),$$

Consequently, total labor demand becomes:

$$\begin{aligned}
N_t &= \int_0^1 Y_t(i)^{\frac{1}{1-\alpha_p}}\, di \\
&= \int_0^1 \left\{ \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon_p} \left(C_{Ht} + C^*_{Ht} + G_{Ht} + G^*_{Ht}\right) \right\}^{\frac{1}{1-\alpha_p}} di \\
&= \left(C_{Ht} + C^*_{Ht} + G_{Ht} + G^*_{Ht}\right)^{\frac{1}{1-\alpha_p}} \int_0^1 \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\frac{\epsilon_p}{1-\alpha_p}} di
\end{aligned}$$

We again approximate the price dispersion term up to second order:

$$\begin{aligned}
&\int_0^1 \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\frac{\epsilon_p}{1-\alpha_p}} di = \\
&\qquad = 1 - \frac{\epsilon_p}{1-\alpha_p}(p_{ht}(i) - p_{ht}) + \frac{1}{2}\frac{\epsilon_p^2}{(1-\alpha_p)^2}(p^2_{ht}(i) - p^2_{ht}) \\
&\qquad = 1 + \frac{1}{2}\frac{\epsilon_p(1-\alpha_p+\alpha_p\epsilon_p)}{(1-\alpha_p)^2}\mathrm{Var}_i\left(p_{ht}(i)\right)
\end{aligned}$$

Thus, price dispersion affects labor demand and marginal costs only through second-order terms. Up to first order, this dispersion is negligible, and the economy behaves as if firms are symmetric.

Therefore, we can approximate each firm's marginal cost (33) by the average marginal cost:

$$\begin{aligned}
mc_t(i) &\approx mc_t \\
&\approx w_t - p_{ht} + \frac{\alpha_p}{1-\alpha_p} y_t.
\end{aligned}$$

A.4 Terms of Trade, Trade Balance, Goods Market Clearing Condition

Following Galí (2015), we define the terms of trade, domestic inflation, and consumer price index (CPI) inflation as:

$$s_t = p_{ft} - p_{ht} \tag{34}$$

$$p_t = p_{ht} + \epsilon_b s_t \tag{35}$$

$$\pi_t = \pi_{ht} + \epsilon_b \Delta s_t \tag{36}$$

$$q_t = (1 - \epsilon_b) s_t \tag{37}$$

where s_t represents the terms of trade, p_t is the price level, π_t is CPI inflation, and q_t denotes the real exchange rate.

The trade balance is given by:

$$NX_t = Y_t - \frac{P_t}{P_{Ht}} C_t - \frac{G_t}{P_{Ht}} \frac{P_{Ht}}{P_t} \tag{38}$$

where NX_t represents net exports.

The goods market clearing condition for domestic output is:

$$Y_t = \left(\frac{P_{Ht}}{P_t}\right)^{-\epsilon_h} \left\{(1 - \epsilon_b) C_t + \epsilon_b Q_t^{\epsilon_h} C_t^* + (1 - \epsilon_b) \frac{G_t}{P_t} + \epsilon_b Q_t^{\epsilon_h} \frac{G_t^*}{P_t^*}\right\} \tag{39}$$

A.5 Steady State

According to the Backus-Smith condition (Eq. 6), in steady state, we have:

$$C = \nu C^* Q^{\frac{1}{\sigma}} \tag{40}$$

where ν is a constant equal to one when both countries share the same preferences and economic environment. However, in our setup, the home country and the rest of the world are asymmetric, as both economies exhibit a preference for home-issued bonds. To address this technical challenge, we calibrate the steady-state ratio of consumption to output in the home country, i.e. C/Y.

Moreover, we assume that all nominal prices are normalized to one in the steady state:

$$P_H = P_F = P = 1 \implies Q = 1 \tag{41}$$

Given the elasticity of substitution across varieties, the steady-state markup for firms is given by:

$$\frac{P}{W} = \frac{\epsilon_p}{(\epsilon_p - 1)} \frac{Y^{\frac{\alpha_p}{1-\alpha_p}}}{(1 - \alpha_P)} \tag{42}$$

Furthermore, following the standard New Keynesian framework, we impose:

$$Y = N^{1-\alpha_p} \tag{43}$$

$$C^\sigma N^\varphi = \frac{W}{P} \tag{44}$$

At this point, we can express steady-state output as:

$$Y = \left(\frac{\frac{\epsilon_p - 1}{\epsilon_p}(1 - \alpha_p)}{(\frac{C}{Y})^\sigma} \right)^{\frac{1}{\sigma + \frac{\varphi + \alpha_p}{1-\alpha_p}}} \tag{45}$$

By evaluating Equations 4 and 5 at the steady state, we derive an expression for the steady-state convenience yield:

$$1 = \beta(1 + i^*) \tag{46}$$

$$1 = \beta(1 + i) + \chi B^{-\psi} C^\sigma \tag{47}$$

$$\implies i^* - i = \frac{\chi}{\beta} B^{-\psi} C^\sigma \tag{48}$$

This equation highlights the role of the convenience yield in determining the interest rate differential. Specifically, the gap between the foreign interest rate and the domestic interest rate ($i^* - i$) is driven by the convenience yield term, which depends on the stock of government bonds and the level of consumption.

A.6 Derivation of the Reduced Dynamical System

To express the equilibrium conditions of the analytical model solely in terms of total domestic government debt, we consider three key equations: the uncovered interest parity (UIP) condition for the home country (Eq. 7), the UIP condition for the rest of the world (Eq. 31), and the market-clearing condition for home-issued government bonds, given by:

$$b_t = \frac{B_H}{B} b_{ht} + \frac{B_H^*}{B} b_{ht}^* \tag{49}$$

In equilibrium, assets must be priced identically in both the home country and the rest of the world. As a result, the market-clearing conditions must be equalized, leading to:

$$-\psi b_{ht}^* + \psi c_t = \sigma c_t - \psi b_{ht} \tag{50}$$

Equations 50 and 49 allow us to express b_{ht} in terms of b_t.

As a final step, we substitute this expression into Equation 4 to derive Equation 13, which defines the reduced dynamical system in Section 2.5.

B Quantitative Framework and Model Derivation

In this appendix, we provide a more detailed exposition of the quantitative model presented in Section 3, highlighting the key differences relative to the analytical framework. Notably, the results and derivations in Subsections A.1 and A.4 remain valid and continue to apply within the context of the quantitative model.

B.1 The household

The home household's log-linearized optimality conditions are given by:

$$\sigma c_t + \varphi n_t + \frac{\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}{1+\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}(1-\alpha)(b_{ht} - c_t) = w_t - p_t \tag{51}$$

$$\sigma \mathbb{E}_t \Delta c_{t+1} + \mathbb{E}_t \pi_{t+1} - i_t - \frac{\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}{1+\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}(1-\alpha)(\mathbb{E}_t \Delta c_{t+1} - \mathbb{E}_t \Delta b_{ht+1}) = \frac{1-\beta(1+i)}{\beta(1+i)}(\alpha c_t - \alpha b_{ht}) \tag{52}$$

$$\sigma \mathbb{E}_t \Delta c_{t+1} + \mathbb{E}_t \pi_{t+1} - i_t^* - \mathbb{E}_t \Delta e_{t+1} - \frac{\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}{1+\alpha\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}(1-\alpha)(\mathbb{E}_t \Delta c_{t+1} - \mathbb{E}_t \Delta b_{ht+1}) = 0 \tag{53}$$

$$q_t = \sigma(c_t - c_t^*) + \left(\frac{\alpha\chi \left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}}{1+\alpha\chi \left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}} - \frac{\alpha\chi^* \left(\frac{B_H^*/Y}{C^*/Y}\right)^{1-\alpha}}{1+\alpha\chi^* \left(\frac{B_H^*/Y}{C^*/Y}\right)^{1-\alpha}} \right)(1-\alpha)(b_{ht} - c_t) \tag{54}$$

and the usual transversality conditions. Equation (51) represents the intra-temporal optimality condition, which balances consumption and hours worked while accounting for transaction costs. Equation (54) is a modified international risk-sharing condition (Backus-Smith).

Equations (52) and (53) are the optimality conditions with respect to real holdings of domestic and foreign government bonds, respectively.

By combining (52) and (53), we obtain the Uncovered Interest Parity (UIP) condition for the domestic economy:

$$i_t^* + \mathbb{E}_t \Delta e_{t+1} - i_t = \frac{1-\beta(1+i)}{\beta(1+i)}(\alpha c_t - \alpha b_{ht}) \tag{55}$$

Compared to the analytical model, the convenience yield in this setting not only creates a wedge in the UIP condition (55) and in the bond Euler equations (52), (53), but also affects the intra-temporal condition (51), the stochastic discount factor, and the complete markets condition (54).

The introduction of transaction costs through the transaction technology adds complexity to the model—one reason why it was omitted in the analytical version. However, it deepens the role of the convenience yield, which is closely linked to the level of consumption. Since liquidity facilitates goods exchange, it plays a pervasive role in shaping both the intertemporal allocation of consumption and portfolio choices across bonds.

Similarly, by analyzing the optimization problem of the foreign household, we derive the Uncovered Interest Parity (UIP) condition for the rest of the world:

$$i_t^* + \mathbb{E}_t \Delta e_{t+1} - i_t = \frac{1-\beta(1+i)}{\beta(1+i)}(\alpha c_t^* - \alpha b_{ht}^* + \alpha q_t) \tag{56}$$

Hence, an additional optimality condition is obtained by equating the UIP conditions for the home and foreign households:

$$\alpha c_t - \alpha b_{ht} = \alpha c_t^* - \alpha b_{ht}^* + \alpha q_t \tag{57}$$

B.2 Steady State

Given the elasticity of substitution across varieties and the decreasing returns to scale in production, the steady-state markup for firms is given by:

$$\frac{P}{W} = \frac{\epsilon_p}{(\epsilon_p - 1)} \frac{Y^{\frac{\alpha_p}{1-\alpha_p}}}{(1-\alpha_p)} \tag{58}$$

Furthermore, evaluating the intra-temporal optimality condition (51) at the steady state yields:

$$C^\sigma N^\varphi \left(1 + \alpha\chi \left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}\right) = \frac{W}{P} \tag{59}$$

Combining these conditions, we can express steady-state output as:

$$Y = \left(\frac{\frac{\epsilon_p - 1}{\epsilon_p}(1-\alpha_p)}{(\frac{C}{Y})^\sigma \left(1 + \alpha\chi \left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}\right)}\right)^{\frac{1}{\sigma + \frac{\varphi + \alpha_p}{1-\alpha_p}}} \tag{60}$$

The quantitative model's increased complexity requires the calibration of additional steady-state quantities, specifically:

- the output ratio between the foreign and home country, Y^*/Y.
- foreign consumption normalized by domestic output, C^*/Y.
- foreign government spending normalized by domestic output, G^*/Y.
- the scale parameter of the foreign transaction technology, χ^*.

These values are jointly determined by solving the following system of equations:

1. Equation (60) for domestic output.
2. Domestic goods market clearing at steady state:

$$\epsilon_b(G^*/Y + C^*/Y) = 1 - (1-\epsilon_b)(G/Y + C/Y)$$

3. World market clearing condition:

$$1 + Y^*/Y = G^*/Y + C^*/Y + G/Y + C/Y$$

4. Intra-temporal optimality condition for foreign households evaluated at the steady state:

$$Y^{\sigma+\varphi}(C^*/Y)^{\sigma}(Y^*/Y)^{\varphi}\left(1+\alpha\chi^*\left(\frac{B_H^*/Y}{C^*/Y}\right)^{1-\alpha}\right)=\frac{\epsilon_p-1}{\epsilon_p}$$

5. Steady-state convenience yield parity, derived by equating the Euler equations for domestic bonds between home and foreign households:

$$\chi\left(\frac{B_H/Y}{C/Y}\right)^{1-\alpha}=\chi^*\left(\frac{B_H^*/Y}{C^*/Y}\right)^{1-\alpha}$$

6. Asset Market Clearing Condition for domestic bonds:

$$B/Y=B_H/Y+B_H^*/Y$$

C Alternative Specification for the Monetary Policy Rule

In this section, we attempt to resolve the exchange rate appreciation puzzle by slightly modifying the Taylor Rule from Section 3 through the introduction of interest rate smoothing, i.e.

$$i_t=\rho i_{t-1}+(1-\rho)(\phi_\pi\pi_t)$$

where ρ represents the degree of interest rate smoothing and is calibrated to 0.80, consistent with the macroeconomic literature and the empirical estimates.

C.1 Equilibrium

From Figure 12, we observe no significant changes in the stability regions compared to Figure 5. Figure 13 shows that the introduction of interest rate smoothing creates a large parameter-space within the Monetary Dominance Regime where the exchange rate appreciation puzzle is solved.

C.2 Impulse Response Functions

C.2.1 Fiscal Dominance Regime

Figure 14 is not qualitatively different from Figure 8. Quantitatively, interest rate smoothing results in less volatile dynamics, leading to weaker reactions to government expenditure shocks. Moreover,

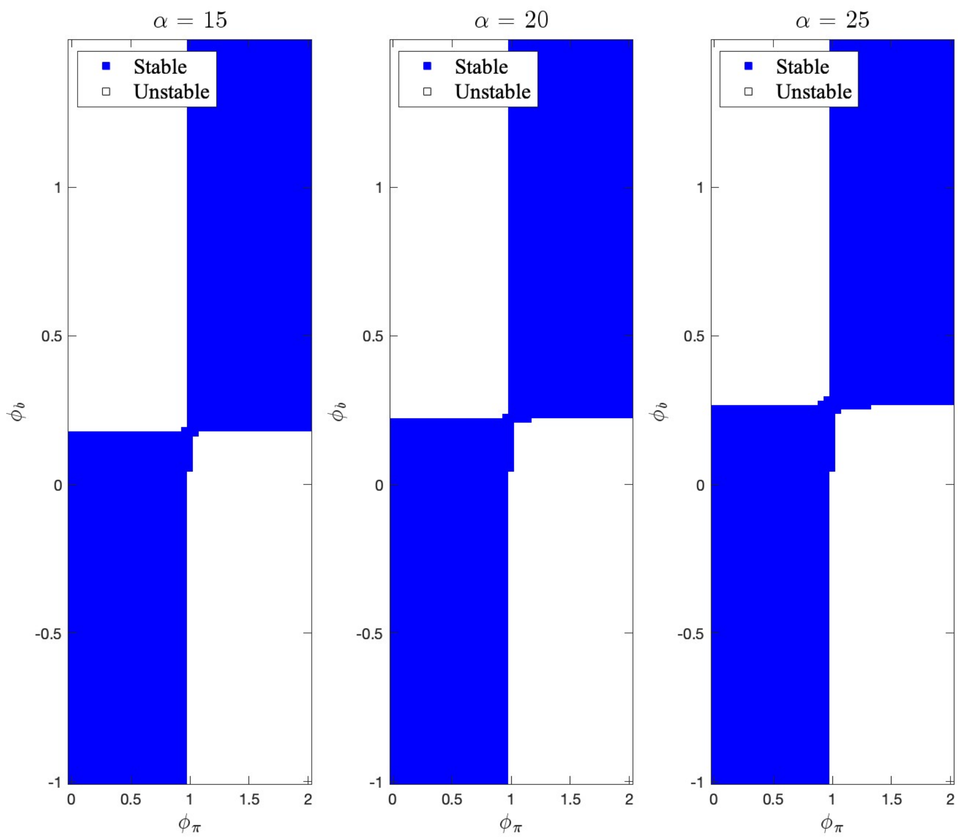


Figure 12: Stability Regions

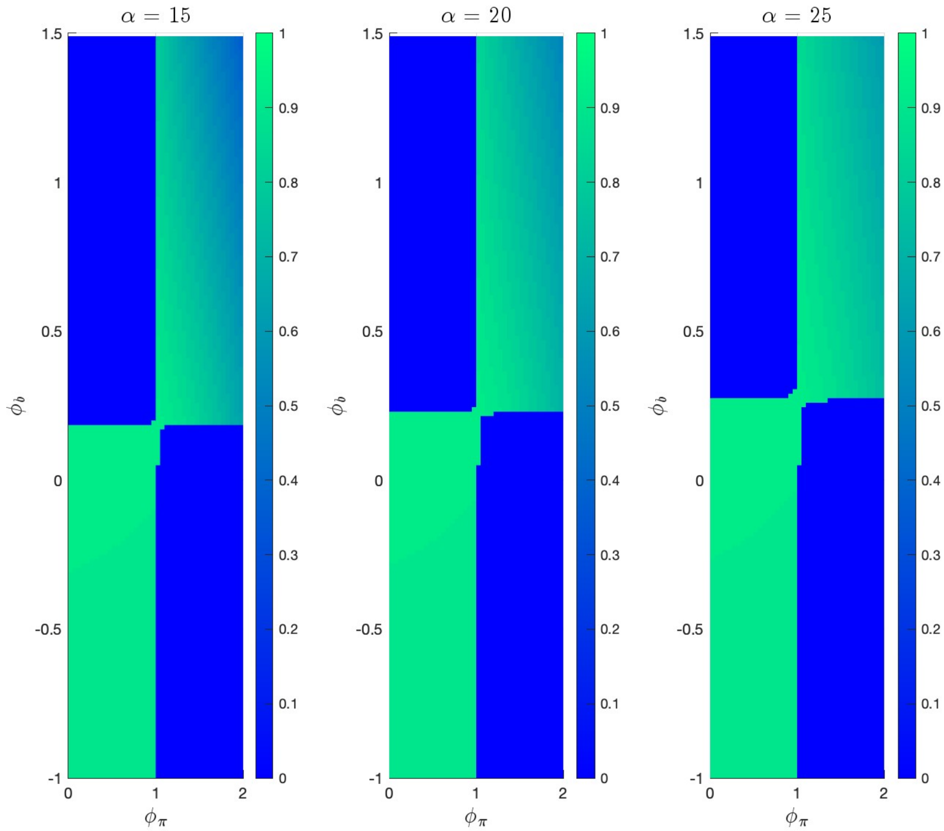
interest rate smoothing does not help the model match the correct sign for the convenience yield.

C.2.2 Monetary Dominance Regime

Figure 15 illustrates how interest rate smoothing induces a depreciation of the real exchange rate across a broader range of parameters governing monetary and fiscal policy. This effect stems from the dynamics of the real interest rate following a debt-financed government expenditure shock. Because the monetary authority cannot fully adjust the nominal interest rate immediately to contain inflation, the real interest rate initially declines for a few quarters before rising.

Consequently, the lower real interest rate reduces the opportunity cost of current consumption

Figure 13: On-impact depreciation regions



through the intertemporal substitution effect, leading to a smoother consumption response compared to the hump-shaped pattern observed in Figure 9. At the same time, the intratemporal substitution effect is strengthened due to the smoother monetary policy response, which helps preserve the real value of government bonds. Furthermore, Figure 15 shows that the intratemporal substitution effect dominates, as evidenced by the immediate decrease in the convenience yield.

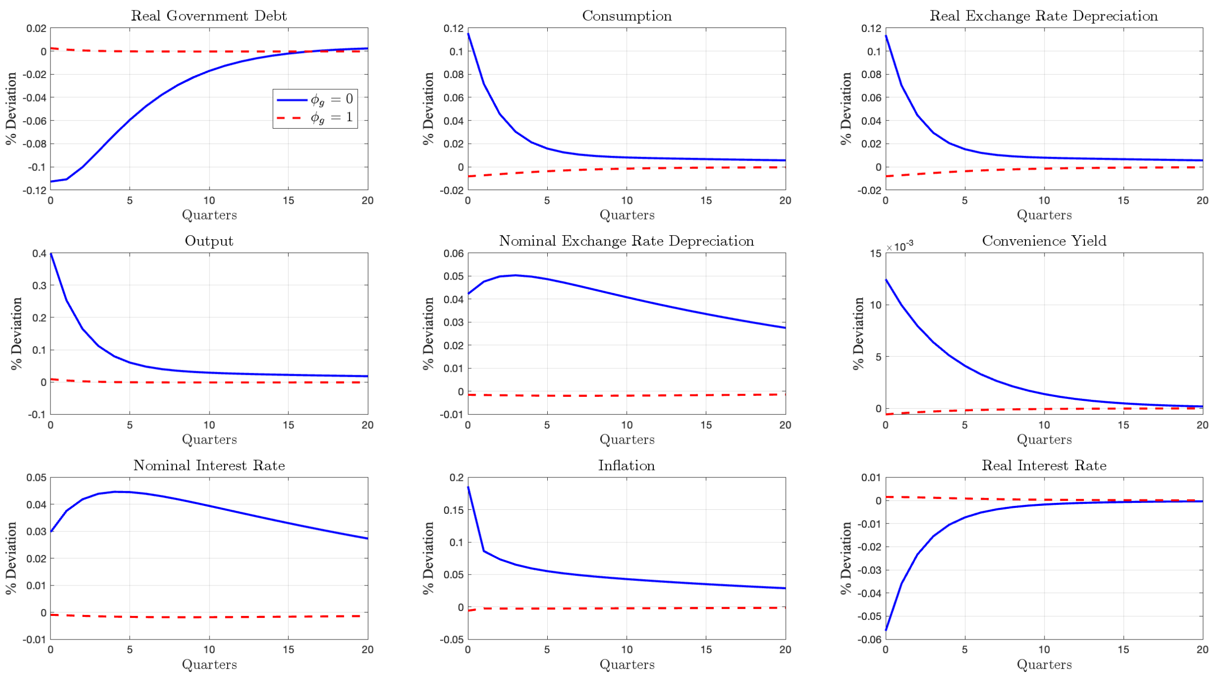


Figure 14: Fiscal Dominance

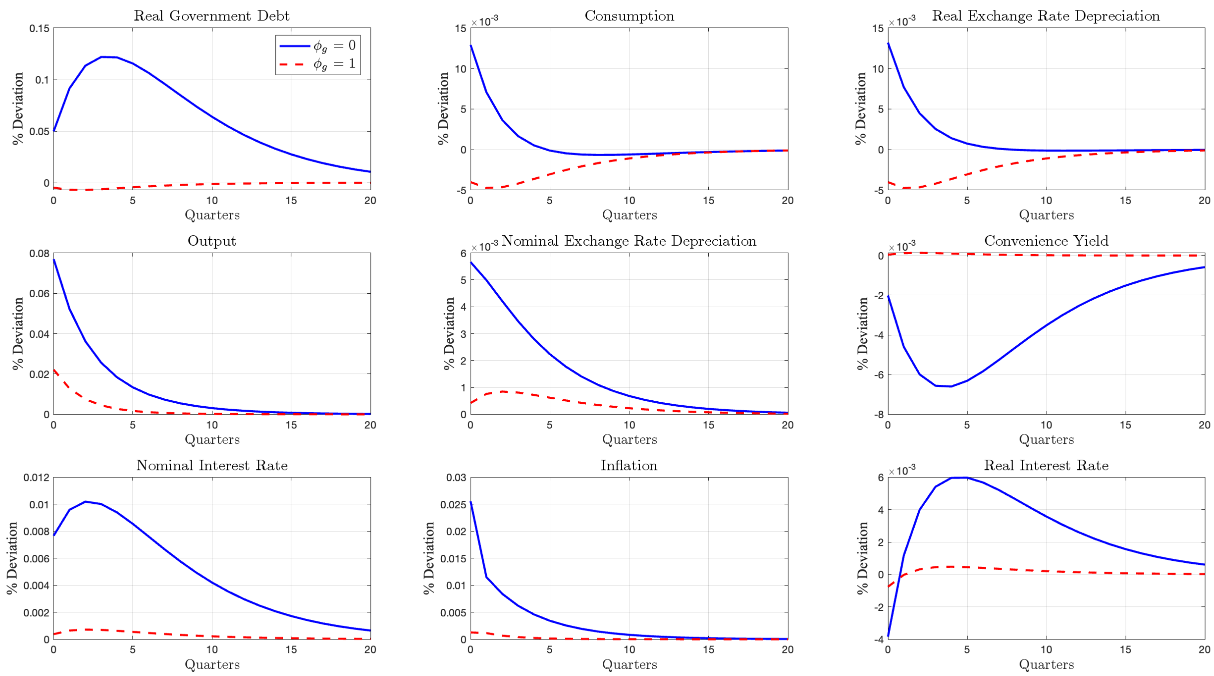


Figure 15: Monetary Dominance