Exchange Rates, Capital Controls and the Hegemon’s Dilemma

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Declaration

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Abstract

In this thesis, I study the interplay between exchange rate dynamics and capital flows in the international macroeconomy, and I consider the optimal policy response for economies that are large in goods and financial markets. I focus on features characterising the modern International Monetary System: the predictability and excess volatility of exchange rates, large and volatile capital and trade flows, and the search for safe (particularly dollar) assets by foreign investors.

Chapter 1 provides a brief introduction of the topics studied and methodologies used, highlighting why the questions I tackle are relevant. Chapter 2, which is co-authored with Simon Lloyd and is entitled Exchange Rate Risk and Business Cycles, presents an empirical study of exchange rate dynamics and, using a simple asset-pricing framework, it links them to business cycle risk and cross-country liquidity yields. We show that currencies with a steeper yield curve depreciate at business-cycle horizons. We identify a tent-shaped relationship between exchange-rate risk premia (ERRP) and the relative yield curve slope across horizons that peaks at 3-5 years and is robust to a number of controls, including liquidity yields. Within the asset-pricing framework, ERRP reflect investors’ changing return valuations over the business cycle. We then calibrate a two-country, two-factor model of interest rates, where exchange rates are driven by business-cycle—transitory and cyclical—risk. The model quantitatively reproduces the tent-shaped relationship, as well as variation in uncovered interest parity coefficients across horizons.

In chapter 3 entitled Capital Controls and Free Trade Agreements, also co-authored with Simon Lloyd, we study the joint optimal determination of trade tariffs and capital controls in a two-country, two-good model with trade in both goods and assets. Policy is driven by the incentive to manipulate the terms of trade both across goods and over time. When tariffs are ruled out by a free-trade agreement (FTA), capital controls are chosen to trade-off the two margins. Absent a FTA, the planner achieves weakly higher welfare by additionally employing tariffs on goods. However, time-varying tariffs have second-best effects on the cost of borrowing, so the size of optimal capital controls depends on trade policy. Specifically, in response to fluctuations in the endowment of goods consumed with home bias, capital controls are larger when the optimal tariff is in place. In contrast, faced with fluctuations in the endowment of the second good, the optimal time-varying tariff partly substitutes for the use of capital controls, so capital controls are smaller. Our results extend to a Nash equilibrium where countries engage in both capital-control and trade wars.

Chapter 4, entitled The Hegemon’s Dilemma, is single-authored. I show that by keeping dollars scarce in international markets, the U.S.—the hegemon—earns monopoly rents when borrowing in dollar debt and investing in foreign-currency assets. However, in equilibrium, these rents result in a strong dollar, which depresses global demand for its exports and leads
to losses on existing holdings of foreign assets, and give rise to private sector over-borrowing. Using an open economy model with nominal rigidities and segmented financial markets, I show that, because of over-borrowing, monetary policy alone cannot achieve the constrained efficient allocation. Absent a corrective macro-prudential tax on capital inflows, the hegemon faces inefficiently volatile output and prices, and lower monopoly rents. By increasing liquidity in international markets, dollar swap lines extended by the central bank improve stabilisation, but, unlike macro-prudential taxes, do so at the cost of eroding monopoly rents for the hegemon. In contrast, dollar swaps improve outcomes for foreign investors. Dollar shortages can also have distributional consequences for the hegemon. A scarce dollar leads to larger monopoly rents which benefit financially-active households, but they over-borrow at the expense of inactive households, who suffer the full brunt of aggregate demand externalities.
“All is well, [indeed] *one must imagine Sisyphus happy.*”
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Chapters two and three are the outcome of papers written in collaboration with Simon Lloyd.
# Contents

1 Introduction

2 Exchange-Rate Risk and Business Cycles
   2.1 Introduction ......................................................... 5
   2.2 Exchange Rates and the Yield Curve Slope ......................... 8
       2.2.1 Canonical UIP Regression ..................................... 8
       2.2.2 Yield Curve-Augmented UIP Regression ....................... 9
       2.2.3 Robustness .................................................... 12
   2.3 Excess Returns, Risk Premia and the Yield Curve Slope .......... 13
       2.3.1 Notation ....................................................... 13
       2.3.2 Empirical Setup .............................................. 13
       2.3.3 Results ....................................................... 14
       2.3.4 Robustness .................................................... 17
       2.3.5 Accounting for Liquidity Yields ............................. 17
   2.4 Theory ............................................................. 19
       2.4.1 Pricing Kernels, Transitory Risk and the Yield Curve Slope 19
       2.4.2 Two-Country Cox, Ingersoll and Ross Model .................. 23
   2.5 Conclusion ......................................................... 29

3 Capital Controls and Free-Trade Agreements
   3.1 Introduction ......................................................... 31
   3.2 Basic Environment .................................................. 35
       3.2.1 Free-Trade Agreements and the Pareto Frontier ............. 36
   3.3 Unilateral Ramsey Planner ......................................... 37
       3.3.1 With Free Trade ............................................... 37
       3.3.2 Without Free Trade ............................................ 39
       3.3.3 Comparing Optimal Allocations ................................ 40
       3.3.4 Implementation ............................................... 42
       3.3.5 Numerical Exercises .......................................... 42
   3.4 Strategic Planning Allocation ...................................... 49
       3.4.1 With Free Trade ............................................... 49
       3.4.2 Without Free Trade ............................................ 51
       3.4.3 Numerical Exercises .......................................... 53
   3.5 Welfare and International Spillovers ................................ 55
   3.6 Discussion: Generality of Results .................................. 57
   3.7 Conclusion .......................................................... 58

xi
C Appendix to Chapter 4

C.1 Supporting Evidence .................................................. 127
C.2 Further derivations for Section 3: Analytical Hegemon’s Dilemma ............. 131
C.3 Further derivations for Section 4: Constrained Optimal Allocation .......... 134
  C.3.1 Deriving indirect utility function .................................... 134
C.4 Further Derivations for Section 5: Limited Financial Market Participation .. 135
C.5 Generalizing preferences .................................................. 137
C.6 Further Results for Numerical Exercise .................................. 140
C.7 Extensions ................................................................. 141
Chapter 1

Introduction

International macroeconomics has always been at the forefront of economics, inspiring pioneering thinkers such as Keynes, Mundell and Friedman. At different periods of history, their work provided intellectual support to a rising tide of globalisation, fuelled by both technological and social progress. In contrast, recent questions in international macroeconomics have largely been prompted by anxieties over the costs of uncontrolled capital and trade flows, that have led some countries to turn to protectionist measures. A sequence of events has contributed to this reversal. The Global Financial Crisis (GFC) in 2007 led to a crash in asset prices that quickly spread across markets and borders, with severe effects on the real economy. The European Sovereign Debt Crisis, which began in 2010, raised questions about the political and economic foundations of even advanced economies. The Taper Tantrum in 2013 showed us how ‘fickle’ capital flows can be, even in the 21st century, as well as how vulnerable the world economy is to U.S. monetary policy. The fallout of the COVID-19 pandemic and associated lockdowns led to rapid retrenchment of both trade and financial flows, and also further exacerbated the world’s fiscal crisis. And, currently, the invasion of Ukraine by Russia, and the sanctions imposed on the latter, have led to political and economic uncertainty which has exacerbated pre-existing energy price pressures and intensified fears of inflation internationally.

The consequence of these events has been a re-assessment of the costs and benefits of unregulated globalisation. Specifically, there is a push for greater understanding of how protectionist measures such as capital controls and tariffs work in conjunction with one another, and with monetary policy, as well as how they interact with features of the current International Monetary System (IMS).\(^1\) Additionally, these events have also prompted a revisiting of historical debates on the role of exchange rate flexibility (Itskhoki and Mukhin, 2021) and the role of the dollar (see e.g. Rey, 2015, Krishnamurthy and Lustig, 2019) which are central themes of my research.\(^2\)

This thesis forms the start of a research agenda on the role of exchange rate markets in sharing and propagating risks across countries, the optimal conduct of capital controls, trade and monetary policy in open economies, and the future of the dollar in international markets. Following this introduction, Chapter 2 analyses the relationship between exchange rates and

\(^1\)Concretely, following the definition in Farhi and Maggiori (2018), the IMS is currently characterised by the exchange rate regime, international institutions such as the International Monetary Fund and the World Trade Organisation that promote multilateral cooperation and resolve international disputes, and the supply and demand for reserve assets – mostly dollar assets.

\(^2\)In related work, Corsetti and Marin (2020) analyses a century of exchange rate movements for the USD-GBP pair, uncovering that modern puzzles have pre-existed since the 1930s and proposes that they can be rationalized in a model of rare disasters.
bond yields in advanced economies, and identifies business-cycle risk as a driver of exchange rate risk premia. Chapters 3 and 4 both use standard open economy macro-economic models to study optimal policy. Chapter 3 focuses on optimal capital controls and trade tariffs in a two-country, two-good endowment economy, emphasising pecuniary (terms of trade) externalities in open economies. Chapter 4 looks specifically at the policy problem faced by the hegemon in the IMS, the U.S. The analysis shows that the role of the dollar in international markets impinges on the efficiency of U.S. monetary policy when capital controls are not available and, because of this, dollar swap lines can be useful as a third-best policy instrument.

Exchange-rate determination has been a topic of controversy, with economists suggesting that they follow a random walk (Meese and Rogoff, 1983) or are disconnected from macroeconomic fundamentals (Itsikhoki and Mukhin, 2021). In Chapter 2 of this thesis, with my co-author Simon Lloyd, we draw a link between exchange rates and bond premia. Bond premia are widely considered to reflect and even predict macroeconomic conditions, (Estrella and Hardouvelis, 1991, Estrella and Mishkin, 1998), therefore we argue that this is further evidence that exchange rates reflect fundamentals. We show that currencies with a steeper yield curve, i.e. higher bond premia, depreciate at medium-term horizons. We identify a tent-shaped relationship between exchange-rate risk premia (ERRP) and the relative yield curve slope across horizons that peaks at 3-5 years and is robust to a number of controls, including liquidity yields. Liquidity yields are the non-pecuniary return investors earn on their portfolio and have received much attention for their ability to explain exchange rate movements, (Engel and Wu, 2018, Jiang, Krishnamurthy, and Lustig, 2021).

Within a preference free no-arbitrage framework, we show that ERRP reflect investors’ changing return valuations over the business cycle, which are also captured by the yield curve slopes. We then construct a two-country, two-factor model of interest rates, building on Cox, Ingersoll, and Ross (1985) and Lustig, Statthopoulos, and Verdelhan (2019), and calibrate it such that exchange rates are driven by cyclical and transitory risk. The model quantitatively reproduces the tent-shaped relationship we document in our empirics, as well as variation in uncovered interest parity coefficients across horizons. At the same time, it can capture other moments of bond and equity markets.

This chapter sets the scene for the rest of the thesis, placing exchange rates firmly at the heart of open economy macroeconomics and has served as the basis for future research.\(^3\)

Chapter 3, also co-authored with Simon Lloyd, studies the joint optimal (Ramsey) determination of trade tariffs and capital controls in a two-country, two-good model with trade in both goods and assets. The optimal policy choice is driven by the incentive to manipulate the terms of trade both across goods and over time. We first look at the case where tariffs are prohibited by a free-trade agreement (FTA), as analysed in Costinot, Lorenzoni, and Werning (2014). Then, capital controls are chosen to trade-off the two margins. We then proceed to relax the assumption that a FTA exists. The planner then achieves weakly higher welfare by additionally employing tariffs on goods. However, we show that the optimal time-varying tariffs have second-best effects on the cost of borrowing, so the size of optimal capital controls depends

\(^3\)In Corsetti et al., 2022, we investigate the relationship between U.S. risk, as reflected in equity premia, and the dollar. Specifically, we show that U.S. risk has risen since 2007 (relative to a panel of advanced economies) but long maturity exchange rate premia have remained roughly unchanged. We attribute this to offsetting movements in deviations from the covered interest rate parity, which have manifested in an inversion of their term structure, (Du, Im, and Schreger, 2018).
on trade policy. Specifically, in response to fluctuations in the endowment of goods consumed with home bias, capital controls are larger when the optimal tariff is in place. In contrast, faced with fluctuations in the country’s endowment of the second good, the optimal time-varying tariff partly substitutes for the use of capital controls, so capital controls are smaller.

Our results extend to a Nash equilibrium where countries engage in both capital-control and trade wars. From a global perspective, both capital control wars and, especially, trade wars are costly. This is because, as pointed out in the seminal contribution by Geanakoplos and Polemarchakis (1986), pecuniary externalities are redistributive and a feature of well functioning markets. In open economies, when a planner sets taxes to internalise these price movements, thus acting monopolistically in goods markets, this is at the expense of the other country. The optimal allocation from a global perspective involves no capital controls or tariffs.

Chapter 4, is single-authored, and focuses on the unique policy problem faced by the U.S. as issuer of dollar assets. I show that the U.S. has an incentive to keep dollars scarce in international markets, in order to earn monopoly rents, (Farhi and Maggiori, 2018, Jiang, Krishnamurthy, and Lustig, 2020). However, in equilibrium, the transfer of these rents from abroad appreciates the dollar, depressing global demand for U.S. exports and leading to losses on existing holdings of foreign assets. Moreover, and key to the policy dilemma, these monopoly rents give rise to private sector over-borrowing, due to both a pecuniary (financial) externality and an aggregate demand externality (Farhi and Werning, 2016). Using an open economy model with nominal rigidities and segmented financial markets, I show that, because of over-borrowing, monetary policy alone cannot achieve the constrained efficient allocation. Specifically, relative to the constrained efficient allocation, the hegemon faces an excessively appreciated dollar, inefficiently volatile output, and lower monopoly rents.

When the optimal macro-prudential policy is not available, there is scope for new instruments to improve domestic welfare. Dollar swap lines are one of the most prominent policies used by the Federal Reserve in recent history. Under this facility, the Federal Reserve extends dollar liquidity to other central banks who in turn lend dollars to foreign banks. Dollar swap lines can support stabilization policy in the U.S., but, unlike macro-prudential taxes, do so at the cost of eroding monopoly rents and so cannot achieve the constrained efficient allocation (from a U.S. perspective). However, unlike the macro-prudential tax, dollar swaps can be Pareto improving globally, and this may explain why they were preferred to any form of capital controls.

The policy dilemma matters for distribution as well as efficiency. I consider an extension of the model which allows for a measure of financially inactive households, as in Alvarez, Atkeson, and Kehoe (2002), Bilbiie (2008) and others. I show that a scarce dollar leads to larger monopoly rents which benefit financially-active households, but they over-borrow at the expense of inactive households, who suffer the full blunt of aggregate demand externalities. Dollar swaps may therefore be chosen because of a preference for redistribution.

In view of the anxieties over unregulated capital and trade flows which motivate this thesis, I draw three conclusions. First, Chapters 3 and 4 both emphasise that taxation of trade and capital flows is optimal from an individual country’s perspective. Specifically, the optimal (unilateral) policy exploits the country’s size in goods –but also financial (e.g. dollar asset)– markets. While goods’ market size has been the topic of a large literature on terms of trade externalities, see e.g. Corsetti and Pesenti (2001) and Benigno and Benigno (2003), size in financial markets has
been understudied but has significant implications on the optimal conduct of policy.\footnote{A notable exception is Farhi and Maggiori (2018) who also look at the scope for the U.S. to act as monopolist supplier of dollar assets and the global welfare implications of this. Recently, building on Gabaix and Maggiori (2015), a number of papers investigate optimal policy when countries are large in financial markets, see e.g. Fanelli and Straub (2022), Basu et al. (2020), Bianchi and Lorenzoni (2021).}

Second, in both cases, capital controls and trade policy are optimal for the country levying these taxes but only at a disproportionally large cost to the rest of the world. Moreover, in Chapter 3 we show that when a country levies trade tariffs, this may increase the desirability and optimal size of capital controls. We show that a Nash equilibrium with competition over both capital controls and tariffs delivers significantly worse welfare than one with just capital control wars. Therefore, the correct design of institutions and commitment mechanisms which can support multilateral cooperation will be a key challenge for the coming years.

Third, during these crisis periods, faced with heightened demand for dollar assets from foreign investors, the U.S. chose not to levy capital controls which would monopolistically restrict the supply of dollar assets, exploiting the country’s size in financial markets. Instead, the Federal Reserve extended dollar swap lines, to alleviate the scarcity of dollars abroad. This is a key example of international cooperation and should be recognized as an effort to prolong and support the international role of the dollar. Moreover, the same fundamental trade-offs, discussed in Chapter 4, between macroeconomic stabilisation and maximizing monopoly rents will confront the U.S. in the case of a shift away from countries holding dollar reserves or the possible adoption of a Global Reserve Currency.
Chapter 2

Exchange-Rate Risk and Business Cycles

2.1 Introduction

A long-standing literature in international macroeconomics has questioned whether exchange rates can be connected to macroeconomic fundamentals, highlighting an ‘exchange rate disconnect’ (Meese and Rogoff, 1983; Itskhoki and Mukhin, 2021) that has motivated attempts to ‘reconnect’ currency moves to fundamentals (e.g. Lilley, Maggiori, Neiman, and Schreger, 2019). In parallel, leading contributions to the asset-pricing literature have taken exchange rate puzzles at face value, assessing the restrictions they impose on the modelling of risk pricing (Backus, Foresi, and Telmer, 2001; Lustig, Stathopoulos, and Verdelhan, 2019). In this chapter, building on both approaches, we reconsider the link between exchange rates and the term structure of interest rates both empirically and theoretically. Based on a panel of advanced-economy currencies, we produce novel evidence that cross-country differences in the yield curve slope predict exchange rate dynamics, especially at medium-term horizons. Given the nature of the yield curve slope as a leading indicator of macroeconomic outcomes (e.g. Estrella and Hardouvelis, 1991; Estrella and Mishkin, 1998; Estrella, 2005), we argue that slope differentials across countries drive exchange rate movements in line with asymmetries in business-cycle risk. Using a no-arbitrage framework, we show that, for this to be true, the risks driving stochastic discount factors (SDFs) must be, at least in part, transitory and cyclical. In light of this, we argue that business-cycle risks drive predictable exchange rate movements.

To this end, we first show that cross-country differences in the yield curve slope are a strong predictor of exchange rates, especially at business-cycle horizons. Our starting point is the canonical uncovered interest parity (UIP) regression. UIP predicts that a high interest rate currency should depreciate to equalise exchange rate-adjusted returns, consistent with risk-neutral no-arbitrage. As is well known, the UIP hypothesis is empirically rejected at short to medium horizons: high-yield currencies tend to excessively appreciate (or insufficiently depreciate) due to exchange-rate risk premia (ERRP) (Fama, 1984). But it cannot be rejected at long horizons (e.g. Chinn and Meredith, 2005). By augmenting a UIP regression with cross-country differences in yield curve factors, we show that information in the term structure of interest rates greatly improves explanatory power for exchange rates. Specifically, we document a tent-shaped relationship between the relative yield curve slope and future exchange rate changes. Countries
with a relatively steep yield curve tend to depreciate in excess of UIP, with the relationship strongest at the 3 to 5-year horizon.

We then investigate the relationship between the relative slope, bond returns and ERRP across holding periods and bond maturities—extending the empirical analysis in Lustig, Stathopoulos, and Verdelhan, 2019. Doing so allows us to isolate the specific contribution of the relative yield curve slope to bond risk premia and ERRP in turn. We find that the predictability of exchange rates by the relative yield curve slope predominantly works through ERRP. Once again, we identify a tent-shaped relationship, across holding periods and for a range of bond maturities.

We also extend our specification to account for liquidity yields (Du, Im, and Schreger, 2018), i.e. the non-monetary return that government bonds provide because of their safety, ease of resale, and value as collateral. We find evidence that the term structure of cross-country liquidity yields explains exchange rate fluctuations, extending the results of Engel and Wu, 2018 across maturities. Nevertheless, the relationship between the relative yield curve slope and ERRP is robust to this extension, suggesting that business-cycle risk operates through a distinct channel.

Armed with these empirical findings, we investigate the SDF dynamics that rationalise the tent-shaped relationship between the relative yield curve slope and ERRP within a standard no-arbitrage framework. We argue that risks driving SDFs must be, in part, transitory and conditionally cyclical. Transitory risk introduces a covariance between today’s SDF and expected future SDFs, and drives bond premia (Alvarez and Jermann, 2005). We define risk to be conditionally cyclical when investors, considering shocks up to a given time, expect booms to be followed by busts, dynamics which imply upward-sloping yield curves on average (Piazzesi and Schneider, 2007). We interpret transitory and cyclical dynamics to be indicative of ‘business-cycle risk’. In turn, cross-country differences in the slope will reflect asymmetries in business-cycle risk and therefore predict ERRP.

To demonstrate the role of business-cycle risk, we present a two-country 1985 (CIR) model for interest rates. We calibrate the model by deriving parametric conditions implied by three widely-documented exchange rate puzzles: (i) the failure to reject UIP at long horizons; (ii) the failure of UIP at short horizons; and (iii) the tendency of high-yield currencies to be contemporaneously appreciated, such that UIP holds in ‘levels’ (Engel, 2016). We show that the restrictions implied by these empirical regularities ensure that risk driving SDFs in the model is transitory and cyclical. Based on this calibration, we show that the model can quantitatively reproduce the tent-shaped relationship between exchange rate changes and the relative slope in line with our empirical evidence. Specifically, the model generates this relationship through two pricing factors with different persistence, upon which yields load with opposing sign.

Through the lens of the model, the relationship between the relative yield curve slope and exchange rates across horizons relies on differences in investors’ valuations of returns over the business cycle. A country with a relatively steep yield curve expects comparatively better times ahead. Therefore, investors value returns more highly in the near term, but expect their valuations to decrease over time. Generally, the country with the steeper yield curve will have a relatively low short-term interest rate and will experience a currency depreciation as compensation for exchange-rate risk, consistent with UIP failures at short horizons. However, cross-country return valuations will reverse as investors move along the cycle. Investors that formerly valued returns highly in a (comparative) bust, value them less as they move into a (relative) boom. The relative path of expected future short-term interest rates will reflect these SDF dynamics,
and the exchange rate will then begin to appreciate—again consistent with short-horizon UIP failures. The currency of a country with a relatively steep yield curve is therefore expected to depreciate in the near-term. The depreciation will peak at business-cycle horizons, before pressure on the currency to appreciate builds to form the tent-shaped relationship we observe in the data.

Overall, this chapter demonstrates that exchange rate fluctuations and, in particular, ERRP can be explained by differences in the term structure of interest rates across countries. In a standard no-arbitrage framework, this implies a role for business-cycle risks, captured by the yield curve slope. So asymmetries in business-cycle risks, reflected in the relative yield curve, drive exchange rate dynamics.

Related literature. Our work is related to a classic literature on the forward-premium puzzle (Hansen and Hodrick, 1980; Fama, 1984), and analysis of UIP across time (Engel, 2016) and horizons (Chinn and Meredith, 2005; Chinn and Quayyum, 2012; Chernov and Creal, 2020). Our analysis is focused on a cross-time component of UIP failures, which Hassan and Mano, 2019 show is an important component of exchange rate predictability. Specifically, our empirical setup builds on Lustig, Stathopoulos, and Verdelhan (2019). They show that, for a given one-month holding period, the term structure of carry trade is decreasing. We extend their specification across holding periods to show that the relative slope is a significant predictor of ERRP at holding periods associated with business-cycle horizons, for a range of maturities.

A number of papers show that yield curve factors can significantly predict ERRP, but many focus on horizons shorter than ours (less than 2 years) (Ang and Chen, 2010; Gräb and Kostka, 2018). While Chen and Tsang (2013) also study longer horizons, they only find significance at short ones. We attribute this difference to the fact Chen and Tsang (2013) capture relative yield curve factors by directly estimating Nelson-Siegel decompositions from relative interest rate differentials, thus assuming common factor structures across countries. In contrast, we construct proxies for factors using yield curves estimated on a country-by-country basis, allowing factor structures to be country-specific.

We argue that the yield curve reflects business-cycle risk, and show that this can explain time-series variation in ERRP. Colacito, Riddiough, and Sarno (2019) also attribute a role to business cycles in explaining ERRP, but in the cross-section—sorting currencies according to their output gap. Insofar as a high output gap contributes to a steeper yield curve slope, our findings are consistent. However, whilst the output gap is backward-looking, this chapter assesses the ability of a forward-looking object (the term structure) in explaining ERRP.

Our theoretical work builds on a prominent literature using no-arbitrage frameworks to derive conditions on SDFs that are consistent with asset prices and asset-pricing puzzles. Alvarez and Jermann, 2005 show that the combination of a high equity premium and low term premium requires most SDF volatility to be due to permanent innovations. Lustig, Stathopoulos, and Verdelhan (2019) extend this result to show that for long-run UIP to hold between two currencies, countries’ SDFs must load symmetrically on permanent innovations. In contrast, we show that differences in the yield curve slope across countries reflect differences in loadings of transitory risk, and has explanatory power for ERRP at short to medium horizons.

Like other papers (e.g. Backus, Foresi, and Telmer, 2001; Lustig, Roussanov, and Verdelhan, 2014; Lustig and Verdelhan, 2019), we use a multi-factor model for interest rates, grounded in
Cox, Ingersoll, and Ross (1985), to study currency anomalies. To the best of our knowledge, we are the first to calibrate such a model to match estimated UIP coefficients across short and long horizons.

Recently, Greenwood et al., 2020 and Gourinchas, Ray, and Vayanos, 2021 relax the assumption of no-arbitrage by considering segmented markets frameworks to explain the relationship between bond premia and ERRP, which we document. This literature is complementary to our work. However, our contribution is to show that the relationship between the relative yield curve slope and ERRP, as well as UIP across horizons, can be reconciled within a standard no-arbitrage framework.

The remainder of this chapter is structured as follows. Section 2.2 presents our yield curve-augmented UIP regression. Section 2.3 documents the empirical relationship between the relative slope and ERRP across holding periods. Section 2.4 illustrates this relationship within a standard no-arbitrage framework, demonstrating the role of business-cycle risk. Section 2.5 concludes.

2.2 Exchange Rates and the Yield Curve Slope

To motivate our analysis, we first estimate canonical UIP regressions across horizons augmented with relative yield-curve factors. Section 2.3 goes a step further, analysing bond and exchange-rate risk premia. Both empirical approaches highlight our headline result: exchange rate dynamics are predictable by the relative yield curve slope, at business-cycle horizons in particular.

2.2.1 Canonical UIP Regression

We estimate the following UIP regression for $\kappa$-month-ahead exchange rate changes:

$$e_{j,t+\kappa} - e_{j,t} = \beta_{1,\kappa} (r_{j,t+\kappa} - r_{t,\kappa}) + f_{j,\kappa} + u_{j,t+\kappa}$$

(2.1)

where $e_{j,t}$ is the (log) exchange rate of the Foreign country $j$ vis-a-vis the Home (base) currency at time $t$. It is defined as the Foreign price of a unit of base currency such that an increase in $e_{j,t}$ corresponds to a Foreign depreciation. $r_{j,t+\kappa}$ is the net $\kappa$-period continuously compounded return in the Foreign country and $r_{t,\kappa}$ is the equivalent return in the Home currency. $f_{j,\kappa}$ is a country fixed effect and $u_{j,t+\kappa}$ is the disturbance.

Under the joint assumption of risk neutrality and rational expectations, the null hypothesis of UIP is $\beta_{1,\kappa} = 1$ for all $\kappa > 0$. Empirical rejections of UIP at short to medium horizons—i.e. finding $\hat{\beta}_{1,\kappa} \neq 1$ for small to medium $\kappa$—have regularly been used to motivate claims that interest rates do not adequately explain exchange rate dynamics.

**Data.** We estimate regression (2.1) using exchange- and interest-rate data for 7 jurisdictions with liquid bond markets: Australia, Canada, Switzerland, euro area, Japan, United Kingdom (UK) and United States (US). The US is the base country among our sample of G7 currencies. To capture the term structure of interest rates in each region, we use nominal zero-coupon government bond yields of 6, 12, 18, ..., 120-month maturities. Yield curves are obtained from a

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1In addition, $f_{j,\kappa} = 0$ for all $j$ and $\kappa > 0$.

2The US is our only base currency throughout this chapter, as it is well-known that UIP patterns are not fully robust to re-basing.
Notes: Red crosses denote $\hat{\beta}_{1,\kappa}$ estimates from regression (2.1). The horizontal axis denotes the horizon $\kappa$ in months. Regressions estimated using pooled monthly data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD from 1980:01 to 2017:12, including country fixed effects. 95% confidence intervals, calculated using Driscoll and Kraay (1998) standard errors, are denoted by red bars around point estimates.

Results. Figure 2.1 plots UIP coefficient estimates $\hat{\beta}_{1,\kappa}$ from regression (2.1), and these results are tabulated in column (1) of Table A.3. The confidence bands around point estimates are derived from Driscoll and Kraay (1998) standard errors, which correct for heteroskedasticity, serial correlation and cross-equation correlation.

The coefficient estimates reinforce that the UIP hypothesis can be rejected at short to medium horizons, but cannot be rejected at longer horizons. At 6 to 36-month tenors, point estimates are negative, indicating that high short-term interest rate currencies tend to appreciate, instead of depreciate. While, at 42 and 48-month horizons point estimates are positive but significantly smaller than unity. Longer-horizon point estimates tend to be positive and close to unity, corroborating with, e.g., Chinn and Meredith (2005) and Chinn and Quayyum (2012).

2.2.2 Yield Curve-Augmented UIP Regression

To illustrate the link between exchange rates and the yield curve slope, we augment regression (2.1) with a measure of the relative yield curve slope $S^*_{j,t} - S_t$, estimating:

$$e_{j,t+\kappa} - e_{j,t} = \beta_{1,\kappa} (r^*_{j,t+\kappa} - r_{t,\kappa}) + \beta_{2,\kappa} (S^*_{j,t} - S_t) + f_{j,k} + u_{j,t+\kappa}$$

(2.2)

for all $\kappa$, where $S^*_{j,t}$ is the slope of the Foreign country $j$ yield curve at time $t$, and $S_t$ is the slope of the base-country yield curve. In robustness analysis in Section 2.2.3, we further extend equation (2.2) to account for the relative yield curve curvature $C^*_{j,t} - C_t$.

As Appendix A.1 documents, our panel of bond yields is unbalanced, with different countries entering the sample at different dates.

Along with the yield curve level, the slope and curvature are known to capture a high degree of variation in bond yields (Litterman and Scheinkman, 1991). We do not include the relative level in regression (2.2) in order to nest UIP, enabling interpretation of the yield curve slope’s contribution over and above spot-yield differentials. Defining the ex post $\kappa$-period ERRP for Foreign currency as $r_{x,j,t,\kappa} \equiv r_{j,t,\kappa} - r_{t,\kappa} - (e_{j,t+\kappa} - e_{j,t})$ and combining with equation (2.2) yields:

$$r_{x,j,t,\kappa} = (1 - \beta_{1,\kappa}) (r_{j,t,\kappa} - r_{t,\kappa}) - \beta_{2,\kappa} (S_{j,t}^* - S_{t}) - f_{j,\kappa} - u_{j,t+\kappa} \quad (2.3)$$

Alongside equation (2.2), $\beta_{2,\kappa}$ can be interpreted as either the average Foreign depreciation (in percent) or the average decrease in the ERRP (in pp) associated with a 1pp increase in the slope of the Foreign yield curve relative to the base country.

We measure the yield curve slope in each region with proxies, using the data described in the previous sub-section. We define the slope as the difference between 10-year and 6-month yields, $S_{j,t}^* = y_{j,t,10y}^* - y_{j,t,6m}^*$. In robustness analysis, we proxy the curvature using a butterfly spread, a function of 6-month, 5 and 10-year yields (Diebold and Rudebusch, 2013): $C_{j,t}^* = 2y_{j,t,5y}^* - (y_{j,t,6m}^* + y_{j,t,10y}^*)$. We prefer these proxies to principal component estimates of the slope and curvature, which potentially contain look-ahead bias, being defined using weights constructed from information in the whole sample. By construction, our proxies are only based on information available up to time $t$. Nevertheless, our findings are robust to the use of principal components. Our relative yield-curve proxies are constructed by taking cross-country differences. Since our proxies are derived from yield curves estimated on a country-by-country basis, we do not assume any symmetry in the factor structure of yield curves across countries.

**Results.** Figure 2.2 presents our key result, plotting the relative slope coefficient estimates $\hat{\beta}_{2,\kappa}$ from equation (2.2). It highlights a tent-shaped relationship across horizons $\kappa$ between the relative slope and $\kappa$-period exchange rate dynamics. Coefficients are insignificantly different from zero at short horizons, but increase in magnitude and significance from short to medium horizons. The $\hat{\beta}_{2,\kappa}$ coefficient peaks at the 3.5-year horizon, quantitatively indicating that a 1pp increase in a country’s yield curve slope relative to the US is, on average, associated with a 4.27% exchange rate depreciation over that horizon. Compared to the 6-month horizon, this point estimate is significantly different too. At longer horizons—from 7-years onwards—the loading on the relative slope is insignificantly different from zero.

Figure 2.3 complements this by plotting the adjusted $R^2$ from regression (2.2) across horizons, together with the comparable figure from the canonical UIP regression (2.1). The adjusted $R^2$ from the augmented regression (2.2) exceeds that of regression (2.1) at all horizons. But the difference is greatest at 3 to 4-year tenors, indicating that information in the yield curve can account for exchange rate fluctuations over and above spot rate differentials at business-cycle horizons in particular.

The full results from regression (2.2), including $\hat{\beta}_{1,\kappa}$ estimates, are documented in Table A.2 of Appendix A.2.1. Augmentation of the UIP regression with the relative yield curve slope does not significantly alter UIP coefficient estimates, as confidence bands from regressions (2.1) and (2.2) overlap. There remains a broadly upward sloping relationship between the UIP coefficient $\hat{\beta}_{1,\kappa}$ and horizons $\kappa$. This implies that the contribution of the relative slope can be interpreted over and above spot-yield differentials, as an additional component of ERRP. However, the $\hat{\beta}_{1,\kappa}$ estimates from regression (2.2) are larger, and standard errors suggest it is harder to reject the
Figure 2.2: Estimated relative slope coefficients from augmented UIP regression

Notes: Black circles denote $\hat{\beta}_{2,\kappa}$ point estimates from regression (2.2). The horizontal axis denotes the horizon $\kappa$ in months. Regressions are estimated using pooled monthly data from 1980:01 to 2017:12, including country fixed effects. 95% confidence intervals, calculated using Driscoll and Kraay (1998) standard errors, are denoted by black bars around point estimates.

Figure 2.3: Explanatory power of UIP regression augmented with relative yield curve slope at different horizons

Notes: Adjusted $R^2$ from the standard UIP regression (2.1) of ex post exchange rate changes on horizon-specific interest rate differentials (thin, red, crosses) and a relative slope-augmented UIP regression (2.2) (thick, black, circles), at different horizons $\kappa$ (horizontal axis, in months). Regressions estimated using pooled end-of-month data for six currencies (AUD, CAD, CHF, EUR, JPY and GBP) vis-à-vis the USD from 1980:01 to 2017:12, and include country fixed effects.
hypothesis that $\beta_{1,\kappa} = 1$ in the augmented regression.

2.2.3 Robustness

In this sub-section, we summarise the robustness of our main empirical finding: that countries with a steeper yield curve tend to experience a subsequent currency depreciation at business-cycle horizons. Further details on the robustness exercises can be found in Appendix A.2.2.

Relative curvature. Adding a proxy for the relative yield curve curvature to regression (2.2) does not significantly alter conclusions around the relative yield curve slope. There remains a tent-shaped relationship on relative slope coefficients across horizons. The relative curvature coefficient has a negative tent-shaped relationship across horizons. But this finding is not robustly significant, and the marginal explanatory power from the relative curvature is comparatively small, justifying our focus on the relative yield curve slope.

Predictability of interest rates. The inclusion of interest rates in specification (2.2) poses a potential challenge, as interest rates are persistent and have a factor structure that is a function of the yield curve slope. To ensure that the relationship between the slope and ERRP is not driven by the predictability of, and correlation with, interest rates, we also estimate a simple regression of exchange rate changes on the relative slope, omitting return differentials. These results, as well as a specification where we include the relative yield curve level alongside slope (and curvature) as in Chen and Tsang, 2013, indicate that the tent-shaped relationship across horizons is robust to these changes.

Long-horizon inference. In long-horizon variants of regressions (2.1) and (2.2), the number of non-overlapping observations can be limited. Therefore, size distortions—i.e. the null hypothesis being rejected too often—are a pertinent concern, especially with small samples and persistent regressors (Valkanov, 2003). To carry out more conservative inference, we draw on 2004 who propose the scaling of $t$-statistics by $1/\sqrt{\kappa}$, showing that these scaled statistics are approximately standard normal when regressors are highly persistent. Our primary result remains significant when using these more conservative $t$-statistics.

Sub-sample stability. Our main results are robust to splitting the sample into two sub-periods. First, a pre-global financial crisis sample (1980:01-2008:06), which excludes the period in which central banks engaged in unconventional monetary policies. Second, a sample covering the post-crisis period (1990:01-2017:12), in which there was a crash in carry trade around 2008 and a switch in UIP coefficients (Bussière, Chinn, Ferrara, and Heipertz, 2018).

Country-specific regressions. The tent-shaped pattern for the relative slope coefficient is statistically significant for at least three currencies vis-à-vis the US dollar. Nevertheless, point estimates exhibit some tent shape for all currencies at short to medium maturities.

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4Using more conservative standard errors, described in the subsequent ‘Long-horizon inference’ paragraph, we do not find a significant relationship between exchange rate changes and the relative curvature across horizons.

5Because this is an approximate result, these standard errors are not our preferred metric for inference. Indeed, the scaled $t$-statistics tend to under-reject the null when regressors are not near-unit root, implying that these confidence bands offer some of the most conservative inference for our regressions.
2.3 Excess Returns, Risk Premia and the Yield Curve Slope

In this section, we build on the results presented in Section 2.2 by assessing the association between the relative yield curve slope and different components of government bond returns. To do so, we analyse returns on bonds of maturity $\kappa$ over different holding periods $h$. In addition to isolating the contribution of the relative yield curve slope to ERRP and local-currency bond premia, this analysis also reduces the challenges posed by the limited number of non-overlapping observations in regressions (2.1) and (2.2) as $\kappa$ increases.

2.3.1 Notation

Before presenting our empirical specification, we introduce notation for returns.

Let $P_{t,\kappa}$ denote the price of a $\kappa$-maturity zero-coupon bond at time $t$ and $R_{t,\kappa} \geq 1$ denote the gross return on that bond. We distinguish a bond’s maturity $\kappa > 0$ from its holding period $h > 0$, where $h \leq \kappa$ and $h = \kappa$ if and only if a bond is held until maturity. The $h$-month holding period return on a $\kappa$-month zero-coupon bond is $HPR_{t,t+h}^{(\kappa)} = P_{t+h,\kappa-h}/P_{t,\kappa}$, i.e. the ratio of the bond’s resale price at $t+h$ when its maturity has diminished by $h$ months relative to its time-$t$ price. The (log) excess return on that bond over the holding period $h$ is thus:

$$rx_{t,t+h}^{(\kappa)} = \log \left( \frac{HPR_{t,t+h}^{(\kappa)}}{R_{t,h}} \right)$$

where $R_{t,h}$ is the gross return on an $h$-month zero-coupon bond at $t$, i.e. the risk-free rate.

The $h$-period (log) return on a Foreign bond, expressed in units of US dollars, in excess of the risk-free return in the base currency, $rx_{t,t+h}^{(\kappa)}$, can be written:

$$rx_{t,t+h}^{(\kappa)} = \log \left( \frac{HPR_{t,t+h}^{(\kappa)*}}{R_{t,h}} \right) + \log \left( \frac{R_{t,h}^{*} \cdot E_{t+h}}{R_{t,h} \cdot E_{t+h}} \right) = rx_{t,t+h}^{(\kappa)*} + rx_{t,t+h}^{FX}$$

where $rx_{t,t+h}^{(\kappa)*}$ represents the (log) local-currency bond return for a Foreign bond and $rx_{t,t+h}^{FX}$ represents the (log) currency excess return.

2.3.2 Empirical Setup

To study the time series properties of returns, we use the above definitions to estimate the following panel regressions for different holding periods $h$ and bond maturities $\kappa$:

$$y_{j,t,h}^{(\kappa)} = \gamma_{1,h}^{(\kappa)} (S_{j,t} - S_{t}) + J_{j,t,h}^{(\kappa)} + \varepsilon_{j,t,h}^{(\kappa)}$$

where $y_{j,t,h}^{(\kappa)}$ is either the excess return on the Foreign bond in US dollar-terms relative to the US return $r_{j,t,t+h}^{(\kappa)} - r_{US,t,t+h}^{(\kappa)}$ (the dollar-bond return difference), the excess return from Foreign currency $r_{j,t,t+h}^{FX} \kappa$, or the excess return on the Foreign bond in Foreign currency units relative to the US return $r_{j,t,t+h}^{(\kappa)*} - r_{US,t,t+h}^{(\kappa)*}$ (the local currency-bond return difference). $\gamma_{1,h}^{(\kappa)}$ has a similar interpretation to $\beta_{2,\kappa}$ from Section 2.2, but with opposite sign. When $y_{j,t,h}^{(\kappa)} = r_{j,t,t+h}^{FX}$, $\gamma_{1,h}^{(\kappa)}$ can be interpreted like $\beta_{2,\kappa}$, albeit in units of annual excess returns.
Focusing on $h = 1$ and $\kappa = 120$ only, using regression (2.6), Lustig, Stathopoulos, and Verdelhan (2019) show that the relative yield curve slope has an insignificant influence on $r_{x_{t,t+h}}^{(\kappa),S}$, but opposing effects on $r_{x_{t,t+h}}^{(\kappa)}$ (positive coefficient) and $r_{x_{t,t+h}}^{FX}$ (negative coefficient), which cancel out for the dollar-bond excess return overall. Our empirical framework extends this, assessing the predictability of excess returns with yield curve slope differentials at a range of maturities $\kappa$ and holding periods $h$, bridging the gap between our results in Section 2.2 and those of Lustig, Stathopoulos, and Verdelhan (2019).

### 2.3.3 Results

The results for regression (2.6) are presented in Tables 2.1 and 2.2. Importantly, where our regression specification most closely matches Lustig, Stathopoulos, and Verdelhan (2019), at short-holding periods $h = 6$ and the longest maturity $\kappa = 120$, our results mirror theirs. The relative slope exerts an insignificant effect on the dollar-bond risk premium difference (Panel A), a positive and significant influence on the local currency-bond risk premium difference $r_{x_{t,t+h}}^{(120)*} - r_{x_{t,t+h}}^{(120)}$ (Panel C), and a negative and significant influence on the currency risk premium $r_{x_{t,t+h}}^{FX}$ (Panel B). The latter two effects are similar in magnitude such that they cancel out for dollar-bond return differences.

Exploring our results at all holding periods $h$ and for all maturities $\kappa$, three observations are noteworthy. First, for a given maturity, the loading on the relative slope exhibits an inverse tent shape across holding periods for both the currency risk premium and the relative dollar-bond risk premium. Although significant at shorter holding periods, the relative slope loadings are quantitatively small for local currency-bond premia and are dominated by loadings on currency excess returns in explaining the relative slope’s impact on relative dollar-bond risk premia. This supports the findings from our benchmark augmented UIP regression in Section 2.2. Furthermore, the relative slope exerts its peak influence on dollar-bond and currency excess returns at the 36-month holding period, close to the peak at 42-month horizon from the augmented UIP regression (2.2).

Second, and related to the first, while the relative yield curve slope does not significantly predict dollar-bond excess return differences at the 6-month holding period for 10-year bonds, the relative slope loading for the same bond maturity is significantly non-zero over longer holding periods. While, in the former case, the influence of the relative slope on currency and local-currency bond returns offset one another (in line with Lustig, Stathopoulos, and Verdelhan, 2019), our results indicate that the influence of the relative slope on the currency premium dominates over longer holding periods, even for long-term bonds. Nevertheless, for a given holding period, the influence of the relative slope on dollar-bond returns decreases in magnitude with maturity.

Third, for a given holding period, the loading on the relative slope for relative dollar-bond returns is similar across maturities. Insofar as the relative slope influences ERRP, the association is strongest at horizons associated with business cycle movements, specifically 3 to 4-years.

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6 Lustig, Stathopoulos, and Verdelhan (2019) consider a 1-month holding period, so comparison is not exact. 7 More generally, the short-horizon local-currency bond return difference predictability confirm results for US bond returns (see, e.g., Fama and Bliss, 1987; Campbell and Shiller, 1991; Cochrane and Piazzesi, 2005).
Table 2.1: Slope coefficient estimates from pooled regression of excess returns

<table>
<thead>
<tr>
<th>Holding Periods</th>
<th>Panel A: Dependent Variable: ( r_{x,t,t-h}^{(κ)} - r_{x,t,t-h}^{US} )</th>
<th>Panel B: Dependent Variable: ( r_{x,t,t-h}^{FX} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>6m</td>
<td>(1) -1.74*** (0.38)</td>
<td>12m -1.84*** (0.37)</td>
</tr>
<tr>
<td>12m</td>
<td>(2) -1.63*** (0.37)</td>
<td>18m -2.29*** (0.37)</td>
</tr>
<tr>
<td>18m</td>
<td>(3) -1.52*** (0.36)</td>
<td>24m -2.80*** (0.36)</td>
</tr>
<tr>
<td>24m</td>
<td>(4) -1.42*** (0.36)</td>
<td>30m -3.04*** (0.36)</td>
</tr>
<tr>
<td>30m</td>
<td>(5) -1.32*** (0.36)</td>
<td>36m -3.28*** (0.36)</td>
</tr>
<tr>
<td>36m</td>
<td>(6) -1.21*** (0.36)</td>
<td>42m -3.57*** (0.36)</td>
</tr>
<tr>
<td>42m</td>
<td>(7) -1.11*** (0.37)</td>
<td>48m -3.87*** (0.37)</td>
</tr>
<tr>
<td>48m</td>
<td>(8) -1.00*** (0.37)</td>
<td>54m -4.16*** (0.37)</td>
</tr>
<tr>
<td>54m</td>
<td>(9) -0.90** (0.38)</td>
<td>60m -4.46*** (0.38)</td>
</tr>
<tr>
<td>60m</td>
<td>(10) -0.80* (0.40)</td>
<td>66m -4.76*** (0.40)</td>
</tr>
</tbody>
</table>

Notes: Coefficient estimates on the relative yield curve slope \( S_{t-h}^{*} - S_{t}^{*} \) from regressions with the log dollar-bond excess return difference (Panel A) or the \( h \)-period log currency excess return (Panel B) as dependent variables. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples. The log returns and yield curve slopes differentials are annualised. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.
Table 2.2: Slope coefficient estimates from pooled regression of excess returns

<table>
<thead>
<tr>
<th>Holding Periods</th>
<th>Panel C: Dependent Variable: $r_{S,t,t+h}^{(e)} - r_{S,t,t+h}^{(US)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) (2) (3) (4) (5) (6) (7) (8) (9) (10)</td>
</tr>
<tr>
<td>6m</td>
<td>0.09*</td>
</tr>
<tr>
<td>12m</td>
<td>0.21** 0.08**</td>
</tr>
<tr>
<td>18m</td>
<td>0.31** 0.15** 0.05</td>
</tr>
<tr>
<td>24m</td>
<td>0.42** 0.23** 0.09 0.01</td>
</tr>
<tr>
<td>30m</td>
<td>0.52** 0.30** 0.14 0.02 0.00</td>
</tr>
<tr>
<td>36m</td>
<td>0.62** 0.39** 0.19* 0.04 0.00 -0.01</td>
</tr>
<tr>
<td>42m</td>
<td>0.73*** 0.48*** 0.26* 0.07 0.01 -0.01</td>
</tr>
<tr>
<td>48m</td>
<td>0.83*** 0.57*** 0.33** 0.12 0.04 -0.01 -0.01</td>
</tr>
<tr>
<td>54m</td>
<td>0.94*** 0.66*** 0.41** 0.16 0.07 0.01 -0.02 -0.02 -0.01</td>
</tr>
<tr>
<td>60m</td>
<td>1.03*** 0.75*** 0.48*** 0.22 0.11 0.03 -0.00 -0.02 -0.02 -0.01</td>
</tr>
<tr>
<td>66m</td>
<td>1.13*** 0.83*** 0.56*** 0.27* 0.15 0.07 0.02 -0.01 -0.02 -0.01</td>
</tr>
<tr>
<td>72m</td>
<td>1.23*** 0.91*** 0.63*** 0.33** 0.20 0.11 0.05 0.01 -0.01 -0.01</td>
</tr>
<tr>
<td>78m</td>
<td>1.30*** 0.99*** 0.69*** 0.38** 0.25* 0.15 0.08 0.03 0.01 -0.00</td>
</tr>
<tr>
<td>84m</td>
<td>1.39*** 1.06*** 0.76*** 0.44** 0.30** 0.19 0.12 0.06 0.02 0.01</td>
</tr>
<tr>
<td>90m</td>
<td>1.47*** 1.13*** 0.81*** 0.49** 0.35** 0.24* 0.16 0.09 0.05 0.02</td>
</tr>
<tr>
<td>96m</td>
<td>1.54*** 1.19*** 0.88*** 0.54*** 0.40** 0.29** 0.20* 0.12 0.07 0.04</td>
</tr>
<tr>
<td>102m</td>
<td>1.62*** 1.26*** 0.93*** 0.59*** 0.45*** 0.33** 0.25* 0.15 0.10 0.06</td>
</tr>
<tr>
<td>108m</td>
<td>1.69*** 1.32*** 0.99*** 0.65*** 0.50*** 0.40*** 0.34** 0.23* 0.15 0.10</td>
</tr>
<tr>
<td>114m</td>
<td>1.76*** 1.38*** 1.04*** 0.69*** 0.55*** 0.43*** 0.32** 0.21* 0.15 0.10</td>
</tr>
<tr>
<td>120m</td>
<td>1.82*** 1.43*** 1.10*** 0.74*** 0.60*** 0.47*** 0.31** 0.21* 0.15 0.10</td>
</tr>
<tr>
<td>N</td>
<td>2.236 2.290 2.254 2.218 2.182 2.146 2.110 2.074 2.038 2.002</td>
</tr>
</tbody>
</table>

Notes: Coefficient estimates on the relative yield curve slope $S_{t}^{(e)} - S_{t}^{(US)}$ from regressions with the $h$-period log local currency-bond excess return difference (Panel C) as dependent variable. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples. The log returns and yield curve slopes differentials are annualised. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.
Table 2.3: Robustness of relative slope coefficient estimates from regression (2.6) for $r_{t,i+h}^F$

<table>
<thead>
<tr>
<th>A: Controlling for interest rate differentials</th>
<th>S$^* - S$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 6m</td>
<td>-0.37</td>
<td>2,299</td>
</tr>
<tr>
<td>(2) 12m</td>
<td>-0.85</td>
<td>2,293</td>
</tr>
<tr>
<td>(3) 18m</td>
<td>-2.00*</td>
<td>2,257</td>
</tr>
<tr>
<td>(4) 24m</td>
<td>-2.66**</td>
<td>2,221</td>
</tr>
<tr>
<td>(5) 30m</td>
<td>-3.57***</td>
<td>2,185</td>
</tr>
<tr>
<td>(6) 36m</td>
<td>-4.11***</td>
<td>2,149</td>
</tr>
<tr>
<td>(7) 42m</td>
<td>-4.26***</td>
<td>2,113</td>
</tr>
<tr>
<td>(8) 48m</td>
<td>-4.13***</td>
<td>2,077</td>
</tr>
<tr>
<td>(9) 54m</td>
<td>-4.02***</td>
<td>2,041</td>
</tr>
<tr>
<td>(10) 60m</td>
<td>-3.90***</td>
<td>2,005</td>
</tr>
</tbody>
</table>

Notes. Coefficient estimates on the relative yield curve slope $S^*_t - S_t$ from regressions with the $h$-period log currency excess return as dependent variables. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples. The log returns and yield curve slopes differentials are annualised. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.

2.3.4 Robustness

In this sub-section, we briefly summarise robustness analyses for these empirical findings. We focus on the relationship between ERRP and the yield curve slope across horizons.

Controlling for interest rate differentials. We extend regression (2.6) by including $h$-period return differentials alongside the relative slope. As Panel A of Table 2.3 demonstrates, the (inverse) tent-shaped relationship on the relative slope is robust to this addition.

Sub-sample stability. Panel B.i of Table 2.3 demonstrates that the association between the relative slope and ERRP is robust to sub-sample splits. Panel B.i presents a pre-global financial crisis sample (1980:01-2008:06) and Panel B.ii shows results from a sample spanning the period after the crisis (1990:01-2017:12).

Cross-sectional returns. To account for returns in the cross-section, we consider the average returns across maturities $\kappa$ and holding periods $h$ from a simple investment strategy based on the yield curve slope. Specifically, we consider a strategy that goes long the Foreign bond and short the US bond when the Foreign yield curve is less steep than the US one, and vice versa. The results are presented in Appendix A.2.3. They demonstrate that average returns have a tent-shaped pattern across holding periods, for different maturities, supporting evidence of the yield curve slope’s predictive role for returns.

2.3.5 Accounting for Liquidity Yields

Recent contributions to the literature have emphasised the role for liquidity yields—i.e. non-pecuniary returns, especially for US bonds—in exchange rate determination (Jiang2018; see, e.g. Engel and Wu, 2018). In this sub-section, we extend our empirical specification to account for these liquidity yields. We demonstrate that the tent-shaped relationship between the relative slope and ERRP across horizons continues to be robust to this extension, and therefore explains variation in exchange rates independently from liquidity yields. We also analyse the link between the term structure of liquidity yields and ERRP.
Liquidity yield-augmented regression. To do this, we use data on the term structure of liquidity yields from Du, Im, and Schreger, 2018. These measure the difference between riskless market rates and government yields at different maturities to quantify the implicit liquidity yield on a government bond, correcting for other frictions in forward markets and sovereign risk. Let $\eta_{j,t,\kappa}^R$ denote the $\kappa$-horizon liquidity premium for a $\kappa$-horizon US government bond relative to an equivalent-maturity Foreign government bond yield in country $j$. An increase in $\eta_{j,t,\kappa}^R$ reflects an increase in the relative liquidity of US Treasuries vis-à-vis country $j$.

Although the Du, Im, and Schreger (2018) data is available from 1991:04 for some countries and tenors (e.g. UK), some series begin as late as 1999:01 due to data availability (e.g. euro area). Given these shorter samples, the problem of non-overlapping observations becomes especially pertinent. For this reason, our preferred empirical specification extends regression (2.6):

$$y_{j,t,h} = \gamma_1 \left( S_{j,t}^* - S_t \right) + \gamma_2 \eta_{j,t,\kappa}^R + f_{j,h} + \varepsilon_{j,t+h} (2.7)$$

where the dependent variable $y_{j,t,h}$ is either the relative dollar-bond return, the currency excess return, or the relative local currency-bond return. The interpretation of $\gamma_1$ is unchanged relative to equation (2.6). $\gamma_2$ can be interpreted as the average influence of a 1pp increase in relative US Treasury convenience. When the currency excess return $r_{x_{FX,t,t+h}}$ is the dependent variable, we expect $\gamma_2$ to be positive, such that an increase in relative US Treasury liquidity is associated with a contemporaneous appreciation of the US dollar (depreciation of Foreign currency) that increases the currency excess return $r_{x_{FX,t,t+h}}$.

Results. The results for the relative dollar-bond excess return are presented in Table 2.4. Panel A.i documents the estimated coefficient loadings on the relative slope, which are similar to those in Table 2.1. As before, the slope loading is insignificant for excess returns over short and long holding periods for long-term bonds, consistent with the failure to reject UIP in the long run. At medium holding periods, the influence of the slope is significant, with the coefficient peaking at business-cycle horizons—in this case, 2.5 to 3-years—similar in magnitude to the results presented in Table 2.1.

Panel A.ii presents the $\gamma_2$ coefficient estimates for relative liquidity yields. For a given maturity, the coefficient on the relative liquidity yield rises monotonically with respect to holding period, growing in significance. In this case, a higher US Treasury liquidity premium is associated with a higher excess return on a Foreign bond in US dollar terms.

Table 2.5 focuses on ERRP, from the decomposition of dollar-bond returns into ERRP and local currency-returns. As in the rest of this section, the coefficients indicate that the influence of both of relative slope and relative liquidity yields on dollar-bond excess returns predominantly works through currency excess returns. In contrast, the $\gamma_2$ loadings (shown in Appendix A.2.4) for local currency-bond excess returns are negative and relatively small in magnitude.

---

8Du, Im, and Schreger (2018) show that over 75% of variation in their measure of the ‘US Treasury premium’ is attributed to liquidity considerations. The data is available for 12, 24, 36, 60, 84 and 120-month tenors only, constraining the maturities we assess in this section.
Table 2.4: Slope and liquidity yield coefficient estimates from pooled regression of excess returns

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Panel A.ii: Dependent Variable: $r^{(e)}_{S.t+h} - r^{(e)}_{US,t+h}$, Coefficient on $\eta^R_{\kappa}$

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Notes: Coefficient estimates on the relative yield curve slope $S^\ast_t - S_t$ (Panel A.i) and cross-country $\kappa$-period liquidity yield $\eta^R_{\kappa}$ (Panel A.ii) from regressions with the log dollar-bond excess return difference as dependent variable. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples within 1991:04-2017:12. The log returns and yield curve slopes differentials are annualised. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.

2.4 Theory

In this section, we show that the tent-shaped relationship between exchange rates and the relative yield curve slope is consistent with no-arbitrage and driven by cross-country differences in business-cycle risk. We present a two-country 1985 (CIR) model and derive three key results. First, we show that the relationship between the relative slope and exchange rates must be driven by transitory risk. Second, we show that a one-factor model with no permanent innovations cannot simultaneously account for short-run UIP failures and positive bond premia. A two-factor model resolves this and reproduces the tent-shaped relationship between the relative slope and exchange rates if interest rates are ‘conditionally cyclical’. Third, we calibrate the model to match moments of bond and equity markets, and show that it quantitatively aligns with our empirical results.

2.4.1 Pricing Kernels, Transitory Risk and the Yield Curve Slope

We consider a two-country environment, in which each country—Home (base currency, i.e. US) and Foreign (denoted by an asterisk)—has a representative investor. Throughout, we assume that investors can trade freely in both Home and Foreign risk-free bonds of multiple maturities.
Table 2.5: Slope and liquidity yield coefficient estimates from pooled regression of excess returns

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**Panel B.I:** Dependent Variable: \( r_{t,t+h} \), Coefficient on \( S^+ - S \), when \( \eta_h \) is additional control

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Notes: Coefficient estimates on the relative yield curve slope \( S^+ - S \) (Panel B.i) and cross-country \( \kappa \)-period liquidity yield \( \eta_h \) (Panel B.ii) from regressions with the log currency excess return as dependent variable. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vs. the USD for different samples within 1991:04-2017:12. The log returns and yield curve slopes differentials are annualised. All regressions include country fixed effects. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively. Because currency excess returns are invariant to bond maturity, and depend only on the holding period (unlike the dollar- and local currency-bond returns), we are able to present coefficient estimates on the relative slope and liquidity yield for all holding periods up to, and including, the bond maturity.

Notation

Pricing kernels and stochastic discount factors. The Home nominal pricing kernel \( V_t \) represents the marginal value of a currency unit at time \( t \). The nominal SDF \( M_{t,t+k} \) represents the growth rate of the pricing kernel between periods \( t \) and \( t+k \); \( M_{t,t+k} = V_{t+k}/V_t \).

The price of a Home zero-coupon bond that promises one currency unit \( \kappa \) periods into the future is given by: 
\[
P_{t,k} = E_t \left[ M_{t,t+k} \right] = E_t \left[ M_{t+1,t+k-1} \right],
\]
where \( M_{t,k+1} \) denotes the one-period SDF and \( M_{t,t+k} = \prod_{i=0}^{k-1} M_{t+i,t+i+1} \). Defining the gross return on the Home \( \kappa \)-period zero-coupon bond as \( R_{t,k} = 1/P_{t,k} \equiv (1 + r_{t,k}) \geq 1 \), this implies:
\[
1 = E_t \left[ M_{t,t+k} R_{t,k} \right] \tag{2.8}
\]
which can be rewritten as:
\[
\frac{1}{R_{t,k}} = E_t \left[ \prod_{i=0}^{k-1} M_{t+i,t+i+1} \right] \tag{2.9}
\]
Expressions for Foreign returns are analogous, denoted by an asterisk.

Exchange rates. \( \xi_t \) represents the exchange rate, defined as the Foreign price of a unit of Home currency, such that an increase in \( \xi \) corresponds to a Foreign depreciation. When engaging
in cross-border asset trade, the Euler equation for a risk-averse Foreign agent with SDF $M^*_t,t+\kappa$ holding a $\kappa$-period Home currency-denominated bond is:

$$1 = \mathbb{E}_t \left[ M^*_t,t+\kappa \frac{\mathcal{E}_{t+\kappa}}{\mathcal{E}_t} R_{t,\kappa} \right]$$  \hspace{1cm} (2.10)

When financial markets are complete, the change in the nominal exchange rate corresponds to the ratio of SDFs:

$$\frac{\mathcal{E}_{t+\kappa}}{\mathcal{E}_t} = \frac{M_{t,t+\kappa}}{M^*_t,t+\kappa}$$  \hspace{1cm} (2.11)

for all $\kappa > 0$. This no-arbitrage definition follows from equations (2.8) and (2.10).

**Currency risk premia.** Assuming one-period SDFs, $M_{t,t+1}$ and $M^*_{t,t+1}$, and the exchange rate, $\mathcal{E}_t$, are jointly log-normally distributed, the (log) one-period ex ante currency risk premium $\mathbb{E}_t [r_{X,t+1}]$ can be written as the half-difference between the conditional variance of (log) Home and Foreign SDFs:

$$\mathbb{E}_t [r_{X,t+1}] = r^*_{t+1} - r_{t,1} - \mathbb{E}_t [\Delta^1 e_{t+1}]$$

$$= \frac{1}{2} \left[ \text{var}_t (m_{t,t+1}) - \text{var}_t (m^*_{t,t+1}) \right]$$  \hspace{1cm} (2.12)

where the second equality uses the logarithmic expansion of equations (2.8), its Foreign analog, and (2.11) when $\kappa = 1$.

**Decomposing the pricing kernel**

To assess the nature of risks driving ERRP predictability, we use the Alvarez and Jermann, 2005 decomposition of the pricing kernel $V_t$ into a permanent component $V^P_t$ and a transitory component $V^T_t$:

$$V_t = V^P_t V^T_t, \quad \text{where } V^T_t = \lim_{\kappa \to \infty} \frac{\delta^t}{P_{t,\kappa}}$$  \hspace{1cm} (2.13)

where the constant $\delta$ is chosen to satisfy the regularity condition: $0 < \lim_{\kappa \to \infty} P_{t,\kappa}/\delta^\kappa < \infty$ for all $t$. A pricing kernel $V_t$ is defined as having only transitory innovations if $\lim_{\kappa \to \infty} \frac{\mathbb{E}_t [V_{t+\kappa}]}{\mathbb{E}_t [V_{t+\kappa}] - 1} = 1$. So, its permanent component follows a martingale, defined by: $V^P_t = \lim_{\kappa \to \infty} \mathbb{E}_t [V_{t+\kappa}] / \delta_{t,\kappa}$.

Under regularity conditions, Alvarez and Jermann, 2005 show that the return on an infinite-maturity bond can be written as a function of transitory innovations to SDFs only: $R_{t,\infty} = \lim_{\kappa \to \infty} R_{t,\kappa} = V^T_t/V^T_{t+1} = \exp(-m^T_{t,t+1})$, where $m^T_{t,t+1}$ denotes the transitory component of the SDF. In contrast, one-period bond returns, defined by equation (2.8), depend on both transitory and permanent innovations to SDFs.

Using equations (2.12) and (2.13), Lustig, Stathopoulos, and Verdelhan (2019) show that the long-horizon ERRP is proportional to cross-country differences in the variance of permanent innovations to investors’ SDFs:

$$\lim_{\kappa \to \infty} \mathbb{E}_t [r_{X,t+\kappa}] = \frac{1}{2} \left[ \text{var}_t \left( \nu^P_{t+1} \right) - \text{var}_t \left( \nu^{P^*_t}_{t+1} \right) \right]$$  \hspace{1cm} (2.14)

where $\nu^{(s)}_t \equiv \log(V^P_{t+\kappa})$. The relative success of long-horizon UIP requires equation (2.14) is approximately zero, therefore implying that cross-country differences in permanent SDF volatilities
are small.\(^9\)

We focus on short to medium horizons, where UIP can be rejected. ERRP at these horizons must reflect transitory innovations to SDFs:

\[
\begin{align*}
\mathbb{E}_t \left[ r_{FX,t+1}^{FX} \right] & \approx \frac{1}{2} \left[ \text{var}_t \left( r_{t+1}^T \right) - \text{var}_t \left( \mu_{t+1}^T \right) \right] \neq 0 \quad \text{(Short-Horizon ERRP)} \\
\mathbb{E}_t \left[ r_{FX,t+\kappa}^{FX} \right] &= r_{t,\kappa} - r_{t,n} - \mathbb{E}_t \left[ \Delta \kappa \epsilon_{t+\kappa} \right] \neq 0 \quad \text{for } 1 < \kappa < \infty \quad \text{(Medium-Horizon ERRP)}
\end{align*}
\]

### Yield Curve Slope and Cyclical Dynamics

To understand the role of the yield curve slope in capturing business-cycle risks, define the (log) excess return from buying a \(n\)-period Home bond at time \(t\) for price \(P_{t,n} = 1/R_{t,n}\) and selling it at time \(t+1\) for \(P_{t+1,n-1} = 1/R_{t+1,n-1}\) as \(r_{t,t+1}^{(n)} = p_{t+1,n-1} - p_{t,n} - y_{t,1}\), where \(p_{t,n} \equiv \log(P_{t,n})\) and \(y_{t,n} \equiv \frac{1}{n}p_{t,n}\) is the annualised yield on a \(n\)-period bond.\(^{10}\) This excess return can be written as:

\[
\mathbb{E}_t \left[ r_{t,t+1}^{(n)} \right] = -\text{cov}_t \left( m_{t,t+1}, \mathbb{E}_t \left[ \sum_{i=1}^{n-1} m_{t+i,t+i+1} \right] - \frac{1}{2} \text{var}_t (r_{t+1,n}) \right) \quad (2.15)
\]

The covariance term on the right-hand side is the bond risk premium, and is also equal to the covariance between the contemporaneous one-period SDF and the expected price or return on a long-term bond tomorrow, i.e. \(p_{t+1,n-1}\) or \(r_{t+1,n-1}\). The Foreign excess return is defined analogously.

Two features of the bond risk premium demonstrate that it is driven by business-cycle risk. First, the bond risk premium only captures transitory innovations to investors’ SDFs. If the SDF is i.i.d., corresponding to the case of only permanent SDF innovations, the covariance in equation (2.15) is zero (see Example 1, Alvarez and Jermann, 2005).

Second, the premium reflects cyclicity of risk. It is positive if today’s one-period SDF is negatively correlated with expected future marginal utility. That is, if households receive relatively good news about the distant future, they expect to value consumption less at long horizons—i.e. lower \(\mathbb{E}_t[m_{t+i,t+i+1}]\) for some \(i > 0\)—but relatively highly in the near term—i.e. higher \(m_{t,t+1}\). Specifically, we define risk to be conditionally cyclical if, conditional on shocks up to time \(t\), investors expect a ‘boom’ to be followed by a ‘bust’, or vice versa.

Piazzesi and Schneider, 2007 note that, over long enough samples, this risk premium is approximately equal to the yield curve slope, \(\mathbb{E}_t[r_{t,t+1}^{(n)}] \approx S_t\) where \(S_t \equiv y_{t,n} - y_{t,1}\), implying that the yield curve will be upward sloping on average if the right-hand side of equation (2.15) is positive.\(^{11}\) Taken together, this suggests that the yield curve slope captures business-cycle risks, with parallels to the literature on recession predictability by the yield curve (Estrella and

---

\(^9\) Alvarez and Jermann, 2005 emphasise that to jointly rationalise high equity premia and low bond premia, most SDF volatility must arise from permanent SDF innovations. The contrast in exchange rate markets may be due to differential transmission and risk sharing across countries.

\(^{10}\) The annualised yield \(y_{t,n}\) and the log \(n\)-period return \(r_{t,n}\) have the following relationship: \(n y_{t,n} = r_{t,n}\).

\(^{11}\) To see this, re-write the excess return \(r_{t,t+1}^{(n)}\) as:

\[
\begin{align*}
p_{t+1,n-1} - p_{t,n} - y_{t,1} &= n y_{t,n} - (n - 1)y_{t+1,n-1} - y_{t,1} \\
&= y_{t,n} - y_{t,1} - (n - 1)(y_{t+1,n-1} - y_{t,n})
\end{align*}
\]

Over a long enough sample and with large \(n\), the difference between the average \((n - 1)\)-period yield and the average \(n\)-period yield is zero, implying that \(\mathbb{E}_t[r_{t,t+1}^{(n)}] \approx y_{t,n} - y_{t,1} \equiv S_t\).
Hardouvelis, 1991; Estrella and Mishkin, 1998; Estrella, 2005). In turn, the relative yield curve slope \( S_t^m - S_t \) reflects asymmetries in business-cycle risk across countries.

We have shown that the relation between the relative slope and ERRP must be driven by transitory and cyclical factors, which we define as ‘business-cycle risk’. The discussion so far has been presented in a preference-free setting. To derive this link in closed form, we next turn to a parametric model of the term structure of interest rates and exchange rates.

### 2.4.2 Two-Country Cox, Ingersoll and Ross Model

We use a calibrated two-country CIR model. To demonstrate the role of business-cycle risk, we impose parametric restrictions. We show that these can be mapped to three widely-documented empirical regularities: (i) the failure to reject UIP at long horizons (Chinn and Meredith, 2005) and for long-maturity bonds over short holding periods (Lustig, Stathopoulos, and Verdelhan, 2019); (ii) the appreciation of high-yield currencies in excess of UIP at short horizons (Fama, 1984); and (iii) the tendency for high interest rate currencies to be contemporaneously appreciated, i.e. UIP holding in ‘levels’ (Engel, 2016). Applying these restrictions, we show that the model can reproduce the tent-shaped relationship across horizons between the relative yield curve slope and ERRP.

Within the model, the representative Home investor’s SDF loads on two country-specific factors \( z_{i,t} \) (\( i = 1, 2 \)):

\[
-m_{i,t+1} = \alpha + \chi z_{1,t} + \sqrt{\gamma z_{1,t} u_{t+1}} + \tau z_{2,t} + \sqrt{\delta z_{2,t} u_{2,t+1}} \tag{2.16}
\]

\[
z_{i,t+1} = (1 - \phi_i)\theta_i + \phi_i z_{i,t} - \sigma_i \sqrt{z_{i,t}} u_{i,t+1} \quad \text{for} \quad i = 1, 2 \tag{2.17}
\]

We assume that the representative Foreign investor’s SDF \( m_{t,t+1}^* \) and country-specific pricing factors \( z_{i,t}^* \) are defined analogously, and with symmetric loadings (\( \alpha^* = \alpha, \chi^* = \chi, \gamma^* = \gamma, \tau^* = \tau, \delta^* = \delta, \phi_i^* = \phi_i, \theta_i^* = \theta_i \) and \( \sigma_i^* = \sigma_i \) for \( i = 1, 2 \)).

Assuming log-normality, then equations (2.16) and (2.17) can be combined with the expression for the (log) price of an \( n \)-period bond, \( p_{t,n} = E_t[m_{t,t+1} + p_{t+1,n-1} + (1/2)\text{var}(m_{t,t+1} + p_{t+1,n-1})] \), to write the the (log) bond price as an affine function of pricing factors:

\[
p_{t,n} = - (A_n + B_n z_{1,t} + C_n z_{2,t}) \tag{2.18}
\]

where \( A_n, B_n \) and \( C_n \) are recursively defined, with \( A_n = A_n(\alpha, \phi_1, \phi_2, \theta_1, \theta_2; A_{n-1}, B_{n-1}, C_{n-1}) \), \( B_n = B_n(\phi_1, \chi, \gamma, \sigma_1; B_{n-1}) \) and \( C_n = C_n(\phi_2, \tau, \delta, \sigma_2; C_{n-1}) \) and initial values of 0 (\( A_0 = B_0 = C_0 = 0 \)). The continuously compounded yield is \( y_{t,n} = -\frac{1}{n}p_{t,n} \). Expressions for Foreign bond prices and yields are analogous.

Since we emphasise the importance of transitory and cyclical risk in explaining the relationship between exchange rate movements and the term structure of interest rates, we use equation (2.13) to decompose the SDF in equation (2.16) into its transitory \( m_{t,t+1}^T \) and permanent \( m_{t,t+1}^P \) components in logarithmic form.

\[
m_{t,t+1}^T = \ln \beta + B_0 \left[ (\phi_1 - 1)(z_{1,t} - \theta_1) - \sigma_1 \sqrt{z_{1,t}} u_{1,t+1} \right]
+ C_0 \left[ (\phi_2 - 1)(z_{2,t} - \theta_2) - \sigma_2 \sqrt{z_{2,t}} u_{2,t+1} \right] \tag{2.19}
\]

\[\text{We discuss the consequences of using country-specific factors, with no cross-country correlation, at the end of this sub-section when evaluating our findings.}\]
\begin{align}
m^P_{t,t+1} &= -\ln \beta - \alpha - \chi z_{1,t} - \sqrt{\gamma z_{1,t}} u_{1,t+1} - \tau z_{2,t} - \sqrt{\delta z_{2,t}} u_{2,t+1} \\
&\quad - B_\infty \left[ (\phi - 1) (z_{1,t} - \theta_1) - \sigma_1 \sqrt{z_{1,t}} u_{1,t+1} \right] \\
&\quad - C_\infty \left[ (\phi - 1) (z_{2,t} - \theta_2) - \sigma_2 \sqrt{z_{2,t}} u_{2,t+1} \right]
\end{align}

Building on these foundations, we study the parametric restrictions necessary for the two-country CIR model to incorporate business-cycle risk. We show that these restrictions can be mapped to empirical regularities for UIP across horizons. We consider each regularity, and the corresponding restrictions, in turn.

**Long-horizon UIP and permanent innovations.** As discussed above, the fact UIP cannot be rejected at long horizons implies that equation (2.14) is approximately zero. This rules out permanent innovations to investors’ SDFs as drivers of ERRP. As such, we eliminate these permanent drivers from the model. To do this, consider the infinite-maturity bond excess return: 13

\[
\mathbb{E}_t \left[ r^P_{x_{t,t+1}} \right] = \left[ B_\infty (1 - \phi_1) - \chi + \frac{1}{2} \gamma \right] z_{1,t} + \left[ C_\infty (1 - \phi_2) - \tau + \frac{1}{2} \delta \right] z_{2,t}
\]

which can be derived by direct substitution of the pricing equation (2.18).

To consider the case with no permanent innovations, we set the infinite-maturity bond excess return to half the variance of the SDF: \( \mathbb{E}_t [r^P_{x_{t,t+1}}] = \frac{1}{2} \gamma z_{1,t} + \frac{1}{2} \delta z_{2,t} \). This requires: \( (B_n (1 - \phi_1) - \chi) \theta_1 + (C_n (1 - \phi_2) - \tau) \theta_2 = 0 \) as \( n \to \infty \). However, for simplicity, we assume that this holds factor-by-factor such that: \( B_\infty (1 - \phi_1) - \chi = C_\infty (1 - \phi_2) - \tau = 0 \). Substituting this into the recursions for \( B_n \) and \( C_n \) yields: \( B_\infty = \sqrt{\gamma} / \sigma_1 \) and \( C_\infty = \sqrt{\delta} / \sigma_2 \). And using these restrictions in equation (2.20) ensures \( m^P_{t,t+1} = -\alpha - \chi_1 \theta_1 - \tau \theta_2 \), a constant, such that there are no permanent innovations: \( \text{var}_t(m^P_{t,t+1}) = 0 \). Because loadings are symmetric across countries, long-run UIP deviations are ruled out under this parametric restriction. So only transitory risk drives exchange rate dynamics.

**Short-horizon UIP and the second factor.** To replicate the short-horizon failure of UIP alongside matching long-horizon UIP, a second factor is necessary in our model. To see this, consider a one-factor model variant, i.e. \( z_{2,t} = 0 \) and \( C_n = 0 \) in the above equations. Within the one-factor model, permanent innovations will be eliminated when \( B_\infty = \sqrt{\gamma} / \sigma_1 \) only, and the infinite-maturity bond excess return will be: \( \mathbb{E}_t [r^P_{x_{t,t+1}}] = \frac{1}{2} \gamma z_{1,t} \). In turn, for the short-run UIP coefficient to be negative, we require \( \text{cov}_t(\mathbb{E}_t[\Delta^1 e_{t+1}], r^*_{t,1} - r_{t,1}) < 0 \). Within the one-factor model, this would imply \( \chi - \frac{1}{2} \gamma < 0 \) and, by the recursion equation for \( B_n \), \( B_n < 0 \) for all \( n \). This contradicts the restriction required to replicate long-run UIP, namely: \( B_\infty = \sqrt{\gamma} / \sigma_1 > 0 \).

**UIP in levels and conditional cyclicity.** To understand the importance of the second factor, we also draw on evidence in Engel, 2016 that high-yield currencies tend to be contemporaneously appreciated, i.e. UIP holds in ‘levels’. This requires the covariance between the current short-term interest rate differential and future one-period exchange rate moves to switch sign across horizons: \( \text{cov}_t(\mathbb{E}_t[\Delta^1 e_{t+1}], r^*_{t,1} - r_{t,1}) < 0 \) for UIP to fail in the short run, but \( \text{cov}_t(\mathbb{E}_t[\Delta^1 e_{t+1}], r^*_{t,1} - r_{t,1}) > 0 \) for some \( i > 1 \), helping to ensure UIP holds in the long run.

---

13 A derivation of the bond excess return, and its infinite-maturity limit, can be found in Appendix A.3.
To replicate this, in tandem with the failure of short-horizon UIP, the inclusion of a second factor in the CIR model—under specific parametric restrictions—is critical. In the Lemma below, we show that the second factor must have a positive loading and be relatively persistent to match these two empirical regularities:

**Lemma (Transitory and Conditionally Cyclical Risks)** We define risk in the two-country CIR model to be transitory and conditionally cyclical if the following three parametric restrictions are met:

(i) \((B_n(1 - \phi_1) - \chi)\theta_1 + (C_n(1 - \phi_2) - \tau)\theta_2 = 0\) as \(n \to \infty\). This rules out permanent innovations to investors’ SDFs, so ensures the model matches long-run UIP.

(ii) \(\chi - \frac{1}{2}\gamma < 0\) and \(\frac{\chi}{\chi - \frac{1}{2}\gamma} \text{var}(z_t^1 - z_{t-1}) < -\tau \frac{\tau - \frac{1}{2}\delta}{\tau - \frac{1}{2}\delta} \text{var}(z_t^2 - z_{t-1})\) for \(\chi, \tau > 0\). This ensures the model replicates short-run failures of UIP.

(iii) The second factor is sufficiently more persistent than the first, \(\phi_2 >> \phi_1\), and \(\tau - \frac{1}{2}\delta > 0\). This ensures the model approximately replicates UIP in levels and generates conditional cyclicality.

**Sketch Proof.** Condition (i) ensures that \(\beta_{UIP}^h\) is unity. Conditions (ii) and (iii) ensure that the UIP coefficient is negative at short horizons and positive at long horizons:

\[
\beta_{UIP}^h = \frac{\chi - \frac{1}{2}\gamma}{\chi - \frac{1}{2}\gamma} (B_h\text{var}(z_t^1 - z_{t-1}) + \tau C_h\text{var}(z_t^2 - z_{t-1}))
\]

(2.21)

See Appendix A.3.1 for a full proof.

Within the two-factor CIR model, it is the cyclicality of risk that allows the model to match UIP at short and long horizons. Specifically, the inclusion of a second factor under condition (iii) ensures that long-term interest rates co-move negatively with the SDF, i.e. \(\text{cov}_{t}(m_{t,t+1}, y_{t,n}) < 0\), delivering a positive average yield curve slope. Using equation (2.16), the bond risk premium can be expressed as:

\[
-\text{cov}_{t}(p_{t+1,n-1}, m_{t,t+1}) = B_{n-1}\sigma_1 \sqrt{\gamma} z_{1,t} + C_{n-1}\sigma_2 \sqrt{\delta} z_{2,t}
\]

(2.22)

If condition (ii) holds, implying \(B_{n-1} < 0\), the bond risk premium is positive only if the second factor is sufficiently more persistent than the first, i.e. \(\phi_2 >> \phi_1\), and \(C_{n-1} > 0\). Conditions (ii) and (iii) therefore simultaneously generate cyclical SDF dynamics, and result in a sign-switch in UIP coefficients across horizons, given by equation (2.21), within the model.

We now return to the main result of the chapter. In the following Proposition, we demonstrate that when imposed jointly, the conditions in the Lemma generate a tent-shaped relationship between expected exchange rate movements and the relative yield curve slope. The Proposition states this for model-implied univariate regressions.

---

14While two-factor multi-country CIR models have been discussed in the literature, (e.g. Lustig, Stathopoulos, and Verdelhan, 2019, Appendix IV.C) our analysis is (to the best of our knowledge) the first to analyse the implications of such a model and consider the role for the term structure of interest rates in exchange rate determination. Away from our CIR setting, Engel (2016) presents a stylised two-country New-Keynesian model with productivity and liquidity risk. These two sources of risk have parallels to the two factors we consider.
Proposition. The two-country CIR model can reproduce a tent-shaped relationship between the expected exchange rate movements $\mathbb{E}_t[e_{t+\kappa} - e_t]$ and the relative slope $S_t^R$ across horizons $\kappa$ if and only if conditions (i)-(iii) in the Lemma hold.

Proof. See Appendix A.3.2.

The relationship between the relative yield curve slope and exchange rates across horizons summarised in the Proposition relies on differences in investors’ valuations of returns over the business cycle. Suppose the Foreign country has a relatively steep yield curve. The representative Foreign investor will value returns more highly in the near term, but expect their valuations to decrease over time, as equation (2.15) demonstrates when yield curves are upward sloping on average. Since the yield curve is mechanically linked to short-term yields, the Foreign country will generally have a relatively low short-term interest rate and will experience a currency depreciation as compensation for exchange-rate risk, consistent with short-run UIP failures. Therefore, the relationship between the relative slope and exchange rate changes is positive at short horizons.

However, cross-country return valuations will reverse as investors move along the cycle. The Foreign investor, who formerly valued returns highly in a (comparative) bust, will value them less as they move into a (relative) boom. These SDF dynamics are reflected in the path of expected relative future short-term interest rates: $E_t[r_{t+i,1}^* - r_{t+i,1}] = B_1(E_t[z_{1,t+i}^* - z_{1,t+i}]) + C_1(E_t[z_{2,t+i}^* - z_{2,t+i}])$ across $i$, derived from cross-country differences in equation (2.18) at $n = 1$. For the Foreign country to have relatively low short-term yields: $z_{1,t}^* > z_{1,t}$ as $B_1 < 0$. And due to the higher Foreign slope: $z_{2,t}^* > z_{2,t}$ as $C_1 > 0$. Since $\phi_2 > \phi_1$, the influence of cross-country differences in the second factor on expected relative short-yield differentials will dominate at longer horizons. Consequently, expected future short-term yield differentials will be increasing for small $i$, as cross-country differences in the first factor matter at short horizons, but dissipate more quickly. For larger $i$, the value of the differential will be decreasing, as differences in the second factor persist, and the exchange rate will begin to appreciate—again consistent with short-run UIP failures. In sum, the currency of the Foreign country—with the relatively steep yield curve—will depreciate in the near-term. The depreciation will peak at business-cycle horizons, before pressure on the currency to appreciate builds to form the tent-shaped relationship we observe in the data.

Numerical calibration. We now calibrate the two-country CIR model to satisfy the conditions in the Lemma, as well as match other empirical moments for bonds and equities. We demonstrate that it can quantitatively reproduce the tent-shaped relationship between exchange rate changes and the relative slope that we identify in the data.

We target 11 moments from the data: the mean and variance of the short and long-term interest rates; the autocorrelation of short-term interest rates; the variance of SDFs; two Feller conditions that help ensure $z_{1,t}$ and $z_{2,t}$ remain positive; short and long-horizon UIP coefficients; and the peak coefficient implied by a univariate regression of exchange rate changes on the relative slope across horizons. These calibration targets are summarised in Table ??, and pin

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15The calibration differs from the restrictions summarised in the Lemma in one small way. Although long-run UIP at the 10-year horizon cannot be statistically rejected, we find the point estimate to be below 1, so target a long-run UIP coefficient of 0.8 (i.e. condition (i) holds approximately, not exactly). Assuming long-run UIP still held exactly would still deliver the tent-shaped coefficient on the relative slope, as per the Proposition.
Figure 2.4: Implied regression coefficients from two-country CIR model across horizons and comparable estimated coefficients

Notes: Black line denotes model-implied conditional regression coefficients across horizons. Red crosses denote calibration targets for the model. Blue line plots estimated coefficients using pooled monthly data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD from 1980:01 to 2017:12, excluding country fixed effects. 95% confidence intervals, calculated using Driscoll and Kraay (1998) standard errors, are denoted by blue bars around point estimates. Left-hand (right-hand) plot shows coefficients for univariate regression of $\kappa$-period exchange rate on return differentials (relative yield curve slope).

down the 11 free model parameters. The parameter values we obtain are listed in Table 2.8.\footnote{Since we limit our focus to assessing the ability of the model to replicate the empirical regularities we outline in this chapter, it is beyond our scope to evaluate the model’s performance against other unmatched moments.}

The calibration identifies key differences between the two pricing factors, whose loadings differ in sign and persistence. Because $\chi - (1/2)\gamma = -0.30 < 0$, bond yields load negatively on the first factor. In contrast, $\tau - (1/2)\delta = 0.80 > 0$, such that bond yields load positively on the second. Consistent with the Lemma, the first factor is less persistent than the second ($\phi_2 = 0.99 > \phi_1 = 0.95$). This ensures that the numerical exercise features transitory and conditionally cyclical risks.

The key results from the calibration exercise are plotted in Figure 2.4. The left-hand chart shows the model-implied UIP coefficient across horizons, alongside empirical estimates (and 95% confidence bands) from equation (2.1).\footnote{For this figure, we omit country fixed effects from the estimation to be consistent with model-implied values.} Between the two calibrated UIP regression coefficients—at $h = 1$ and $h = 120$—the model-implied values broadly lie within the estimated confidence bands. To the best of our knowledge, this is the first multi-country CIR model to quantitatively replicate UIP coefficients across horizons.

The right-hand chart plots the model-implied coefficient from a univariate regression of exchange rate changes across horizons on the relative yield curve slope. Corresponding empirical estimates are presented alongside.\footnote{The empirical estimates documented in this figure come from a univariate pooled OLS regression of exchange rate changes on the relative yield curve slope to be consistent with model-implied values.} Although the model is calibrated to match the empirical estimates at one point only—i.e. $h = 36$ months—the model-implied coefficients have a tent shape across horizons that broadly lie within the estimated confidence bands. As in the data, the relationship between exchange rate changes and the relative slope is small at short horizons, peaks at business-cycle horizons, and becomes small (or even negative) at longer horizons.

We have chosen a symmetric two-country CIR model with country-specific factors for its...
Table 2.6: Targeted moments for two-country CIR model

<table>
<thead>
<tr>
<th>Moment</th>
<th>Analytical Expression</th>
<th>Target (Annualised)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathbb{E}[r_{t,1}]$</td>
<td>$\alpha + (\chi - 12\gamma)\theta_1 + (\tau - 12\delta)\theta_2$</td>
<td>0.401% (4.81%)</td>
</tr>
<tr>
<td>std($r_{t,1}$)</td>
<td>$\sqrt{(\chi - 12\gamma)^2\text{var}(z_{1,t}) + (\tau - 12\delta)^2\text{var}(z_{2,t})}$</td>
<td>0.312 (3.74)</td>
</tr>
<tr>
<td>$\rho(r_{t,1})$</td>
<td>$(\chi - 12\gamma)^2\text{var}(\hat{z}<em>{1,t}) + (\tau - 12\delta)^2\text{var}(\hat{z}</em>{2,t})$</td>
<td>0.992</td>
</tr>
<tr>
<td>std($m_{t,t+1}$)</td>
<td>$\sqrt{\chi^2\text{var}(z_{1,t}) + \tau^2\text{var}(z_{2,t}) + \gamma\theta_1 + \delta\theta_2}$</td>
<td>14% (50%, Sharpe ratio)</td>
</tr>
<tr>
<td>$\beta_{1,1}$</td>
<td>$\frac{(\chi - 12\gamma)^2\text{var}(z_{1,1} - z_{1,t}) + \tau(\tau - 12\delta)^2\text{var}(z_{1,2} - z_{1,t})}{\chi - 12\gamma}$</td>
<td>-0.5 (Short-run UIP)</td>
</tr>
<tr>
<td>$\beta_{1,120}$</td>
<td>$\frac{(\chi - 12\gamma)^2\text{var}(\hat{z}_{1,t}) + \gamma(\chi - 12\gamma)\theta_1 + \delta(\chi - 12\gamma)\theta_2}{\chi - 12\gamma}$</td>
<td>0.8 (Long-run UIP)</td>
</tr>
<tr>
<td>$\mathbb{E}[r_{t,120}]$</td>
<td>$\frac{1}{120}\left[\sum_{t=0}^{120} B_{0,t}^{(120)} + B_{1,t}^{(120)}\theta_1 + C_{1,t}^{(120)}\theta_2\right]$</td>
<td>0.524% (6.29%)</td>
</tr>
<tr>
<td>std($r_{t,120}$)</td>
<td>$\sqrt{\frac{1}{120}\sum_{t=0}^{120} \text{var}(z_{1,t}) + \left(\frac{1}{120}\sum_{t=0}^{120} \text{var}(z_{2,t})\right)^2}$</td>
<td>0.26 (3.148)</td>
</tr>
</tbody>
</table>

Table 2.7: Target moments. Monthly calibration based on US. One month US rates FFR. Sharpe ratio taken from Lustig, Roussanov, and Verdelhan, 2014. We differentiate between $\text{var}(z_{i,t}) = \sigma_i^2\theta_i$, the conditional variance and $\text{var}(z_{i,t}) = \frac{\sigma_i^2}{1 - \phi_i}$.

Table 2.8: Calibrated parameters from two-country CIR model

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$\chi$</th>
<th>$\gamma$</th>
<th>$\tau$</th>
<th>$\delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.0165</td>
<td>0.971</td>
<td>2.534</td>
<td>1.085</td>
<td>0.567</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$\theta_1$</th>
<th>$\sigma_1$</th>
<th>$\phi_1$</th>
<th>$\theta_2$</th>
<th>$\sigma_2$</th>
<th>$\phi_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0018</td>
<td>0.0239</td>
<td>0.946</td>
<td>0.0263</td>
<td>0.0029</td>
<td>0.993</td>
</tr>
</tbody>
</table>
simplicity and analytical transparency, as opposed to a model with asymmetric loadings on a common factor (see, e.g., Lustig, Roussanov, and Verdelhan, 2014) or multiple correlated factors. This comes with two main costs. First, our analysis is conditional, because moments with cross-country terms, e.g. implied regression coefficients, will have an unconditional mean of zero. Second, in the absence of common factors, the cross-country correlation of interest rates is counterfactually zero. However, the mechanisms we discuss, and the role of business-cycle risks for exchange rate fluctuations would carry over to a more complex model with common factors, where our results would then hinge on asymmetries in factors loadings across countries.

### 2.5 Conclusion

In this chapter, we explore the relationship between the term structure of interest rates and ERRP, both empirically and theoretically. Empirically, our main finding is that a country with a relatively steep yield curve will tend to depreciate at business-cycle horizons, even when controlling for bond liquidity yields. We find a tent-shaped relationship between ERRP and the relative yield curve slope across horizons, which peaks at around 3 to 5 years.

This relationship is consistent with a no-arbitrage framework. For this to be the case, risks driving exchange rates must, at least in part, be transitory and conditionally cyclically, suggesting a role for business-cycle risks. We show that a two-country, two-factor model for interest rates, calibrated to reflect business-cycle risk, can quantitatively match the tent-shaped relationship for the relative slope that we observe in the data. The no-arbitrage framework can also reproduce three other well-documented empirical regularities for exchange rates, namely: the failure of UIP at short horizons, the failure to reject UIP at long horizons, and UIP holding in levels.

\[ E_t[rx_{t,t+1}^i] = (1/2)(\gamma(z_{1,t}^i - z_{1,t}) + \delta(z_{2,t}^i - z_{2,t})). \]

The unconditional ERRP is equal to 0 in the symmetric, country-specific factor setup.

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19For example, consider the conditional ERRP: $E_t[rx_{t,t+1}^i] = (1/2)(\gamma(z_{1,t}^i - z_{1,t}) + \delta(z_{2,t}^i - z_{2,t}))$. The unconditional ERRP is equal to 0 in the symmetric, country-specific factor setup.
Chapter 3

Capital Controls and Free-Trade Agreements

3.1 Introduction

The management of trade and capital flows has been a key pillar of macroeconomic policy over the past century, and has come into sharp focus following global events such as the GFC and the COVID-19 pandemic. As a result, academic and policy debates around both trade tariffs and capital controls have grown in prominence, but for largely independent reasons. Discussions around trade policy often balance economic forces with political factors, while recent debates about capital controls have centred on their role in insulating countries from large and volatile cross-border flows. In this chapter, we provide a theory for the joint determination of trade policy and capital controls in a model in which both policy instruments are optimally chosen to act monopolistically in markets and manipulate the terms of trade. Within this framework, we assess how prevailing trade arrangements influence the incentives for, and the size of, optimal capital controls, and we analyse the implications for global welfare.

Our analysis is motivated by two observations. First, following at least two decades of growing trade integration (Baier and Bergstrand, 2007), the process of trade liberalisation has stalled in recent years. Perhaps the most notable example is the US-China trade war, one of the first episodes of large-scale tariff increases amongst major world economies since the inter-war period (Amiti, Redding, and Weinstein, 2019). This, and other events, have substantially heightened uncertainty around world trade, as the World Trade Uncertainty index (Ahir, Bloom, and Furceri, 2018) in Figure 3.1 demonstrates. Alongside this, data from the World Trade Organisation shows a declining number of new regional trade agreements since the mid-2010s, and there also is evidence of a deceleration in global value chain integration since the global financial crisis. Against this backdrop, the conduct of trade policy is of renewed academic and policy interest (see, e.g., Auray, Devereux, and Eyquem, 2020; Bergin and Corsetti, 2020; D’ Aguanno, Davies, Dogan, Freeman, Lloyd, Reinhardt, Sajedi, and Zymek, 2021).

Second, international institutions, such as the International Monetary Fund, have revised their view on financial openness and developed a nuanced approach which emphasises a role for capital flow taxation (Qureshi, Ostry, Ghosh, and Chamon, 2011; Basu, Boz, Gopinath, Roch, and Unsal, 2020). Consistent with this, Figure 3.2 shows the increasing use of macroprudential regulations specifically targeting cross-border flows over time (see Ahnert, Forbes, Friedrich,
and Reinhardt, 2020). In support of the growing use of capital controls, academic discourse has gone beyond the canonical ‘Mundellian Trilemma’—which prescribes that monetary policy independence can be achieved alongside free capital mobility, as long as exchange rates are flexible (Rey, 2015). Recent contributions emphasise that capital flow management is necessary to support monetary policy transmission in open economies due to terms-of-trade externalities (Farhi and Werning, 2012), financial frictions (Basu et al., 2020) or, specifically for the U.S., dollar scarcity (Marin, 2022).

Building on these observations, we study the interaction between optimal capital flow taxation and trade policy. The starting point for our analysis is a canonical two-country, two-good endowment economy, without nominal or financial frictions. Within the model, a Ramsey planner in a large-open economy has incentives to manipulate the terms of trade due to the presence
of pecuniary externalities (Geanakoplos and Polemarchakis, 1986). When making their inter-temporal consumption-savings decision and choosing their intra-temporal consumption basket, households do not account for the effect their actions have on relative prices. In contrast, the planner internalises its size in global markets and acts as a monopsonist both for aggregate consumption over time—manipulating the world interest rate—and across goods varieties—manipulating the relative price of goods statically.\(^1\)

Our point of departure is the analysis of Costinot, Lorenzoni, and Werning (2014), who study optimal capital controls in a model with a free-trade agreement (FTA). As such, trade taxes are precluded in their setup. In Costinot, Lorenzoni, and Werning (2014), the planner taxes capital inflows at times when the economy is growing faster than the rest of the world. Doing so serves to drive down the world interest rate so that households can borrow more cheaply, but has second-best implications for relative goods prices. In this chapter, our main methodological contribution is to relax the constraint imposed on the planner by a FTA, and jointly solve for optimal capital controls and trade policy. We study both the unilateral policy equilibrium, where a Ramsey planner maximises domestic welfare while the other country levies no taxes, and the Nash equilibrium, where both countries set taxes strategically.

We emphasise four main findings. First, we show that in the absence of a FTA, the planner generally wants to use trade tariffs in addition to capital controls. To isolate the mechanisms at play, we first consider the case where the Home country levies taxes and the Foreign country is passive. In response to changes in the endowment of the good consumed with home bias (good 1), we show that incentives to manipulate the terms of trade inter- and intra-temporally are aligned for the planner. Specifically, if the endowment of good 1 falls, households over-borrow in early periods, failing to internalise that their actions drive up the world interest rate (inter-temporal). In addition, households consume too many domestic goods, driving up their price in a period when they are relatively scarce (intra-temporal). Instead, if the endowment of good 2 falls, inter- and intra-temporal motives move in opposite directions. In both cases, because there are two margins of adjustment, optimal capital controls alone cannot achieve the first-best allocation. Therefore, when a FTA is not in place, the domestic planner sets tariffs on imports to address this.

Second, we show that the optimal determination of capital controls and trade tariffs is interlinked, and the covariance between the two instruments depends on the state of the economy. Our key insight is that tariffs have second-best effects on the path of real exchange rates over time which leads households to borrow inefficiently. When the endowment of good 1 is away from its long-run level (e.g. a domestic downturn), inter- and intra-temporal incentives to manipulate the terms of trade are aligned. We show that in this case, optimal capital flow taxes are larger when there is no FTA and an optimal trade tariff is employed. Instead, when inter- and intra-temporal incentives are not aligned, such as when the endowment of good 2 is away from its long-run level (equivalent to temporarily high trade costs), tariffs generate real exchange rate movements that would—absent further action—incentivise under-borrowing. In this case,

\(^{1}\)Although each economy is populated by identical agents, policy is driven by the fact that the choice made by an individual agent is inefficient from a social point of view, i.e. different from the choice made if the country was populated by a single agent. This can be interpreted as a macroeconomic approach to the common-agency externality (Tirole, 2003), which emphasises lack of coordination in private borrowing. This is a complementary to a large macroeconomic literature which studies the implications of heterogeneity for outcomes and policy (e.g. Bilbiie, 2008; Kaplan, Moll, and Violante, 2018). Marin2021 studies a TANK model where the two channels interact.
the optimal time-varying tariff is a partial substitute for capital controls.

Third, we consider the Nash equilibrium where both countries optimally set capital controls and, in the absence of a FTA, trade tariffs. We verify the mechanisms we analyse in the unilateral equilibrium. Moreover, we show that countries compete using both instruments and follow an ‘inverse elasticity rule’. Capital controls are larger when the elasticity of inter-temporal substitution is low. Similarly, tariffs are more prevalent when the intra-temporal elasticity of substitution between goods is low. In the Nash equilibrium, the total wedge introduced by capital flow taxes and tariffs is larger—consistent with the idea of capital control and tariff wars. In contrast, we show that the cooperative optimal involves no capital control or trade tariffs.

Fourth, we calculate that the costs to global welfare are disproportionately large when trade policy is employed in addition to capital controls. In the unilateral setting, trade policy is not simply redistributive. Domestic welfare gains are small in comparison to Foreign losses, and overall global welfare is lower. When the domestic planner sets tariffs, they push Foreign households away from their efficient allocations, generating costly cross-border spillovers. In a Nash equilibrium, concurrent capital control and trade wars result in larger welfare losses, for each country, than capital control wars alone. These welfare costs predominantly originate from distortions in intra-temporal decisions, since welfare costs fall substantially when the elasticity of substitution between goods rises.

Literature Review. Our work is most closely related to Costinot, Lorenzoni, and Werning (2014). They study the role of capital controls as dynamic terms-of-trade manipulation in large-open endowment economies. While policy in our setup is driven by the same underlying pecuniary externality, we study an environment where goods-specific taxes are permitted, departing from their assumption that a FTA is always in place.

The terms-of-trade externality underpinning our optimal policy prescriptions is a key part of the broader literature on capital controls, surveyed in Rebucci and Ma (2019) and Bianchi and Lorenzoni (2021). Mendoza (2002) and Bianchi (2011) study small-open economy models where goods prices appear in borrowing constraints. These models highlight how incentives to manipulate the terms of trade via capital controls can have first-order effects on countries’ ability to borrow. Farhi and Werning (2014), Farhi and Werning (2016) and Schmitt-Grohé and Uribe (2016), amongst others, study the use of capital controls to correct aggregate demand externalities in models with nominal rigidities.

Unlike our paper, the literature on trade tariffs has predominantly focused on environments with no trade in assets, albeit with a richer supply-side setup with monopolistic (often heterogeneous) firms. Demidova and Rodriguez-Clare (2009) show that the optimal trade tariff trades off a domestic mark-up distortion and the incentive to increase the number of imported good varieties by spending more on imports. Caliendo, Feenstra, Romalis, and Taylor (2021) revisit the analysis and introduce roundabout production. Using a second-best argument, relying on the double-marginalisation of the domestic mark-up, they show that the optimal tariff is smaller

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2In line with the optimal taxation literature (Atkinson and Stiglitz, 1980; Chari and Kehoe, 1999), the planner taxes inelastic commodities more.

3Heathcote and Perri (2016) study capital controls in two-country, two-good model with incomplete markets and capital. But, unlike our paper and Costinot, Lorenzoni, and Werning (2014), they do not derive the optimal policy.
and can even be negative. Our results can be interpreted in a similar vein: relative to the case of financial autarky, tariffs become second-best instruments due to their effects on the cost of borrowing for households. However, in contrast to Caliendo et al. (2021), our results highlight that the second-best tariff can be either larger or smaller depending on the state of the economy.

Our key contribution is to combine analyses of inter-temporal terms-of-trade manipulation with intra-temporal incentives, in order to provide a theory for the joint determination of capital controls and import taxes. There is strong empirical evidence that tariffs are chosen to manipulate the terms of trade. Specifically, Broda, Limao, and Weinstein (2008) show that larger countries face less elastic export supply curves suggesting that, on average, they have more market power and providing a rationale for tariffs in line with our modelling framework.

Our paper also belongs to a new growing literature looking at trade and stabilisation policies jointly. Auray, Devereux, and Eyquem (2020) study the scope for trade wars, modelled via optimal strategic tariffs, and currency wars in a New Keynesian model. But this model features balanced trade, so there is no scope for capital control wars. Bergin and Corsetti (2020) study the optimal response of monetary policy to tariff shocks. They find that the optimal policy response to a symmetric tariff war is generally expansionary, while the response to a unilateral tariff imposed by a trade partner is to engineer a depreciation to offset its effects. Basu et al. (2020) argue that capital controls can form part of an ‘integrated policy framework’ for optimal macroeconomic stabilisation under certain conditions. However, their paper abstracts from trade policy.

The remainder of the paper is structured as follows. Section 3.2 describes the two-country, two-good environment and introduces the features of a FTA. Section 3.3 characterises the optimal Ramsey policy for a unilateral planner. Section 3.4 considers strategic cross-country interactions between planners, discussing the scope for capital control and trade wars. Section 3.5 analyses global welfare and cross-border spillovers. Section 3.6 discusses the generality of our results. Section 3.7 concludes.

### 3.2 Basic Environment

There are two countries, Home $H$ and Foreign $F$, each populated by a continuum of identical households. Time is discrete and infinite, $t = 0, 1, \ldots$, and there is no uncertainty. The preferences of the representative Home consumer are represented by the additively separable utility function:

$$U_0 = \sum_{t=0}^{\infty} \beta^t u(C_t)$$

where $C_t$ denotes aggregate Home consumption and $u(C)$ is a twice continuously differentiable, strictly increasing and strictly concave function with $\lim_{C \to 0} u'(C) = \infty$. $\beta \in (0, 1)$ is the discount factor. The preferences of the representative Foreign consumer are analogous, with an asterisk denoting Foreign variables.

Consumers in both countries consume two goods, good 1 and good 2. We denote the Home representative consumer’s consumption of good 1 and good 2 by $c_{1,t}$ and $c_{2,t}$, respectively, and group them into the vector $c_t = [c_{1,t} \ c_{2,t}]'$. Home aggregate consumption is defined by the aggregator $C_t \equiv g(c_t)$, where $g(\cdot)$ is a function that is twice continuously differentiable, strictly increasing, concave and homogeneous of degree one. We define the Jacobian of $g(c_t)$
by \( \nabla g(c_t) = [g_{1,t}, g_{2,t}]' \), where \( g_i = \frac{\partial g(c_t)}{\partial c_i,t} \) for \( i = 1, 2 \), while second derivatives are written as \( g_{ij} = \frac{\partial^2 g(c_t)}{\partial c_i,t \partial c_j,t} \) for \( i, j = 1, 2 \). The aggregator for the representative Foreign consumer is written as \( C_t^* \equiv g^*(c_t^*) \), with analogous derivatives.

We consider an environment where both countries can be endowed with both goods. Throughout, without loss of generality, we assume that consumers in the Home country have a ‘home bias’ for good 1, and we describe this as the ‘domestic good’. This is captured by \( \alpha > 0.5 \) when we specialise preferences, (3.8). Likewise, Foreign consumers prefer good 2 (the ‘foreign good’). We assume these preferences are symmetric across countries such that \( \alpha = \alpha^* \).

Home and Foreign households receive a sequence of endowments of each good. The Home consumer’s period-\( t \) endowments of goods 1 and 2 are denoted by \( y_{1,t} \) and \( y_{2,t} \), respectively. Similarly, the Foreign consumer’s period-\( t \) endowments are \( y_{1,t}^* \) and \( y_{2,t}^* \). The total world endowment of goods 1 and 2 are \( Y_{1,t} \equiv y_{1,t} + y_{1,t}^* \) and \( Y_{2,t} \equiv y_{2,t} + y_{2,t}^* \), respectively. Endowments are weakly positive in all periods.

We assume that both countries begin with zero assets in period 0. The Home inter-temporal budget constraint is given by:

\[
\sum_{t=0}^\infty p_t \cdot (c_t - y_t) \leq 0 \tag{3.1}
\]

where \( p_t = [p_{1,t}, p_{2,t}]' \) denotes the vector of period-\( t \) world goods prices and \( y_t = [y_{1,t}, y_{2,t}]' \) is the vector of Home endowments. The budget constraint for the representative Foreign consumer is analogous.

We define two additional quantities. First, the terms of trade is given by \( S_t = p_{2,t}/p_{1,t} \) and we refer to an increase in \( S_t \) as a deterioration of the Home terms of trade. We further assume the law of one price holds, such that this also corresponds to an improvement in the Foreign terms of trade. Second, the real exchange rate is given by the ratio of consumer price indices \( Q_t = P_t^*/P_t \), where \( P_t^* = \min_{c_t^*} \{ p_t \cdot c_t^* : g^*(c_t^*) \geq 1 \} \). An increase in \( Q_t \) corresponds to a depreciation of the Home real exchange rate.

### 3.2.1 Free-Trade Agreements and the Pareto Frontier

In this chapter, we study how prevailing trade agreements influence the incentives of a Ramsey planner to levy taxes on capital flows, both unilaterally and when accounting for cross-country strategic interactions. Without a FTA in place, the Ramsey planner can, in effect, seek to set consumption quantities for individual goods \( \{c_{1,t}, c_{2,t}\} \) separately. In practice, they can achieve this by setting goods-specific taxes, which we implement as import tariffs. As a result of these tariffs, households’ consumption allocations in any period \( t \) \( (c_t, c_t^*) \) need not be individually Pareto efficient. In fact, we show that, by exploiting deviations from the Pareto frontier, a unilateral Ramsey planner can achieve weakly higher welfare when there is no FTA, versus a world with a FTA.

In contrast, there are no goods-specific taxes when there is a FTA in place. In this case, households’ consumption allocations will be Pareto efficient and can be summarised by:

\[
C^*(C_t) = \max_{c_t, c_t^*} \{ g^*(c_t^*) \} \text{ s.t. } c_t + c_t^* = Y_t \text{ and } g(c_t) \geq C_t \tag{3.2}
\]

for some \( C_t \), where \( Y_t = [Y_{1,t}, Y_{2,t}]' \). This problem yields a Pareto Frontier, which summarises efficient combinations of consumption \( (c_{1,t}, c_{2,t}) \) for a given level of aggregate consumption \( C \).
**Definition 1 (Pareto Frontier)** The Home and Foreign Pareto Frontiers for consumption are summarised by $c(C)$ and $c^*(C^*)$ in Appendix B.1.1.

When a FTA is in place, once the unilateral Ramsey planner has chosen aggregate consumption $C$, Home households will choose their consumption basket $c$ along the static Pareto frontier. In the subsequent sections, we investigate how optimal policy prescriptions differ by comparing environments with and without an FTA, assessing how departures from the Pareto frontier induced by tariffs can influence macroeconomic outcomes.

### 3.3 Unilateral Ramsey Planner

We first study an environment in which the Home planner optimally sets capital flow taxes to maximise domestic welfare, while the Foreign planner is assumed to be passive—it does not levy taxes in response to Home policy. This unilateral policy setting helps to isolate the mechanisms at play. Within it, we compare an environment with a FTA in place to one without. The FTA-case corresponds to the two-good environment studied in Costinot, Lorenzoni, and Werning (2014). Individual goods allocations are chosen on the Pareto Frontier. In the no-FTA case, the Home planner sets individual consumption allocations $\{c_{1,t}, c_{2,t}\}$, unconstrained by the Pareto frontier. We study how this allocation can be implemented via a combination of capital flow taxes and goods-specific taxes—i.e., trade tariffs.

In the unilateral setup, the equilibrium conditions of the representative Foreign household act as a constraint for the Home Ramsey planning problem. Foreign households undertake a standard optimisation problem, maximising Foreign discounted utility subject to their inter-temporal budget constraint at world prices $p_t$. The first-order conditions of this problem are:

$$\beta^t u^*(C^*_t)\nabla g^*(c^*_t) = \lambda^* p_t \quad (3.3)$$

$$\sum_{t=0}^{\infty} p_t \cdot (c^*_t - y^*_t) = 0 \quad (3.4)$$

where $\lambda^*$ is the Lagrange multiplier on the Foreign inter-temporal budget constraint.

#### 3.3.1 With Free Trade

We use the primal approach to characterise the optimal policy of the Home government. The Home government sets the sequence of Home aggregate consumption $\{C_t\}$ in order to maximise the discounted lifetime utility of the Home representative consumer subject to (i) the representative Foreign consumer’s utility maximisation at world prices, (ii) market clearing in each period, and (iii) the Pareto frontier arising from the presence of a FTA.

The Foreign optimality conditions, equations (3.3) and (3.4), the domestic inter-temporal budget constraint (3.1), and the market clearing conditions can be summarised in a single implementability condition described in the following proposition, as in Lucas and Stokey (1983).

**Proposition 1 (Implementability for Unilateral Planner)** When the Foreign country is passive, an allocation $\{c_t, c^*_t\}$, together with world prices $p_t$, form part of an equilibrium if they

---

4See Appendix B.1.2 for a statement of the representative Foreign household’s optimisation problem.
satisfy
\[ \sum_{t=0}^{\infty} \beta^t \rho(C_t) \cdot [c_t - y_t] = 0 \] (IC)

where \( \rho(C_t) \equiv u^*(C^*(C_t))\nabla g^*(c_t^*(C_t)) \) denotes the price of consumption at each \( t \).

The Home Ramsey planning problem is thus given by:

\[
\begin{align*}
\max_{\{C_t\}} & \sum_{t=0}^{\infty} \beta^t u(C_t) \\
\text{s.t.} & \sum_{t=0}^{\infty} \beta^t \rho(C_t) \cdot [c_t - y_t] = 0 \quad \text{(IC)} \\
& c_t = c(C_t), \quad c_t^* = c^*(C_t) \quad \text{(FTA)}
\end{align*}
\]

where the third line (FTA) summarises the Pareto frontier constraint imposed by the presence of a FTA. After substituting (FTA) into (IC), we assume that \( \rho(C_t) \cdot [c_t - y_t] \) is a strictly convex function of \( C_t \) to guarantee a unique solution to (P-Unil-FTA). Since utility is time-separable and the planner chooses the whole sequence of consumption allocations, the problem can be represented by the following Lagrangian:

\[ L = u(C_t) - \mu \{ \rho(C_t) \cdot [c_t - y_t] \} \]

where \( \mu \) is the multiplier on the implementability constraint.

**Optimal Allocation.** The first-order condition from the Home planning problem, in the presence of a FTA, can be written as:

\[ u'(C_t) = \mu \mathcal{MC}^{FTA}_t \] (3.5)

where

\[
\mathcal{MC}^{FTA}_t \equiv u''(C^*_t) \nabla g^*(c_t^*(C_t)) \cdot c'(C_t) + u''(C^*_t) C^{**'}(C^*_t) \nabla g^*(c_t^*(C_t)) \cdot [c_t - y_t] \\
+ u''(C^*_t) \frac{\partial \nabla g^*(c_t(C_t))}{\partial C_t} \cdot [c_t - y_t]
\]

Equation (3.5) has the following interpretation. The left-hand side is the marginal utility from one additional unit of aggregate consumption for the representative Home consumer. The right-hand side represents the marginal cost of that unit of consumption, captured by \( \mathcal{MC}^{FTA}_t \). The first term in \( \mathcal{MC}^{FTA}_t \) is the price of one unit of consumption. It can be shown to be equal to \( u''(C^*_t)Q_t^{-1} \). The second term reflects how the inter-temporal price of consumption changes when importing one additional unit of consumption, for given relative goods prices. The final term reflects how relative goods prices change with aggregate consumption.

Notice that if endowments and consumption outcomes coincide, \( c_t = y_t \), equation (3.5) collapses to \[ u'(C_t) = \mu u'(C_t)Q_t^{-1} \], which corresponds to the decentralised allocation. Moreover, \( \mu = 1 \) coincides with perfect risk sharing.

Consider the case where the fraction of good 1 owned by the Home country \( y_{1,t}/Y_{1,t} \) temporarily falls today—holding the overall stock of good 1 fixed over time \( (Y_{1,t} = Y_1 \text{ for all } t) \).
Faced with a higher stream of endowments in the future, Home households will borrow to smooth consumption. However, each additional unit of consumption brought forward raises the cost of borrowing. Additionally, the Home household will buy relatively more units of the the domestic good (good 1) from abroad. Specifically, the fall in \( y_1 \) is greater than the fall in \( c_1 \) so that \((c_1 - y_1) \uparrow\). Home households are buying more of good 1 from abroad at a time when it is relatively more expensive. Both the increase in the cost of borrowing and the increase in the price of good 1 reflect pecuniary externalities, which atomistic households do not internalise.

The planner sets policy to force households to internalise the pecuniary implications of their decisions. From an inter-temporal perspective, they tax capital inflows to delay consumption. Intra-temporally, the planner seeks to decrease the price of good 1. In the presence of a FTA, they achieve this by taxing capital inflows (aggregate consumption). So when the good-1 endowment deviates from its long-run level, the planner’s inter- and intra-temporal incentives to manipulate the terms of trade are aligned. Both push the planner to tax capital inflows and delay aggregate consumption.

In contrast, suppose the fraction of the foreign good (good 2) owned by the Home country \((y_{2,t}/Y_2)\) temporarily falls. While the planner’s inter-temporal incentive to delay consumption is analogous to before, the intra-temporal incentive differs since the Home country will now sell relatively more of good 1 abroad. Specifically, \( c_1 \) will fall despite \( y_1 \) remaining unchanged so that \((c_1 - y_1) \downarrow\). The planner has an incentive to act monopolistically intra-temporally, and drive up the price of good 1. Absent a FTA, this can be achieved by taxing purchases of good 1 from abroad. But, with a FTA in place, the planner will instead subsidise capital inflows, raising \( C \), as a second-best policy. Inter- and intra-temporal incentives are not aligned in this case, and thus optimal capital controls trade off interest rate and terms of trade manipulation. The relative direction of inter- and intra-temporal incentives plays a key role in our subsequent analysis of the relationship between optimal capital controls and trade tariffs.

### 3.3.2 Without Free Trade

Without a FTA, the Home planner, unconstrained by the Pareto frontier, directly chooses the allocation of both goods 1 and 2. Aggregate consumption \( C_t \) can then be backed out of the consumption aggregator \( g(c_t) \). The Home government’s problem is thus:

\[
\max_{\{c_{1,t},c_{2,t}\}} \sum_{t=0}^{\infty} \beta^t u(C_t) \quad \text{(P-Unil-nFTA)}
\]

\[
s.t. \sum_{t=0}^{\infty} \beta^t \rho(C_t) \cdot [c_t - y_t] = 0 \quad \text{(IC)}
\]

\[
C_t = g(c_t) \quad \text{(nFTA)}
\]

where the third line \((nFTA)\) reflects the fact the individual consumption allocations \(\{c_{1,t},c_{2,t}\}\) in a given period \(t\) are combined to yield aggregate consumption \(C_t\). Notice that the implementability condition is unchanged. As in the FTA-case, we make an assumption—specifically that \( \rho(g(c_t)) \cdot [c_t - y_t] \) is strictly convex—to ensure a unique solution to the planning problem.
Optimal Allocation. The first-order conditions of the planning problem—with respect to $c_{1,t}$ and $c_{2,t}$, respectively—are given by:

$$u'(C_t)g_{1,t} = \mu MC_{1,t}^{FTA}$$  \hspace{1cm} (3.6)
$$u'(C_t)g_{2,t} = \mu MC_{2,t}^{FTA}$$  \hspace{1cm} (3.7)

where $\mu$ denotes the Lagrange multiplier on the implementability constraint and:

$$MC_{1,t}^{FTA} \equiv u''(C_t^*)g_1^*(c_t) + u''(C_t^*) \frac{\partial g_1^*(c_t^*)}{\partial c_{1,t}} \cdot [c_t - y_t]$$
$$+ u''(C_t^*) \frac{\partial g_1^*(c_t^*)}{\partial c_{1,t}} \cdot [c_t - y_t]$$

$$MC_{2,t}^{FTA} \equiv u''(C_t^*)g_2^*(c_t) + u''(C_t^*) \frac{\partial g_2^*(c_t^*)}{\partial c_{2,t}} \cdot [c_t - y_t]$$

Equations (3.6) and (3.7) equate the marginal benefit from a unit of good-specific consumption to its marginal cost—for goods 1 and 2, respectively. The planner optimises over the consumption allocation good by good. Take equation (3.6), for example. As before, the first term on the right-hand reflects the price of one unit of good 1. The next term reflects how the inter-temporal component of that price (i.e. the cost of borrowing) increases. The final term, captures the intra-temporal margin. Specifically, how each good-specific price changes with an additional unit of $c_1$ consumed.

3.3.3 Comparing Optimal Allocations

For the Home planner, the first-order condition under a FTA, equation (3.5), represents a constrained first-best allocation. However, the no-FTA optimality conditions, equations (3.6) and (3.7), represent the first-best outcome for the Home country, as the following proposition explains.

**Proposition 2 (Optimal Capital Controls without a FTA)** In the absence of a FTA, the unilateral optimal allocation $c_t$ satisfies (3.6) and (3.7). Moreover:

1. The level of $C$ achieved in (P-Unil-nFTA) is always weakly higher than that achieved in (P-Unil-FTA);
2. If the optimal allocation $c$ in (P-Unil-nFTA) violates the Pareto frontier (3.2) given by a FTA, then (i) holds strictly; and
3. The welfare achieved, and corresponding allocation $c$, in (P-Unil-FTA) and (P-Unil-nFTA) coincide when endowments are proportional to consumer preferences, $y_1 \propto \alpha$, $y_2 \propto 1 - \alpha$, $y_1^* \propto 1 - \alpha$ and $y_2^* \propto \alpha$.

**Proof:** See Appendix B.1.3.

The results in Proposition 2 can be understood in Figure 3.3, which plots the optimal allocations with (blue) and without (green) a FTA alongside the loci of $\{c_1, c_2\}$ which attain different

---

5For ease of notation, we do not make explicit the dependence of $c_t^*$ on $c_t$. 

---
Notes: Plot of optimal consumption allocations for Home consumer from Ramsey capital flow taxation (i) with a FTA in place (blue circles, i.e. the Pareto frontier) and (ii) absent a FTA, with goods-specific taxation (green crosses) at different Home endowments. Specifically using nine equally-spaced allocations for $y^*_1 \in [\alpha - 0.25, \alpha + 0.25]$, with $y^*_1 = 1 - y_1$, $y_2 = 1 - \alpha$ and $y^*_2 = \alpha$. Other model parameters are: $\beta = 0.96$, $\sigma = 2$, $\phi = 1.5$, and $\alpha = 0.75$. Grey/black lines denote loci of $\{c_1, c_2\}$ which attain different levels of aggregate consumption (black for $C = 1$, grey otherwise).

levels of aggregate consumption (grey, and black for $C = 1$). For this, and all subsequent numerical exercises, we use a constant relative risk aversion (CRRA) specification for per-period utility:

$$u(C) \equiv \frac{C^{1-\sigma} - 1}{1 - \sigma}$$

where $\sigma > 0$ denotes the coefficient of relative risk aversion. The aggregate consumption of the representative Home agent is given by the Armington (1969) aggregator:

$$C_t \equiv g(c_t) = \left[ \frac{1}{\alpha^\phi c_{1,t}^\phi} + (1 - \alpha)\frac{1}{\phi^\phi c_{2,t}^\phi} \right]^\frac{\phi}{\phi - 1} \quad (3.8)$$

where $\phi > 0$ is the elasticity of substitution between good 1 and 2. The Foreign aggregator is analogous.

In the figure, the blue line maps the Pareto frontier: the efficient combinations of $\{c_1, c_2\}$ for different levels of aggregate consumption $C$, which are consistent with a FTA. But when not constrained by a FTA, the planner can achieve a higher level of consumption by changing the Home consumption allocation $\{c_1, c_2\}$, as in parts (i) and (ii) of Proposition 2. For $y_1 > \alpha$—the area above the black line—the allocation absent FTA is more biased towards $c_1$. Whereas for $y_1 < \alpha$—the area below the black line—the allocation is more biased towards $c_2$. The allocations under a FTA (P-Unil-FTA) and without a FTA (P-Unil-nFTA) coincide in the case $y_1 = y^*_2 = \alpha$—part (iii) of Proposition 2. Moving away from the no-trade point the solutions do not generally coincide.
Proposition 2, however, is silent on how the implementation of the allocation differs when the FTA is relaxed, so does not describe how the magnitude of capital controls differs with or without a FTA. Moreover, it does not outline the macroeconomic response to fluctuations in endowments under the optimal policies. To address these questions, we first turn to discuss how the optimal allocation can be implemented using tax instruments.

### 3.3.4 Implementation

With a FTA in place, we consider the implementation of the optimal allocation via a capital inflow tax only. In the no-FTA case, two instruments are needed to implement the optimal allocation and we consider an implementation with a capital-inflow tax and an import tariff. While this implementation need not be unique, we choose it because it relies on policy-relevant and observable instruments.\(^6\)

To discuss implementation via a capital-inflow tax, we need to specify the structure of financial markets. We assume households trade in non-contingent bonds, denominated in each good variety. The Home planner imposes the same proportional tax \(\theta_t\) on the gross return on net lending in all bond markets. So the per-period budget constraint for the Home consumer can be written:

\[
\tilde{p}_{t+1} \cdot a_{t+1} + \tilde{p}_t \cdot c_t = \tilde{p}_t \cdot y_t + (1 - \theta_{t-1}) (\tilde{p}_t \cdot a_t) - T_t
\]

where \(\tilde{p}_t\) with a FTA, \(a_t\) denotes the vector of asset positions and \(T_t\) is a lump-sum rebate.

Given a no-Ponzi condition, \(\lim_{t \to \infty} \tilde{p}_t \cdot a_t \geq 0\), the first-order conditions associated with Home households’ utility maximisation are given by:

\[
u'(C_t)g_i(c_t) = \beta(1 - \theta_t)(1 + r_{i,t})u'(C_{t+1})g_i(c_{t+1})
\]

for \(i = 1, 2\), where \(r_{i,t} \equiv \frac{p_{i,t}}{p_{i,t+1}} - 1\) is a good-specific interest rate. Combining this with the analogous Foreign Euler equation, the Home’s tax on international capital flows can be written as:

\[
(1 - \theta_t) = \frac{u'(C_t)}{u'(C_{t+1})} \frac{u'(C_{t+1})}{u'(C_t)} \frac{Q_t}{Q_{t+1}}
\]

(3.10)

A tax on capital inflows (or a subsidy for capital outflows) is then captured by values of \(\theta_t < 0\), which can be interpreted as a tax on current consumption relative to future consumption.

Without a FTA, the Home planner additionally levies a proportional import tariff \(\tau_t\), and \(\tilde{p}_t = \tau_t \cdot p_t\). The representative Home household faces import price \(p_{2,t}(1 + \tau_t)\) so the relative demand is given by:

\[
\frac{c_{1,t}}{c_{2,t}} = \frac{\alpha}{1 - \alpha} \left( \frac{1}{S_t(1 + \tau_t)} \right)^{-\phi}
\]

(3.11)

An import tariff is captured by \(\tau_t > 0\).

### 3.3.5 Numerical Exercises

We next study two numerical scenarios to illustrate the macroeconomic implications of the optimal policy response to fluctuations in endowments. In the first scenario, we investigate the optimal policy response to a departure of the Home endowment of the domestic good (good...
1) from its long-run value. In the second, we study the implications of variation in the Home endowment of the foreign (good 2). For each, we highlight differences in the incentives driving policy-making.

Both experiments are deterministic. We specify initial and terminal values for the endowments, and construct the full sequence of endowments for all periods by assuming that endowments follow a first-order autoregressive process:

\[ y_{i,t+1}^{(*)} = (1 - \rho_i^{(*)}) y_{i,t}^{(*)} + \rho_i^{(*)} y_{i,t}, \quad \forall t > 0 \text{ and } i = 1, 2, \]

where for simplicity we assume \( \rho_1 = \rho_2 = \rho_1^* = \rho_2^* \).

In both experiments, we assume there is no change in the aggregate endowment (\( Y_{1,t} \) and \( Y_{2,t} \) are constant). As a result, with households able to fully insure their consumption against known changes in their endowment, perfect consumption smoothing is achieved in the decentralised allocation.\(^8\) The planner’s allocation contrasts sharply to the decentralised benchmark.

Based on the CRRA per-period utility function and the Armington (1969) specification for aggregate consumption, the model calibration for both experiments is detailed in Table 3.1. In each experiment, we compare the decentralised allocation, the unilateral Ramsey planning allocation with a FTA in place, and one without a FTA. To compare the dynamic implications of the three variants in a consistent manner, we equalise the long-run equilibrium (i.e. ‘steady state’) of each model by using a steady state import tariff for the Home country.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>0.96</td>
<td>Discount factor, annual frequency</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>2</td>
<td>Coefficient of relative of risk aversion</td>
</tr>
<tr>
<td>( \phi )</td>
<td>1.5</td>
<td>Elasticity of substitution between goods 1 and 2</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.6</td>
<td>Share of good 1 (good 2) in Home (Foreign) consumption basket</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0.8</td>
<td>Persistence of endowments</td>
</tr>
</tbody>
</table>

**Scenario 1: Temporarily Low Home Endowment of Domestic Good**

Our first experiment simulates the Home economy recovering from a domestic downturn, or catching up to the rest of the world. Specifically, the Home country’s endowment in good 1 is low in the near term, and grows towards its long-run level. Denoting initial endowment values by \( y_{i,0}^{(*)} \) and long-run levels by \( y_{i,1}^{(*)} \) for \( i = 1, 2 \), we assume that \( y_{1,0} = 0.75 y_1 \) and \( y_{2,0} = y_2 \). To ensure there is no aggregate uncertainty: \( y_{1,0}^{*} = 1 - y_{1,0} \) and \( y_{2,0}^{*} = 1 - y_{2,0} \). The resulting time profiles for the allocations are plotted in Figure 3.4.

Faced with a higher stream of good-1 endowments in the future, Home households will borrow to smooth consumption in the decentralised allocation. However, since each additional unit of consumption brought forward raises the cost of borrowing, the planner has an incentive to postpone consumption relative to the decentralised allocation. The optimal policy, both with

\(^7\)Nevertheless, the mechanisms we isolate generalise to more complex paths for endowments.

\(^8\)Our findings are robust to allowing the aggregate endowment to fluctuate.
Figure 3.4: Time Profile of Optimal Allocations as the Home Endowment of Good 1 Rises in Experiment 1

Notes: Time profile for macroeconomic outcomes in Experiment 1, simulated for 50 periods. See Table 3.1 for calibration details. “(No) FTA-Ramsey” refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The decentralised and FTA-Ramsey models include a steady-state tariff to ensure their steady-state allocations replicate the No FTA-Ramsey case.
and without a FTA, involves leaning against capital flows. This is demonstrated in the bottom-left panel of Figure 3.4, plotting the evolution of the balance of payments, which varies by less under the two planning solutions relative to the decentralised outcome. Additionally, because the Home endowment of good 1—the good consumed with home bias domestically—is initially lower, the planner has an incentive to restrict the global excess demand for good 1 over and above their endowment \( y_1 \). Driving these incentives is the planner’s expectation that the future price of \( c_1 \) and \( C \) will fall. Therefore, the planner taxes aggregate consumption \( C \) via a capital inflow tax \( \theta < 0 \) and, in the absence of a FTA, levies an increasing path for import tariffs.

The main result of this chapter is that the planner taxes capital inflows more heavily when the FTA is relaxed. In the presence of a FTA, the planner achieves the desired allocation by choosing a lower level of aggregate consumption \( C \) in the near term, which entails a disproportionately lower \( c_1 \) on account of Home consumers’ preference for good 1. When unconstrained by a FTA, the planner can restrict the net global supply of good 1 via an import tariff, which incentivises Home consumers to purchase a larger fraction of the good-1 endowment on the global market. While the required capital control taxes are generally small—between 6 and 8% on impact for the planner with and without an FTA, respectively—the goods tax is large and variable in the absence of a FTA—over 50% in the long run and increasing from around 15%.

Scenario 2: Temporarily Low Home Endowment of Foreign Good

Our second experiment simulates a scenario in which the Home endowment of the foreign good (good 2) starts at a low value relative to its long-run level. This is akin to a positive Foreign export-sector shock, as the Foreign country’s endowment of good 2 is high in the near term, but falls towards its long-run level. We assume that \( y_{2,0}^* = 1.25y_2^* \) and \( y_{1,0}^* = y_1^* \). To ensure there is no aggregate uncertainty: \( y_{1,0} = 1 - y_{1,0}^* \) and \( y_{2,0} = 1 - y_{2,0}^* \). The resulting time profiles for the allocations are plotted in Figure 3.5.

As in Experiment 1, the Home country borrows in the near term in the decentralised allocation, knowing that their endowment will increase in the future. However, in contrast to Experiment 1, the net supply of good 1 that Home sells abroad rises, because \( c_1 \) falls while \( y_1 \) is unchanged. The Home planner wants to delay aggregate consumption \( C \) inter-temporally, but also has an intra-temporal incentive to drive up the relative price of good 1. Absent a FTA, the planner levies a high import tariff in the near term to increase \( c_1 \) and drive up its relative price. In Experiment 2, the optimal capital inflow tax is smaller absent an FTA, as it must strike a balance between restricting \( C \) and boosting \( c_1 \).

This scenario can also be interpreted through the lens of trade costs. For example, suppose that there are shipping costs associated with transporting the Home country endowment of foreign goods (good 2) to the Home country. Were these to take the form of iceberg trade costs \( \hat{\tau} \geq 1 \), the Home households would de facto be endowed with \( y_2 / \hat{\tau} \) units of good 2 after trade costs. Home households could consume this amount of good 2 at most without importing more of the good from Foreign. If these are one-directional trade costs, then Scenario 2 can be interpreted as a temporary rise in trade costs for Home. This interpretation leads to an interesting result: both capital controls and trade tariffs are needed to optimally respond to changes in trade costs.
Figure 3.5: Time Profile of Optimal Allocations as the Foreign Endowment of Good 2 Falls in Experiment 2

Notes: Time profile for macroeconomic outcomes in Experiment 2, simulated for 50 periods. See Table 3.1 for calibration details. “(No) FTA-Ramsey” refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The decentralised and FTA-Ramsey models include a steady-state tariff to ensure their steady-state allocations replicate the No FTA-Ramsey case.
Relationship Between Capital Flow and Goods Taxation

We now analyse the impact of import tariffs on capital flow taxation. We ask: does a regime of free trade encourage or discourage the use of capital controls?

In Experiments 1 and 2, the relative sign of inter- and intra-temporal incentives differ. In line with this, we show that the determinants of capital flow taxes and goods tariffs depend on the nature of shocks hitting the economy. In Experiment 1, the planner’s inter- and intra-temporal incentives are aligned, such that the planner seeks to move both $C$ and $c_1$ in the same direction. As a result, capital flow taxes are larger in the absence of a FTA. In contrast, incentives are opposed in Experiment 2 and, consequently, capital flow taxes are smaller in the absence of a FTA.

To investigate the drivers of this, we decompose capital flow taxes $\theta$ into two wedges. We do so by taking logs of equation (3.10):

$$
\ln(1 - \theta_t) \approx -\theta_t = -\sigma \left( \hat{C}_t - \hat{C}_{t+1} + \hat{C}^*_t - \hat{C}^*_t + 1 + \hat{C}^*_t + 1 - \hat{C}^*_t \right)
$$

where $\hat{x}$ denotes the natural logarithm of $x$. The ‘consumption wedge’ component captures incentives to tax capital inflows pertaining to the evolution of relative consumption over time. The ‘RER wedge’ reflects capital flow taxation incentives linked to the evolution of the real exchange rate $Q$.

Figures 3.6 and 3.7 plot the two wedges for Experiments 1 and 2, respectively. In both, and regardless of whether a FTA is in place or not, the consumption wedge explains the majority of variation in the capital flow tax $\theta$.

However, comparing the sign of the RER wedge across experiments highlights some notable differences. Consistent with inter- and intra-temporal incentives being aligned in Experiment 1, Figure 3.6 shows that the RER wedge and consumption wedge have the same sign, regardless of the presence of an FTA. In contrast, in Experiment 2 incentives are opposed, and so differences arise in the FTA and no-FTA cases. When the planner has import tariffs available to them, in addition to capital flow taxes, Figure 3.7 demonstrates that the RER wedge has the opposite sign to both the consumption wedge and the RER wedge for the planner constrained by a FTA. This helps to explain why, in Experiment 2, capital flow taxes are smaller with no FTA. In essence, the planner can levy tariffs that stabilise the terms of trade and, at the same time, offset the need to use capital flow taxes to manipulate relative prices for inter-temporal incentives.

Comparative Statics

Within the model, two parameters are particularly important for governing the size of the planner’s intra- and inter-temporal incentives to manipulate the terms of trade: the intra-temporal elasticity of substitution between goods $\phi$ (i.e. the trade elasticity) and the coefficient of relative risk aversion $\sigma$ (i.e. the inverse inter-temporal elasticity of substitution). In doing so, these parameters influence the size of both the optimal capital inflow taxes and optimal import tariffs. They do so in a manner that is inversely related to the elasticity: the lower the elasticity, the higher the taxes, and vice versa.

Figure 3.8 demonstrates this for the inter-temporal trade elasticity in the content of Experiment 1—although the ‘inverse elasticity rule’ holds in both experiments. As the right-hand
Figure 3.6: Decomposition of Optimal Capital Flow Taxes for Experiment 1

Notes: Time profile for Home capital flow tax components in Experiment 1, simulated for 50 periods. See Table 3.1 for calibration details. "(No) FTA-Ramsey" refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The decentralised and FTA-Ramsey models include a steady-state tariff to ensure their steady-state allocations replicate the No FTA-Ramsey case.

Figure 3.7: Decomposition of Optimal Capital Flow Taxes for Experiment 2

Notes: Time profile for Home capital flow tax components in Experiment 2, simulated for 50 periods. See Table 3.1 for calibration details. "(No) FTA-Ramsey" refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The decentralised and FTA-Ramsey models include a steady-state tariff to ensure their steady-state allocations replicate the No FTA-Ramsey case.
figure shows, optimal import tariffs are both larger and vary more over time when the trade elasticity is lower. These intra-temporal incentives interact with the optimal capital flow taxes too, which are higher for lower trade elasticities, regardless of the prevailing trade agreement.

Similarly, Figure 3.9 shows that optimal capital flow taxes are larger when the inter-temporal elasticity of substitution is lower (i.e. higher coefficient of relative risk aversion $\sigma$). In turn, variation in import tariffs is larger when $\sigma$ is high.

3.4 Strategic Planning Allocation

We now consider the case in which both countries seek to maximise domestic welfare. We denote the Home and Foreign proportional taxes on gross returns by $\theta_t$ and $\theta_t^*$, respectively. Likewise, Home and Foreign tariffs are given by $\tau_t$ and $\tau_t^*$. We look for a Nash equilibrium, considering each government’s optimisation problem and taking the other’s tax sequence as given. As in Section 3.3, we consider the with- and without-FTA cases in turn. In the former case, we analyse capital control wars. In the latter, we consider both capital control and trade wars.

3.4.1 With Free Trade

We continue to use the primal approach to characterise the optimal policy. Focusing on the Home planning problem, we can characterise the optimal allocation with a FTA in place, taking the sequence of Foreign capital flow taxes $\{\theta_t^*\}$ as given. Faced with these taxes, the Foreign Euler equations, for $i = 1, 2$ can be written:

$$u^\prime(C_t^*)g_t^*(c_t^*) = \beta(1 - \theta_t^*)(1 + r_{i,t})u^\prime(C_{t+1}^*)g_t^*(c_t^*)$$  \hspace{1cm} (3.13)

These Foreign optimality conditions, the Home inter-temporal budget constraint and the market clearing conditions yield an implementability condition for the Home planner, which is described in the following proposition.

Proposition 3 (Implementability for Nash Planner with FTA) \hspace{1cm} Since $1 + r_{i,t} = p_{i,t}/p_{i,t+1}$, when the Foreign country seeks to set $\{c_t^*\}$ in order maximise domestic welfare, then the Home allocation $\{c_t\}$ forms part of an equilibrium if it satisfies:

$$\sum_{t=0}^{\infty} \left[ \prod_{s=0}^{t-1}(1 - \theta_s^*) \right] \beta^t u^\prime(C_t^*)\nabla g^*(c_t^*) \cdot [c_t - y_t] \leq 0$$ \hspace{1cm} (IC-Nash-FTA)

The Home planning problem, accounting for the optimal response by the Foreign planner, is given by:

$$\max_{\{C_t\}} \sum_{t=0}^{\infty} \beta^t u(C_t)$$ \hspace{1cm} (P-Nash-FTA)

subject to:

$$\sum_{t=0}^{\infty} \left[ \prod_{s=0}^{t-1}(1 - \theta_s^*) \right] \beta^t u^\prime(C_t^*)\nabla g^*(c_t^*) \cdot [c_t - y_t] \leq 0$$ \hspace{1cm} (IC-Nash-FTA)

$$c_t = c(C_t), \quad c_t^* = c^*(C_t)$$ \hspace{1cm} (FTA)
Figure 3.8: Comparative Statics of Optimal Capital Flow Taxes and Tariffs with Respect to the Intra-temporal Trade Elasticity $\phi$ in Experiment 1

Notes: Time profile for Home capital flow tax and import tariff in Experiment 1, simulated for 50 periods, with three different values of intra-temporal elasticity of substitution between goods 1 and 2 $\phi$. See Table 3.1 for calibration details. “(n)FTA” refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The FTA-Ramsey model includes a steady-state tariff to ensure that the steady-state allocation replicates the nFTA-Ramsey case.

Figure 3.9: Comparative Statics of Optimal Capital Flow Taxes and Tariffs with Respect to the Coefficient of Relative Risk Aversion $\sigma$ (Inverse Inter-temporal Elasticity of Substitution) in Experiment 1

Notes: Time profile for Home capital flow tax and import tariff in Experiment 1, simulated for 50 periods, with three different values of the coefficient of relative risk aversion $\sigma$ (i.e. inverse inter-temporal elasticity of substitution. See Table 3.1 for calibration details. “(n)FTA” refers to allocation arising from a Home planner acting unilaterally with (without) a FTA in place. The FTA-Ramsey model includes a steady-state tariff to ensure that the steady-state allocation replicates the nFTA-Ramsey case.
which is comparable to the unilateral problem (P-Unil-FTA), albeit with an additional term in the implementability constraint reflecting the Foreign capital flow tax \( \theta^*_t \).

**Optimal Allocation.** Problem (P-Nash-FTA) yields the optimality condition:

\[
    u'(C_t) = \mu \left[ \prod_{s=0}^{t-1} (1 - \theta^*_s) \right] \hat{MC}_t^{\text{FTA}}
\]

where \( \mu \) denotes the Lagrange multiplier on the implementability constraint and:

\[
    \hat{MC}_t^{\text{FTA}} \equiv u''(C^*_t) \nabla g^*(c^*_t) \cdot c'(C_t) + u'''(C^*_t) C''(C_t) \nabla g^*(c^*) : [c_t - y_t] \\
    + u''(C^*_t) \frac{\partial \nabla g^*(c^*_t)}{\partial c_t} \cdot [c_t - y_t]
\]

Taking the ratio of \( t \) and \( t + 1 \) optimality conditions further implies that:

\[
    \frac{u'(C_t)}{u'(C_{t+1})} = \frac{1}{1 - \theta_t^*} \frac{\hat{MC}_t^{\text{FTA}}}{\hat{MC}_{t+1}^{\text{FTA}}}
\]

Combining equation (3.15) with the Foreign Euler equations (3.13) and the analogous Home Euler equations, yields an expression for \( 1 - \theta_t^* \). The planning problem of the Foreign government is symmetric, so an analogous expression for \( 1 - \theta^*_t \) can be derived. After some simplification, the combination of these expressions yields a mutual best response function, given by:

\[
    \frac{\hat{MC}_t^{\text{FTA}}}{\hat{MC}^{\text{FTA}}_{t+1}} = \alpha_0^{\text{FTA}}
\]

where

\[
    \alpha_0^{\text{FTA}} \equiv \frac{\hat{MC}_0^{\text{FTA}}}{\hat{MC}_0^{\text{FTA}}}
\]

This is the strategic counterpart of equation (3.5) in Section 3.3.1. In the Nash bargaining setup, \( \alpha_0^{\text{FTA}} \) can be interpreted as the bargaining power of the Foreign country relative to the Home.

### 3.4.2 Without Free Trade

Absent a FTA, the Home planner must now take both the sequence of Foreign capital flow taxes \{\( \theta^*_t \)\} and the sequence of Foreign tariffs \{\( \tau^*_t \)\} as given. The Foreign tariff is levied by the Foreign planner on Foreign consumers’ purchases of good 1.

As a result of the Foreign tariff, the implementability constraint for the Home planner is different to Proposition 3, equation (IC-Nash-FTA). Defining the vector of inverse Foreign goods-specific tariffs by \( \tau^*_t \equiv [(1 + \tau^*_t)^{-1} - 1]' \), the following proposition details the implementability for the Home planner when acting strategically in the absence of an FTA.\(^9\)

\(^9\)In contrast to the unilateral case, the implementability condition for the Home planner differs in the absence of a FTA because of tariffs set by the Foreign planner.
Proposition 4 (Implementability for Nash Planner without FTA) The Home allocation forms art of an equilibrium without an FTA if it satisfies:

\[
\sum_{t=0}^{\infty} \left[ \prod_{s=0}^{t-1} (1 - \theta^s_i) \right] \beta^t u^*(C^*_t) \tau_t^{*^{-1}} \cdot \nabla g^*(c^*_t) \cdot [c_t - y_t] \leq 0 \quad \text{(IC-Nash-nFTA)}
\]

The Home planning problem is thus given by:

\[
\max_{\{c_t\}} \sum_{t=0}^{\infty} u(C_t) \quad \text{(P-Nash-nFTA)}
\]

\[
\text{s.t.} \quad \sum_{t=0}^{\infty} \left[ \prod_{s=0}^{t-1} (1 - \theta^s_i) \right] \beta^t u^*(C^*_t) \tau_t^{*^{-1}} \cdot \nabla g^*(c^*_t) \cdot [c_t - y_t] \leq 0 \quad \text{(IC-Nash-nFTA)}
\]

\[
C_t = g(c_t) \quad \text{(nFTA)}
\]

which is comparable to the unilateral no-FTA problem (P-Unil-nFTA), albeit with additional terms in the implementability constraint reflecting Foreign taxes \{\theta^t, \tau^*_t\}.

Optimal Allocation. Problem (P-Nash-nFTA) yields the optimality conditions:

\[
u'(C_t)g_1(c_t) = \mu \hat{MC}^{nFTA}_{1,t}
\]

\[
u'(C_t)g_2(c_t) = \mu \hat{MC}^{nFTA}_{2,t}
\]

where \(\mu\) denotes the Lagrange multiplier on the implementability constraint and:

\[
\hat{MC}^{nFTA}_{1,t} = u''(C^*_t)(1 + \tau^*_t)g_1^*(c^*_t) + u'''g_1^*(c^*_t)\tau_t^{*^{-1}} \cdot \nabla g^*(c^*_t) \cdot [c_t - y_t]
\]

\[
+ u''(C^*_t)\tau_t^{*^{-1}} \cdot \frac{\partial \nabla g^*(c^*_t)}{\partial c_{1,t}} \cdot [c_t - y_t]
\]

\[
\hat{MC}^{nFTA}_{2,t} = u''(C^*_t)g_2^*(c^*_t) + u'''g_2^*(c^*_t)\tau_t^{*^{-1}} \cdot \nabla g^*(c^*_t) \cdot [c_t - y_t]
\]

\[
+ u''(C^*_t)\tau_t^{*^{-1}} \cdot \frac{\partial \nabla g^*(c^*_t)}{\partial c_{2,t}} \cdot [c_t - y_t]
\]

The Foreign planner undertakes an analogous maximisation. Combining the optimality conditions of the Home and Foreign planners yields the equilibrium allocation, which is summarised in the following proposition.

Proposition 5 (Capital Control and Tariff Wars) In a Nash equilibrium where each country chooses optimal capital controls \{\theta_t, \theta^*_t\}_{t\geq0} and tariffs \{\tau_t, \tau^*_t\}_{t\geq0}, the allocations \{c_t, c^*_t\}_{t\geq0} must satisfy

\[
\frac{\hat{MC}^{nFTA}_{1,t}}{\hat{MC}^{nFTA}_{1,0}} = \alpha^{nFTA}_{1,0} \quad \frac{\hat{MC}^{nFTA}_{2,t}}{\hat{MC}^{nFTA}_{2,0}} = \alpha^{nFTA}_{2,0}
\]

where

\[
\alpha^{nFTA}_{i,0} = \frac{\hat{MC}^{nFTA}_{i,0}}{\hat{MC}^{nFTA}_{i,0}} \quad \text{for } i = 1, 2
\]
Proof: See Appendix B.2.1.

The conditions above are intuitive, reflecting the ratio of the marginal cost of a unit of consumption for the planner across the Home and Foreign country, for each good variety.

3.4.3 Numerical Exercises

Using these strategic optimality conditions, we revisit our result on the direction and level of capital flow taxes with and without a FTA. We again consider the path of capital flow taxes and tariffs when the Home endowment of good 1 is low relative to its long-run value—i.e. experiment 1. The key insights from the Nash allocation are true for experiment 2 as well.

Figure 3.12 (LHS) illustrates that, in response to a good-1 downturn at Home, capital inflow taxes are larger absent a FTA, and this difference is larger in the Nash equilibrium. Moreover, the capital inflow tax in response to a downturn driven by goods-2 (Experiment 2), is also larger in the absence of an FTA in the Nash equilibrium. Our baseline result, namely that optimal capital controls are larger in the absence of a FTA, is therefore stronger when both countries act strategically.

Second, we study policy wars. We define two new quantities which capture the difference in the cost of borrowing in the Home vis-à-vis Foreign country, and the relative ratio of tariffs at Home vis-à-vis in Foreign:

\[
\Delta R = \frac{1 - \theta_t}{1 - \theta^*_t}, \quad \Delta \tau = \frac{1 + \tau_t}{1 + \tau^*_t}
\]

(3.20)

If \( \Delta R > 1 \), the cost of borrowing in the Home country is higher vis-à-vis the Foreign country, while \( \Delta \tau > 1 \) reflects a higher tariffs at Home vis-à-vis the Foreign country.

Figure 3.13 illustrates the evolution of these objects following a domestic downturn driven by good 1 (Experiment 1). Consistent with optimality conditions, the Home planner taxes capital inflows in an attempt to drive down the price of aggregate consumption and levies a smaller import tariff in the short run, in order to drive down good 1 consumption, while the Foreign planner attempts the opposite. As a result, \( \Delta R > 1 \) on impact and approaches 0 as \( y_{1,t} \) approaches \( y_1 \), while \( \Delta \tau > 1 \) on impact and rises thereafter.

Comparative Statics. At the benchmark calibration (\( \sigma = 2, \phi = 1.5 \)), countries engage in competition over both capital controls and trade tariffs leading to \( \Delta R, \Delta \tau \neq 1 \). We show that, as the elasticity of inter-temporal substitution \( \frac{1}{\sigma} \) falls—i.e. \( \sigma \) rises—countries levy larger capital controls, in turn inciting a larger response from each other, in an attempt to reallocate consumption inter-temporally and is reflected in a high \( |\Delta R| \). When \( \sigma \) is high, a representative household is more insensitive to change in the interest rate when choosing to allocate consumption across periods. In contrast, as \( \frac{1}{\sigma} \) rises, households are more sensitive to changes in the interest rate and smaller capital controls are levied in the Nash equilibrium.

Conversely, when the trade elasticity \( \phi \) is low, countries engage more in a tariff war leading to a higher \( |\Delta \tau| \). This reflects the well-understood result in public finance that a planner optimally chooses to tax commodities for which demand is price-inelastic. We show the inverse-elasticity result extends to a policy war involving competition in capital flow taxes and import tariffs (see,
Figure 3.10: Optimal Capital Flow Taxes and Import Tariffs in the Nash Equilibrium in Experiment 1

Notes: Optimal capital controls and taxes. ‘U’ subscript denotes unilateral optimal policy result (for Home). ‘N’ denotes Nash outcome.

Figure 3.11: Capital Control and Tariff Weds in the Nash Equilibrium in Experiment 1

Notes: Difference in cost of borrowing and tariffs across countries.
for example, Chari and Kehoe, 1999).\footnote{10}

### 3.5 Welfare and International Spillovers

Finally, we assess the consequences and spillovers of policy for welfare. Does the optimal policy simply reallocate from the Foreign country to the Home, or does it contribute to increase Home welfare at a disproportional cost to Foreign welfare and therefore world welfare? What are the costs of capital control wars, and are policy wars costlier when a FTA is not in place?

To answer this, we consider the cooperative problem where consumption allocations are chosen to maximise joint (world) welfare as our benchmark. The cooperative planning problem is given by:

\[
\max_{\{c_t\}} \sum_{t=0}^{\infty} \beta^t \left[ u(g(c_t)) + \kappa u(g^*(c_t^*)) \right],
\]

\[\text{(P-Coop)} \]

subject to:

\[
c_t + c_t^* = Y_t,
\]

\[\text{(RC)} \]

\[
c = c(C), \quad c^* = c^*(C)
\]

\[\text{(FTA)} \]

where \(\kappa\) is the weight attributed to Foreign welfare.

The following proposition summarises the key property of the global cooperative problem.

**Proposition 6 (Globally Cooperative Allocation)** *In the cooperative allocation, no intervention is optimal such that, if \(\kappa = 1\), \(\theta_t = \tau_t = 0\).*

*Proof:* See Appendix B.3.1.

Since the optimal cooperative policy coincides with the decentralised allocation, it must be that at the optimal policy—unilateral or Nash, with or absent an FTA—world welfare, as defined in (P-Coop), falls.

Table 3.2 reports to difference in present discounted welfare in Experiments 1 and 2 under the optimal policy, relative to the decentralised allocation, for the Home and Foreign representative agents respectively. Our results confirm that capital and goods taxation is distortionary and does not simply reallocate consumption across borders. In the case where the Foreign country is passive, the costs to the Foreign country outweigh the gains in the Home country leading to a loss in global welfare. In the presence of an FTA, capital controls change in the path of consumption over time which is inefficient for the Foreign country. In a Nash equilibrium where an FTA holds, the Foreign country benefits relative to the unilateral case by levying taxes itself, but global welfare falls further.

In the absence an FTA, countries levy taxes not only to change the path of consumption over time, but also its composition across goods varieties, so the the welfare costs from policy wars are higher when countries engage in both capital controls and tariff wars. In the working paper version of this chapter, we also investigate the origins of welfare losses. We show that, as the elasticity of inter-temporal substitution rises, welfare costs from capital control wars under FTA become very small but are almost unchanged absent an FTA. In contrast, costs sharply fall as \(\phi\) rises both with and without an FTA in place. We therefore find evidence that the costs to both capital control and tariff wars are predominantly from intra-temporal choice distortions.

\[\footnote{10}\text{These findings are consistent with the Arrow-Debreu approach of relabelling the future delivery of commodities as a separate good.}\]
Figure 3.12: Experiment 1: Comparative Statics with respect to $\phi$

![Figure 3.12](image)

Notes: Optimal capital controls and taxes. ‘U’ subscript denotes unilateral optimal policy result (for Home). ‘N’ denotes Nash outcome.

Figure 3.13: Experiment 1: Comparative Statics with respect to $\sigma$

![Figure 3.13](image)

Notes: Difference in cost of borrowing and tariffs across countries.
Table 3.2: Welfare and Spillovers. Welfare expressed in terms of % consumption equivalent variation (−ve implies welfare gain).

<table>
<thead>
<tr>
<th>Experiment 1</th>
<th>H</th>
<th>F</th>
<th>Global (\sum_{H,F})</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTA (Unilateral)</td>
<td>−0.13</td>
<td>0.23</td>
<td>0.050</td>
</tr>
<tr>
<td>without FTA (Unilateral)</td>
<td>−0.22</td>
<td>0.27</td>
<td>0.025</td>
</tr>
<tr>
<td>with FTA (Nash)</td>
<td>0.068</td>
<td>0.067</td>
<td>0.068</td>
</tr>
<tr>
<td>without FTA (Nash)</td>
<td>1.71</td>
<td>1.58</td>
<td>1.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>with FTA (Unilateral)</td>
<td>−0.061</td>
<td>0.011</td>
<td>0.0027</td>
</tr>
<tr>
<td>without FTA (Unilateral)</td>
<td>−0.082</td>
<td>0.39</td>
<td>0.15</td>
</tr>
<tr>
<td>with FTA (Nash)</td>
<td>0.16</td>
<td>−0.0007</td>
<td>0.080</td>
</tr>
<tr>
<td>without FTA (Nash)</td>
<td>5.2</td>
<td>0.93</td>
<td>3.1</td>
</tr>
</tbody>
</table>

3.6 Discussion: Generality of Results

Throughout this chapter, we have used a comparatively pared back two-country, two-good endowment model. This simplification has enabled us to provide analytical solutions, but has abstracted from many features discussed in the existing literature—for example firm and household heterogeneity, firm entry and exit, roundabout production, borrowing constraints etc. While these features may have additional policy implications, we nevertheless emphasise that the pecuniary externalities at the heart of our analysis are sufficiently general. We detail two dimensions along which our results can be generalised.

Endowment vs. Production Economies. We focus on an endowment economy to abstract from the complexities of price-setting, which have been a key focus of open-economy macroeconomics in past decades (e.g. Devereux and Engel, 2003; Benigno and Benigno, 2003; Corsetti, Dedola, and Leduc, 2010). Nevertheless, with full specialisation assumed \((y_1 = 1, y_2 = 0, y_1^* = 0 \text{ and } y_2^* = 1)\), our endowment setup is isomorphic to one with production subject to technology \(y_1 = f(A, L)\), where each country is endowed with a fixed quantity of labour \(L\). If we further assume that the function \(f\) is first-order homogeneous in \(A\), fluctuations in \(y_1\) and \(y_2^*\) in our endowment economy can be interpreted as reflecting movements in Home and Foreign productivity—\(A\) and \(A^*\), respectively.\(^{11}\) Moving away from the full specialisation case, we assume labour in each country, is employed in two sectors, one which produces good 1 and another producing good 2. The latter can be interpreted as an ‘export’ sector and fluctuations in \(y_2^*\) can represent fluctuations in export-sector productivity.

Size in Goods and Financial Markets. This chapter considers a two-country model where each country is large in both goods and financial markets. As a consequence, the planner internalises the effect of domestic allocations on both goods prices and the real interest rate, motivating the use of capital controls and tariffs. Similar conclusions can be reached when considering two generalisations of this. First, moving to a small-open economy setting (i.e. with

\(^{11}\text{Alternatively, if technology is linear and productivity is constant, } y_1 \text{ and } y_2^* \text{ can reflect exogenous movements in labour supply (} L \text{ and } L^*, \text{ respectively) such as those studied in Guerrieri, Lorenzoni, Straub, and Werning (2020).}\)
As detailed in Costinot, Lorenzoni, and Werning (2014), countries remain large in goods markets for their domestic variety. So, the incentive for intra-temporal manipulation of the terms of trade remains.

Second, for countries to be able manipulate the real (world) interest rate using capital controls or tariffs, countries must be large enough to individually influence world consumption. Arguably, this can only apply to a small set of countries, e.g. U.S. and China. However, this result can be recovered in the presence of financial frictions. A recent literature, including Basu et al. (2020), Bianchi and Lorenzoni (2021) and Marin (2022), consider an upward-sloping supply curve for international borrowing and emphasise that capital controls can be used to manipulate interest rates through premia. For example, Marin (2022) models the U.S. as a small-open economy (taking $C^*$ as given) but emphasises it is large in dollar markets. Capital controls or tariffs which reduce the supply of dollar borrowing by the U.S. can reinforce monopolistic rents and have significant welfare implications.

Finally, Egorov and Mukhin (2021) show that in the presence of nominal rigidities and dollar currency pricing, i.e. when world exports are priced in dollars, U.S. prices affect the world stochastic discount factor and the U.S. is able to manipulate the inter-temporal terms of trade even if it is small.

### 3.7 Conclusion

In this chapter, we analyse optimal capital flow taxation comparing outcomes with and without a binding FTA. We find that optimal capital controls and trade taxes are interdependent and their relationship depends on the nature of economic fluctuations.

Within a standard two-country, two-good endowment model, trade occurs along two margins—over time and across goods varieties. If, in addition to capital controls, we allow for goods-specific taxation (for instance, in the form of import tariffs), we show that a planner who levies taxes can achieve higher welfare. The departure from an FTA offers the planner a second instrument, such that the first-best allocation can be achieved. The planner taxes capital inflows at times when the Home country is borrowing between two periods, so as to drive down the interest rate and address inter-temporal incentives. In conjunction, the planner uses an import tax to increase the relative demand for Home consumption in periods where the country is exporting Home goods, thus constraining net supply to drive up the price of the Home good and address intra-temporal incentives.

Moving away from an FTA, if the Foreign country is passive, optimal capital flow taxes levied by the Home country are larger if the planner’s inter- and intra-temporal terms-of-trade manipulation incentives are aligned. In such cases, optimal import tariffs amplify relative consumption changes and real exchange rate misalignments, thus requiring larger capital flow taxes to implement the optimal allocation. When inter- and intra-temporal incentives are opposed, the resulting capital flow taxes are smaller. In this case, tariffs move the real exchange rate in a direction that supports efficient levels of borrowing so the required of capital controls is smaller.

In a Nash equilibrium, due to competition in capital flow taxes, the level of capital flow taxes rises in both cases when the FTA is relaxed. Allowing countries to engage in policy wars, we show

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12 This is a critique espoused by Rebucci and Ma (2019) amongst others.

13 These frictions build on Gabaix and Maggiori (2015) which in turn builds on a large literature on limits to arbitrage, e.g. Gromb and Vayanos (2010).
capital control wars dominate when the elasticity of inter-temporal substitution is low, while tariff wars intensify as the trade elasticity falls—consistent with an inverse-elasticity rule. When the Foreign country is passive, the optimal policy brings welfare gains to the Home policymaker, but cross-border spillovers are negative and disproportionately large. Absent an FTA, we show that trade policy is not simply redistributive. By levying trade taxes, the planner pushes foreign households away from their efficient allocation of goods varieties, generating further costly cross-border spillovers in addition to inefficient reallocation of consumption over time.

In ongoing research, we extend the environment in a number of dimensions. First, we consider the mapping between pecuniary externalities and financial frictions, such as the case of a borrowing constraint. Prices in the borrowing constraint drive the interaction between optimal capital control and trade policy since, usually, a terms of trade appreciation tends to relax this constraint (see, for example, Bianchi, 2011). This motive to appreciate the terms of trade in periods where the borrowing constraint is most binding is of first-order interest to policymakers. Second, while in this chapter we have focused on the intensive margin—i.e. how large are capital controls, we extend our analysis to the extensive margin—i.e. when are capital controls used. We focus on a strategic setting with retaliation and show, amongst other results, that a trade union (such as the European Union) fosters a capital flows union.
Chapter 4

The Hegemon’s Dilemma

4.1 Introduction

In periods of global financial distress, international capital systematically flows into dollar assets. Dollar shortages in foreign markets are an important and recurrent feature of recent financial crises, including as the 2007 GFC and the early-stages of the Covid-19 pandemic. Foreign investors demand dollar debt in large quantities even though, as dollars becomes scarce, the dollar tends to appreciate and the return on a portfolio that is long in dollar bonds, funded by borrowing in foreign currencies becomes significantly negative.\(^1\) Because of the specialness of the dollar, fluctuations in the supply and demand of dollar assets, and the conduct of U.S. policy matter disproportionately in the world economy.\(^2\) Strong and volatile demand for dollars by foreign investors, however, also has stark implications for U.S. domestic outcomes.

The contribution of this chapter is to re-consider the trade-offs faced by the hegemon, as issuer of dollar assets. On the one hand, a scarce dollar leads to a higher return on the net investment position of the U.S.—interpretable as monopoly rents from issuing dollar debt— which results in a transfer from abroad. On the other hand, this transfer leads to an equilibrium appreciation of the dollar which depresses the global demand for U.S. exports, resulting in unemployment and, on impact, results in losses on the portfolio of foreign-currency denominated assets coming due.\(^3\) I show that, in the absence of an optimal macro-prudential tax to correct inefficient levels of private sector borrowing, monetary policy alone cannot support the constrained efficient allocation in the hegemon when there are dollar shortages abroad. In particular, the hegemon experiences inefficiently volatile output and prices and lower monopoly rents. I then highlight the scope for direct liquidity provision, through the Federal Reserve’s Dollar Swap Line facilities, described in Section 4.2.4, to be welfare improving for both the hegemon and foreign

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\(^1\) McGuire and Peter (2009) document that European Banks’ short term dollar funding gap (i.e dollar roll-over needs) were at least 7% of U.S. GDP at the onset of the GFC. Aldasoro et al. (2020) document that in June 2018, non-U.S. banks had $12.8 trillion of dollar-denominated borrowing, used to finance purchases of U.S. assets.

\(^2\) For instance, an acute shortage of dollar assets can lead to deflationary safety traps (Caballero, Farhi, and Gourinchas (2017)) and a sharp tightening in international financial conditions (Jiang (2021)). Rey (2015), Kalemli-Ozcan (2019), Miranda-Agrippino and Rey (2020), and Jiang, Krishnamurthy, and Lustig (2020), amongst others, show that U.S. monetary policy has large spillovers in foreign and particularly emerging economies.

\(^3\) As documented in Figure C.1, a portfolio funded by dollar borrowing and long in foreign assets suffers losses at the onset of the crisis. However, this is followed by large returns during the crisis. Jiang, Krishnamurthy, and Lustig (2020) describe the higher expected future returns on the U.S. portfolio as a “capitalization” effect and document a wealth inflow to the U.S. during the GFC. This net wealth flow is debated in the literature: on empirical grounds, Maggiori (2017) finds evidence of losses for the U.S., albeit using a narrower definition for wealth, see Figure C.7.
I adopt a standard open-economy model, featuring nominal rigidities and financial frictions in international markets. Specifically, dollar and foreign currency markets for financial assets are separate, building on the segmented markets framework of Gabaix and Maggiori (2015). In this framework, dollar assets can be issued by U.S. agents and they can also be manufactured, at an increasing cost, by heterogeneous international financial intermediaries (e.g., non-U.S. banks). Following an increase in the demand for dollar debt by foreign investors, because intermediation is costly, the dollar appreciates and the cost of borrowing in dollars fall in equilibrium. Moreover, because aggregate intermediation costs are increasing in the size of dollar shortages, the hegemon faces a downward sloping demand for dollar debt.

The model is consistent with key recurrent patterns of the dollar around periods of international turmoil when the demand for dollars is high, see Figure C.1 (Appendix A). In particular, the dollar appreciates at the onset of crises and depreciates thereafter. Interest rates on 3-month U.S. treasuries fall, but only moderately. Together, these patterns imply that foreign investors forego significant returns to hold a portfolio of dollar debt which they finance by borrowing in foreign currency during crises. For example, the return on this portfolio in August 2008 was \(-6\%\) over the next 12 months.\(^4\) Intuitively, foreign currencies which tend to contemporaneously depreciate vis-à-vis the dollar in periods of dollar shortages, systematically appreciate thereafter, therefore the dollar cost of repaying foreign debt rises, even if interest rate differentials are small.

The main results of my analysis are as follows. First, I establish that dollar shortages abroad lead to private sector over-borrowing by hegemon households because of two externalities: a financial externality and an aggregate demand externality. The former arises because atomistic households borrowing in financial markets do not internalize that the country as a whole faces a downward sloping demand for dollar debt (the result of frictions faced by financial intermediaries). In other words, atomistic households fail to internalize that issuing an additional unit of dollar debt lowers the the price for all other units of debt. Aggregate demand externalities are the result of nominal rigidities in goods markets, preventing the adjustment of prices. Households do not take into account the stimulative effects of their spending on domestic goods on employment. To show that these two externalities result in over-borrowing in the hegemon, I derive that the optimal macro-prudential response to an increase in dollar shortages, at the constrained efficient allocation, is a positive tax on borrowing. I define the constrained efficient allocation as the best feasible allocation that can be supported by the optimal mix of monetary and macro-prudential policy.

Second, I show that when the borrowing tax is not set optimally or is not available, private sector over-borrowing weighs on the trade-offs faced by monetary policy. On the one hand, monetary policy wants to cut interest rates to boost demand for exports and prevent a costly dollar appreciation. However, because of the presence of over-borrowing, monetary policy has an offsetting incentive to raise interest rates and prevent the inefficient (and temporary) boom. Relative to the constrained efficient equilibrium, the equilibrium with monetary policy alone is characterized by excessively volatile output and prices and lower monopoly rents.

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\(^4\)This mechanism is consistent with evidence in Krishnamurthy and Lustig (2019) and Georgiadis, Müller, and Schumann (2021) who find that in response to an increase in the demand for dollars, non-U.S. banks increase their issuance of dollar liabilities.

\(^5\)Krishnamurthy and Lustig (2019) provide direct evidence of foreign investors taking loss-making positions, see Figure C.3.
This result complements the idea put forth by Rey (2015) who argues that countries cannot set monetary policy independently because of a global financial cycle in asset prices driven by the dollar. Following Farhi and Werning (2014), I define monetary policy to be independent if it can achieve the constrained efficient allocation absent the use of any tax on borrowing from abroad. My findings suggest that the U.S. also faces a Mundellian policy dilemma, since monetary policy does not achieve the constrained efficient allocation due to capital flows driven by foreigners’ demand for dollars.\(^6\)

Third, I find that the policy dilemma gives scope for direct dollar liquidity provision in international markets, as exemplified by the Federal Reserve (FED) dollar swap lines, to improve hegemon welfare. Swap lines are agreements according to which the FED lends dollars to a foreign central bank, against good collateral and over short maturities, in exchange for foreign currency. The foreign central bank, in turn, lends dollars to its domestic financial institutions alleviating their dollar constraints. Since the GFC, swap lines have been used extensively. The outstanding dollar swap liabilities amounted to 38% of U.S. GDP in 2008 Q4.\(^7\) Like the (missing) macro-prudential borrowing tax, dollar swaps allow the hegemon to address inefficient over-borrowing and stabilize output, but, in stark contrast with the borrowing tax, they achieve these objectives at the cost of eroding monopoly rents as dollar assets become more easily available. As a result, dollar swaps improve outcomes for foreign investors, in contrast to the optimal macro-prudential tax. Since dollar swaps address over-borrowing, they help the hegemon regain monetary policy “independence”. In the baseline model, dollar swaps never improve welfare when the optimal macro-prudential tax is used.

The workings of dollar swap lines in the model are as follows. Financial intermediaries can manufacture dollar debt but are subject to portfolio costs and position limits. Because of this, they are only willing to issue dollar debt if the cost of borrowing in dollars is lower than the cost of borrowing in foreign currency. The tighter the intermediaries’ portfolio constraint, the larger the spread required for the dollar market to clear. By exchanging dollars for foreign currency, dollar swaps increase liquidity in international markets and alleviate the frictions constraining the supply of dollar debt by financial intermediaries. Since smaller dollar shortages moderate the pressure on the dollar to appreciate, swaps contribute to sustaining employment and weaken the incentive for hegemon residents to (over-)borrow. In the case where the only shock in the economy is a one-off dollar demand shock, dollar swaps can, by themselves, fully mute the effects of the shock—but, the resulting allocation does not coincide with the constrained optimal. This is because a macro-prudential tax that postpones consumption can simultaneously address over-borrowing and increase the size of monopoly rents transferred from abroad.

Fourth, I highlight that dollar shortages have strong domestic distributional consequences. Given the over-borrowing inefficiency, I consider an extension of the model which distinguishes between households who are financially-active, and can trade in dollar debt vis-à-vis financial intermediaries, and inactive households who consume their current income. Dollar shortages abroad have heterogenous effects one these two types of households. Financially-active house-

\(^6\)Mundell’s classical view is that countries can achieve two objectives out of capital market openness (no taxes on capital flows), monetary policy independence (addressing domestic objectives) and exchange rate stability. Recent literature has instead suggested that efficient monetary policy requires taxation in capital markets as well, therefore the policy choice is between exchange rate stability with free capital mobility and no monetary independence or monetary policy independence with capital flows management.

\(^7\)Dollar swaps signal a recognition by the FED of the role of dollars in the international markets, and its own role as a global lender of last resort in the spirit of Bagehot, see Bahaj and Reis (2018).
holds benefit from higher returns on their financial position (short in dollar bonds and long in
foreign assets) and, unlike inactive households, are partly able to smooth the income loss from
depressed exports and from losses on the government’s portfolio of assets. Inactive households
lose out even if, in equilibrium, financially-active households spend part of the rents they earn
on domestic goods, raising domestic income for all residents. The use of dollar swap lines sys-
tematically redistributes from financially-active to inactive households because they mute the
effect of shortages on the exchange rate and erode monopoly rents.\(^8\)

I close the paper with a simple numerical illustration. I consider a one-off unanticipated
shock to foreign investors’ demand for dollars which leads to a 6-8% appreciation of the dollar
(depending on the interest rate response), and results in a spread in the cost of borrowing
in foreign currency vis-à-vis dollars of about 4%, consistent with the U.S. experience during
the GFC (see Figure C.1). While optimal monetary policy alone (a 3% interest rate cut) can
improve aggregate outcomes in the face of dollar shortages, it achieves only \textit{one-third} of the
welfare gain which is possible at the constrained optimal allocation. The constrained efficient
allocation instead requires interest rates to adjust by about 5%. At the constrained efficient
allocation, a one-off unexpected increase in dollar shortages improves welfare, whereas welfare
falls when neither monetary or macro-prudential policy respond optimally. Finally, I find that
the distributional implications of dollar shortages persist even when monetary policy adjusts and,
surprisingly, the allocation becomes can become more inequitable at the constrained efficient
allocation.

Related Literature. Thematically, this paper belongs to the literature on the role of the
U.S. and the dollar in the International Monetary System (IMS). Amongst recent contributions,
Maggiori (2017), Gourinchas, Rey, and Govillot (2018), Kekre and Lenel (2020) consider general
equilibrium models where the U.S. has a larger capacity to bear risk, earning excess returns
outside of crises but facing losses during crises. Farhi and Maggiori (2018) emphasize, that the
U.S. faces a downward sloping demand for its debt, derived from mean-variance investors, and
earns monopoly rents. However, in their framework, monopoly rents arise only through lower
interest rates. Similarly, Jiang, Krishnamurthy, and Lustig (2020) consider a model where the
U.S. earns seignorage rents from issuing debt because foreign investors assign a convenience yield
to dollar debt. Relative to these papers, I highlight the role for policy to manage the trade-offs
faced by the U.S. and I highlight the macroeconomic externalities which arise.

I draw on a new, mostly theoretical, literature on optimal capital controls which aims to
identify macroeconomic externalities in goods and financial markets. Specifically, Costinot,
Lorenzoni, and Werning (2014) and Lloyd and Marin (2020), study the use of capital controls
to internalise terms of trade externalities both inter-temporally and intra-temporally. Schmitt-
Grohé and Uribe (2016) and Farhi and Werning (2016) look at aggregate demand externalities
and Basu et al. (2020) and Bianchi and Lorenzoni (2021) analyze financial externalities.\(^9\) My
analysis of second-best monetary policy relates to Bianchi and Coulibaly (2021), who show that
monetary policy can be used to address inefficiently high borrowing in the economy, when capital

\(^8\)Chien and Morris (2017) show that financial market participation varies by U.S. state even when controlling
for household income. Therefore, dollar shortages introduce a political trade-off in the hegemon and the extension
of dollar swap lines can become a political decision.

\(^9\)Farhi and Werning (2014) emphasize that capital controls are generally useful, in addition to monetary policy,
to smooth the terms of trade in a small open economy, New-Keynesian model.
controls are not available and Itskhoki and Mukhin (2022) who show that monetary policy must compromise between stabilizing the output gap and achieving efficient risk sharing because of intermediation frictions.\footnote{Their model emphasizes that the exchange rate volatility needed to stabilize the output gap itself impinges on efficient risk sharing because of financiers’ intermediation capacity is decreasing in exchange rate volatility.}

Even though dollar swap lines have been one of the most prominent policy innovations over the past decade, there is comparatively little literature on their effect on macro outcomes.\footnote{McCauley and Schenk (2020) detail the history of liquidity provision policies by the U.S. and other central banks.}

A number of contributions have assessed the efficacy of dollar swaps empirically: Baba and Packer (2009) and Moessner and Allen (2013) analyse the effect of swap lines during the GFC using variation across currency pairs and Aizenman, Ito, and Pasricha (2021) conduct a similar analysis for the aftermath of COVID-19. Bahaj and Reis (2018) use both cross-sectional and time-series variation to show that dollar swaps introduce a ceiling on deviations from the covered interest rate parity, reduce portfolio flows into dollar assets and lower the price of dollar corporate bonds. The contribution of this paper is to characterize dollar swap lines as part of the (Ramsey) optimal policy and highlight a meaningful trade-off facing the U.S. when it extends these to foreign central banks.

Finally, this paper relates to an established literature that studies the implications of limited financial market participation on risk-sharing outcomes in closed and open economies.\footnote{See e.g Alvarez, Atkeson, and Kehoe (2002), Alvarez, Atkeson, and Kehoe (2009), Kollmann (2012) and Cociuba and Ramanarayanan (2017)}

Recently, Fanelli and Straub (2022) derive optimal foreign exchange interventions in a model with segmented international financial markets where hand-to-mouth households are hurt by a pecuniary externality. De Ferra, Mitman, and Romei (2019) study the effects of a sudden stop in capital inflows in a small-open HANK economy where household debt is partly denominated in foreign currency. Auclert et al. (2021), build on Corsetti and Pesenti (2001), to analyze the effects of household heterogeneity on the costs of an appreciation.

This chapter is structured as follows. Section 4.2 lays out the model. Section 4.3 considers a stylized framework which outlines the key trade-offs. Section 4.4 solves for welfare maximizing policy and analyzes the hegemon’s policy dilemma. Section 4.4.3 considers the distributional implications of dollar shortages in a two-agent version of the model. Section 4.5 conducts a calibration exercise. Section 4.6 concludes.

### 4.2 Model Setup

There is a continuum of countries $i \in [0, 1]$. I denote the \textit{hegemon} by $i = 0$ and suppress the subscript for domestic variables. The baseline setup builds on a standard open-economy model as in Galí and Monacelli (2005), recently adopted in, e.g. Farhi and Werning (2016) and Egorov and Mukhin (2021). To distinguish between a market for dollar assets and a market for foreign currency assets, I allow for financial market segmentation in the spirit of Gabaix and Maggiori (2015). The hegemon differs from other countries in $i = [0, 1]$ in one important way– it is the monopoly issuer of dollar assets in its market segment.
4.2.1 Households

A representative household in country $i = 0$ (Home) has preferences described by the following instantaneous utility function,

$$\mathcal{U}_t = \frac{C_t}{1 - \sigma} - \frac{\kappa L_t^\psi}{1 + \psi}$$  \hspace{1cm} (4.1)$$

where $C_t$ is consumption of private goods and $L_t$ is labour supplied. Private consumption is an index composed of Home and Foreign good varieties,

$$C_t = \left[ \chi \frac{1}{\theta} C_{H,t}^{\frac{\theta-1}{\theta}} + (1 - \chi) \frac{1}{\theta} C_{F,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$ \hspace{1cm} (4.2)

and $C_{H,t}, C_{F,t}$ consists of,

$$C_{H,t} = \left[ \int_0^1 C_{H,t}(j) \left(1 - \frac{1}{\epsilon} \right) dj \right]^{\frac{\epsilon}{\epsilon-1}}$$ \hspace{1cm} (4.3)

$$C_{F,t} = \left[ \int_0^1 C_{F,t}(j) \left(1 - \frac{1}{\epsilon} \right) dj \right]^{\frac{\epsilon}{\epsilon-1}},$$

where $j$ denotes different varieties of the same good and $\epsilon$ is the constant elasticity of substitution between varieties, $i$ denotes countries and $\theta$ is the constant (macro) elasticity of substitution between imports from different countries. The parameter $\chi$ reflects the weight of domestic goods in a country’s final consumption index, where $\chi > 0.5$ captures home bias. Foreign households have analogous preferences and face a symmetrical problem.

Households purchase goods, earns wages $W_t$ from providing labour $L_t$ and receive profits $\Pi_t = \Pi^g_t + \Pi^f_t$ from their ownership of goods’ and financial firms respectively. Households borrow in one-period, non-contingent bonds $x_t$ at time $t$, denominated in domestic currency, and repay $R_t$ at $t+1$. I also allow households to have an exogenous exposure to foreign-currency denominated assets. Households take a long position of $a^F_t$ dollars in foreign currency debt (purchasing $\frac{1}{E_t} a^F_t$ units) with a dollar return $R^*_t E_t$ at $t+1$. The budget constraint is given by,

$$P_{F,t} C_{F,t} + P_{H,t} C_{H,t} \leq \Pi_t + W_t L_t + x_t - R_{t-1} x_{t-1} - a^F_t + R^*_t a^F_{t-1}$$  \hspace{1cm} (4.4)$$

The household’s optimization problem consists of choosing a sequence $\{C_{H,t}, C_{F,t}, L_t, x_t\}$ to maximize lifetime utility (4.1) subject to the budget constraint (4.4), taking initial debt $x_0$, foreign exposures $a^F_t$, production $\{Y_{H,t}\}$ and prices $\{E_t, W_t, R_t, P_{H,t}, P_{F,t}\}$ as given.

The first-order conditions characterizing the households’ optimal allocation are given by,

$$C_{t}^{-\sigma} \frac{P_t}{P_{t+1}} \left[ C_{t+1}^{\sigma} \right] R_t = 0,$$  \hspace{1cm} (4.5)$$

$$\kappa L_t^\psi P_t^{\sigma} = \frac{W_t}{P_t},$$  \hspace{1cm} (4.6)$$

$$C_{H,t} = \frac{\chi}{1 - \chi} \left( \frac{P_{H,t}}{P_{F,t}} \right)^{-\theta} C_{F,t},$$  \hspace{1cm} (4.7)$$
where (4.5) is the household Euler equation governing the inter-temporal allocation of consumption, (4.6) characterises the optimal labour allocation and (4.7) determines the allocation of spending between home and foreign good varieties.

For simplicity, I assume the foreign asset position of hegemon households is exogenous and not derived from maximizing behaviour.\(^{13}\)

### 4.2.2 Firms

In each country there is a continuum of firms indexed by \(j\), which produce a unique variety of tradable goods and are endowed with linear production technology which uses only labour,

\[
Y_{H,t}(j) = A_t L_t(j) \tag{4.8}
\]

where \(A_t\) is a Home (aggregate) productivity. Goods are consumed both domestically and exported abroad:

\[
Y_{H,t} = C_{H,t} + C^*_H, \tag{4.9}
\]

where \(C^*_H\) denotes foreign demand.

I focus on the case where prices are perfectly rigid.\(^{14}\) I consider a model which allows for price rigidities in traded goods therefore I can assess the implications of limited exchange rate pass-through to U.S. imports. Under producer currency pricing (PCP), domestic producers set identical domestic prices for all the goods they produce, regardless of whether they are consumed domestically or exported, as assumed in Galí and Monacelli (2005) and Farhi and Werning (2014). However, in the data, exported goods are predominantly denominated in dollars. This is referred to as DCP and is documented in Gopinath et al. (2020). I assume the hegemon also issues the dominant currency, consistent with the case of the dollar.\(^{15}\)

I allow for a constant employment tax \(\tau_L\) and define the effective wage for firms by \(\tilde{W}_t = W_t (1 + \tau_L)\).

Consider the maximization faced by a firm \(j\) in the Home country when prices are perfectly rigid,

\[
\max_{P_{H,t}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \left[ P_{H,t}(j) Y_{H,t}(j) - \frac{\tilde{W}_t}{A_t} L_t(j) \right] \tag{4.10}
\]

In a symmetric equilibrium \(P_{H,t}(j) = P_{H,t}, Y_{H,t}(j) = Y_{H,t}\). The price is given by,

\[
P_{H,t} = \frac{\epsilon}{\epsilon - 1} (1 + \tau_L) \frac{\mathbb{E}_t \left[ \sum_{s=0}^{\infty} \Lambda_{t+s} W_{t+s} Y_{H,t+s} \right]}{\mathbb{E}_t \left[ \sum_{s=0}^{\infty} \Lambda_{t+s} Y_{H,t+s} \right]}, \tag{4.11}
\]

where the labour subsidy is chosen to eliminate steady state monopolistic distortions \(1 + \tau_L = (\epsilon - 1)/\epsilon\) and \(\Lambda_t\) is households stochastic discount factor. Consistent with the literature, I assume firms set the same price for all export destinations. In contrast, if prices are perfectly flexible,

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\(^{13}\)In Fanelli and Straub (2022), the authors assume there is a maximum position in foreign currency that households can take, i.e. \(\frac{P_t}{\epsilon R_t} > R_t\). Partial segmentation is considered in the online appendix of Gabaix and Maggiori (2015) where the demand \(a_t^F\) is limited to linear rules.

\(^{14}\)This assumption, also used in Egorov and Mukhin (2021) and Basu et al. (2020), allows me to abstract from price dynamics and dispersion. Price dynamics in open economies have been the focus of a large literature on open economy New-Keynesian models, see Galí and Monacelli (2005), Farhi and Werning (2014) and Corsetti, Dedola, and Leduc (2018) amongst others.

\(^{15}\)Recent literature argues that the dominance of the dollar in financial and goods market is closely connected, see Gopinath and Stein (2018) and Chahrour and Valchev (2021).
firm $j$ chooses prices such that for each period,

$$\max_{P_{H,t}(j)} P_{H,t}(j)Y_{H,t}(j) - \frac{\tilde{W}_t}{A_t}L_t(j)$$

and in equilibrium,

$$P_{flex,H,t} = \frac{\epsilon}{\epsilon - 1} (1 + \tau_L) \frac{W_t}{A_t}$$

such that firms charge a constant mark-up over $\tilde{W}_t/A_t$.

**Price indices, exchange rates and foreign variables.** The home consumer price index (CPI) is defined as

$$P_t = [\chi P_{H,t}^{1-\theta} + (1 - \chi) P_{F,t}^{1-\theta}]^{\frac{1}{1-\theta}}.$$ 

I define $E_t$ as the effective dollar nominal exchange rate, where an increase in $E_t$ reflects a depreciation of the dollar. Import and export prices for the home country satisfy:

$$P_{*H,t} = \frac{P_{H,t}}{E_t}, \quad P_{*F,t} = P_{*F,t}E_t^{\lambda_*}$$

where $\lambda$ is exchange rate pass-through to imports in $i = 0$ and $\lambda^*$ is exchange rate pass-through on hegemon exports. Under (full) DCP, $\lambda = 0, \lambda^* = 1$. Assuming prices at the border are perfectly rigid, consumer prices are time-varying only if pass-through is non-zero. Without loss of generality, I assume $P_{*F} = 1$.

To emphasize the distinction between the Home (hegemon) and other countries, I assume all foreign countries are symmetric and I model a single foreign sector consisting of $i \in (0, 1]$ countries. Foreign sector variables are denoted by an asterisk.

### 4.2.3 International Financial Markets

Asset markets are incomplete and segmented. Markets are incomplete because households in each country trade in non-contingent bonds denominated in domestic currency. Markets are segmented because households are confined to trade within their own financial market segment only, i.e. they cannot directly trade with households in other countries. For simplicity, I focus on a ‘dollar’ and a ‘foreign’ market segment only. Figure 4.1 below illustrates the market structure.

A continuum of financial intermediaries indexed by $k \in [0, \hat{k})$ trade one-period, non-contingent bonds at each time $t$, across market segments, with agents in the home and foreign segments. Each financier starts with no initial capital, faces a participation cost $k$ and position limits $\{-Q, Q\}$. The variable $k$ corresponds to both the financiers’ cost of participating and their index. Without loss of generality, I assume financial intermediaries trade in a single foreign bond with the foreign sector with dollar return $R_t^*E_t$. Since foreign countries are symmetric, $R_{i,t} = R_t^*$ for $i > 0$. Financiers choose a position in dollar bonds $q_t(k)$, financed by a position $-\frac{q_t(k)}{E_t}$ in foreign-currency bonds, to maximize profits earned at $t + 1$. Specifically, $q_t(k) < 0$ denotes a short position in dollar bonds, i.e. financiers sell a promise to a dollar tomorrow in exchange

---

16 For comparison, $\lambda = \lambda^* = 1$ under PCP where the law of one price holds.

17 The formulation of this problem is closest to Fanelli and Straub (2022). Position limits can be motivated by collateral constraints, see e.g Gromb and Vayanos (2002), Gromb and Vayanos (2010) or value at risk constraints, see Adrian and Shin (2014). The timing of the intermediation problem follows Alvarez, Atkeson, and Kehoe (2002) and Cociuba and Ramanarayanan (2017). Position limits restrict the level of dollar liquidity in markets.
for $q_t(k)$ dollars today. The problem of an individual financier, indexed by $k$, at time $t$ can be summarised as,

$$\max_{q_t(k) \in \{-Q_t, Q_t\}} \left( R_t - R_t^* \mathbb{E}_t \left[ \frac{\xi_{t+1}}{\xi_t} \right] \right) q_t(k) - k$$

Financial intermediaries participate as long as $|R_t - R_t^* \mathbb{E}_t \left[ \frac{\xi_{t+1}}{\xi_t} \right]| \mathbb{E}_t > k$. In equilibrium, a measure $k_t = |R_t - R_t^* \mathbb{E}_t \left[ \frac{\xi_{t+1}}{\xi_t} \right]| \mathbb{E}_t$ participate. The total demand for dollars by financiers is given by $Q_t = \text{sign}(R_t - R_t^* \mathbb{E}_t \left[ \frac{\xi_{t+1}}{\xi_t} \right]) \mathbb{E}_t k_t$. I define $\Gamma_t = 1/\mathbb{E}_t^2$.

In equilibrium, because of non-zero entry costs and position limits, financial intermediaries require excess returns when there are dollar imbalances in international markets ($Q_t \neq 0$), leading to deviations from UIP:

$$\left( R_t - R_t^* \mathbb{E}_t \left[ \frac{\xi_{t+1}}{\xi_t} \right] \right) = \Gamma_t Q_t$$

(4.15)

The LHS of (4.15) reflects the return required by financiers to engage in arbitrage across markets. Suppose there is a shortage of dollars $Q_t < 0$. Then, (4.15) is the compensation financiers require to intermediate dollar shortages for a given level of (inverse) dollar liquidity $\Gamma$. In periods of low liquidity, when financiers are more constrained (i.e $\mathbb{E}_t$ is low and $\Gamma_t$ is high) a larger spread is required for a given $Q_t$. As a result, the dollar price of dollar debt exceeds that of foreign-currency denominated debt. In the limit where dollar liquidity is abundant ($\Gamma_t = 0$) the spread does not depend on $Q_t$.

Furthermore, I assume there is a separate group of non-optimizing, unconstrained agents belonging to the foreign sector who have inelastic demand $\xi_t \geq 0$ for dollar debt, which they finance by taking a position $-\xi_t/\xi_t$ in foreign currency debt. Market clearing in the dollar segment

---

\[\text{Figure 4.1: International financial market structure}\]
requires:

\[ Q_t = x_t - \xi_t, \]  

(4.16)

For markets to clear, the financiers’ aggregate position in dollar debt \( Q_t \) is equal to the supply of dollar assets \( x_t \) minus the demand for dollar debt \( \xi_t \). Equations (4.15) and (4.16) summarise the dollar market equilibrium.

The model implies an upward sloping supply curve for dollar debt by financial intermediaries. Figure 4.2 below illustrates the equilibrium in the dollar market. The demand faced by financial intermediaries when foreign investors inelastically demand \( \xi_t \) and U.S. households supply an exogenous quantity \( x \) is \( \xi_t - x \). The Figure considers the case where \( x_t = a_t^F \). Excess demand for dollar debt generates monopolistic rents for both financiers (green triangle) and the hegemon (purple rectangle), which I discuss in detail later on.

Figure 4.2: LHS: Equilibrium in the dollar market. \( F^S \) denotes the supply of dollars \( (Q_t < 0) \) by financial intermediaries and \( F^D \) denotes the demand for dollar debt financial intermediaries face. RHS: Extending dollar swaps lines lowers the gradient of \( F^S \).

**Multipolar World.** To highlight the special position of the hegemon in the model, consider the case when there are \( N \) competing issuers within a segment, and for clarity, consider the dollar segment. Market clearing is then given by,

\[ Q_t = x_t + \sum_{i>0}^{N-1} x_t^i - \xi_t, \]  

(4.17)

where \( x_t^i \) is the issuance of dollar assets by issuer \( i > 0 \) households. If foreign issuers of close-substitute debt respond to changes in \( \xi_t \) (which leads to a fall in \( R_t \)) by a factor \( \epsilon > 0 \), as the number of issuers becomes large, shortages cannot arise in the market segment.\(^{20}\)

\(^{20}\)In Appendix C.2, I show within a stylized model that if \( N \) symmetric governments compete à la Cournot when issuing substitutable varieties of debt, dollar shortages in international markets go to zero, as do rents from issuance.
4.2.4 Dollar Swap Lines

A key institutional innovation in recent years has been the (re-)establishment of dollar swap lines. As part of a swap line agreement, the U.S. FED lends dollars to a foreign central bank over a short maturity. The foreign central bank, in turn, lends dollars to their domestic financial institutions— in this instance, the financial intermediation sector. The FED receives a foreign currency deposit as collateral and at the end of the loan, the FED gets its currency back at the original exchange rate. In the model, I assume the FED swaps dollars directly with financial intermediaries expanding the portfolio limits they face.

Absent dollar swaps, each financier can promise to deliver a maximum $Q$ dollars tomorrow. Instead, when dollar swaps are available, I assume the financier can promise an additional $Q^s$ dollars tomorrow, which it draws from the swap facility. Financiers will choose to do so as long as the currency-adjusted interest rate differential is greater than the participation cost and the cost of taking up dollar-swaps. Specifically, when dollar swap lines are available, a financier indexed by $k$ faces the following maximization:

$$\max_{\mathcal{q}_t(k) \in \{-Q, Q\}, \mathcal{q}^s_t(k) \in \{-Q^s, 0\}} \left\{ \left( R_t - R^*_t \mathbb{E}_t \left[ \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] \right) \left( q_t(k) + q^s_t(k) \right) - \tau^s q^s_t(k) - k \right\}$$

where $q^s_t(k)$ reflects the financier’s position in dollars, backed by dollar swaps. The cost of drawing $q^s_t(k)$ from the dollar swap line is $q^s_t(k) \tau^s$. Financiers’ enter with a position $Q + Q^s$ as long as,

$$\left( R_t - R^*_t \mathbb{E}_t \left[ \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] \right) (Q + Q^s) - \tau^s (Q + Q^s) \frac{Q^s}{(Q + Q^s)} \geq k$$

(4.18)

In equilibrium, redefining $\Gamma = \frac{1}{Q + Q^s}^2$.

$$\left( R_t - R^*_t \mathbb{E}_t \left[ \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] \right) - \tau^s \frac{Q^s}{(Q + Q^s)} = \Gamma Q_t$$

(4.19)

The next lemma summarises the effect of dollar swaps on the equilibrium UIP deviations.

**Lemma 1 (Dollar Swaps)**

If $\tau^s = 0$ (no spread on dollar swaps), then, the model is isomorphic to the baseline with UIP deviations given by (4.15), except the semi-elasticity of demand is now given by:

$$\Gamma_t = \left( \frac{1}{Q + Q^s} \right)^2 < \left( \frac{1}{Q} \right)^2$$

Total up-take of dollar swaps in the model is given by:

$$k_t Q^s = -Q_t \frac{Q^s}{Q + Q^s} \geq 0$$

(4.20)

\footnote{Note that a period in the model corresponds to a quarter, whereas dollar swaps are usually completed within a week. Therefore, I assume financial intermediaries are exposed to the entirety of the currency fluctuation even when they engage in swap line operations.}
When dollar swaps are extended, fewer, more specialized financiers are able to take larger positions and satisfy the demand for dollar debt. This has a number of implications. First, the aggregate cost of intermediating dollar shortages is lower, resulting in a narrower equilibrium spread.22 Lemma 1 details that dollar swap lines lower $\Gamma_t$, as illustrated in Figure 4.2 (right panel). A key contribution of this paper is to show that the hegemon planner faces a meaningful trade-off when deciding whether or not to extend dollar swap lines, which does not rely on the spread $\tau^*$. Therefore I consider the limit as $\tau^* \to 0$.23 Second, equation (4.20) maps directly to the data on dollar swap up-take in Figure C.5 (Appendix A). Through the lens of the model, the up-take of dollar swaps is proportional to the size of dollar shortages with coefficient $\frac{Q_s}{Q_s + Q^*}$. Finally, since dollars are easier to come by, financiers’ profits captured by the green triangle are lower when swaps are available.

### 4.2.5 Equilibrium

In this chapter, I make two assumptions for simplicity and to derive sharp results. First, the hegemon is modelled as a small open economy (SOE) which takes $P_{F}^*$, the price of foreign goods, and $R^*$ as given, but is large in dollar markets. Therefore, the hegemon affects its interest rate only by manipulating excess exchange rate premia.24 Second, I specialize preferences to the case of unitary elasticity of substitution, unitary macro elasticity $\sigma = \theta = 1$.25 Following the tradition in public finance, building on Lucas and Stokey (1983), I summarise the equilibrium using a small number of equations.

**Lemma 2 (Implementability)**

Given $\{\xi_t\}$, a household allocation $\{C_{H,t}, C_{F,t}, x_t, L_t, a_t^F\}$ and a swap policy $\{Q_t^s\}$ with prices $\{E_t, R_t, W_t, P_{H,t}, P_{F,t}\}$, taking $\{C_t^*, R_t^*, P_{F,t}^*\}$ as given, constitute part of equilibrium if and only if conditions (4.5), (4.7), (4.8), (4.9), and (4.19) hold.

Substituting the expressions for $C_{H,t}^*$ and $\Pi_t$ into (C.48), using (4.9) and (4.19) yields the

---

22The literature has emphasized that subsidizing entry of financial intermediaries can effectively remove the financial constraint, see e.g. Kiyotaki and Moore (1997), Gabaix and Maggiori (2015) and He and Krishnamurthy (2013). Here, dollar swaps reduce the measure of participating intermediaries. However, more efficient intermediaries are able to intermediate larger positions, thus relaxing the financial constraint.

23The model can be generalised to the case where the FED earns a positive spread $\tau^* > 0$. In this case, an individual financier can choose to take position $Q$ or $Q + Q^*$. In the limit where all financiers take a position $Q + Q^*$ and dollar swap lines are large $\frac{\tau^*}{Q + Q^*} \to 1$, the semi-elasticity of demand is $\Gamma_t = \frac{1}{Q + Q^*}$, the relevant spread is $\left(R_t - R_t^* E_t \left[ \frac{\xi_{t+1}}{\xi_t} \right] \right) - \tau^*$ and the hegemon earns $\tau^* Q^k$ rents from extending the dollar swap.

24Generally, there are three channels through which the home country can manipulate its interest rate $R_t$: its size in financial markets, its size in goods markets and as a result of dominant currency pricing. This paper focuses on the first, rules out the second by assuming the hegemon is a small in goods markets and rules out the third channel. For a recent analysis of (goods market) terms of trade manipulation see Costinot, Lorenzoni, and Werning (2014), and Lloyd and Marin (2020) for an extension with trade taxes. Egorov and Mukhin (2021) show the U.S. can manipulate foreign prices and the foreign SDF, even if it is a SOE, under DCP and Corsetti, Dedola, and Leduc (2020) investigate optimal policy in large open economy with DCP.

25Appendix C.5 studies the case of $\theta, \sigma = 1$. 

72
Additionally, (4.22) can also be rewritten as:

\[
C_{F,t} \leq \mathcal{E}_{t}^{-\lambda} \left\{ \xi_{t}^{\eta} \mathcal{P}_{H}^{1-\eta} + \frac{(x_{t} - a_{t}^{F})}{\mathcal{E}_{t}} \right\} - R_{t}^{*} \frac{\mathcal{E}_{t-1}[\xi_{t}]}{\mathcal{E}_{t-1}}(x_{t-1} - a_{t-1}^{F})
\]

\[\left\{ \begin{array}{l}
\text{net foreign liabilities} \\
\text{(a) Monopoly rents} \\
\text{(b) Valuation effects} \\
\text{(c) Financiers' profits (+ve)}
\end{array} \right. \]

\[(4.23)\]

The first term on the right-hand side reflects total revenues earned from the export of goods. The next two terms reflect the return on the net external position for the U.S. which is financed at cost \(R_{t-1}\). If there are no dollar shortages (or dollar liquidity is abundant \(\Gamma \to \infty\)), and no unexpected movements in the supply or demand for dollars, then \(Q_{t} = 0\) and \(\mathbb{E}_{t-1}[\xi_{t}] = \mathcal{E}_{t}\) so the terms (a), (b) and (c) are zero. The model then coincides with a canonical SOE where dollar and foreign currency debt are interchangeable. Instead, consider the case of an unexpected increase in the demand for dollars by foreigners \(\xi_{t} - \mathbb{E}[\xi_{t}] > 0\). Then \(Q_{t} < 0\) and term (a) captures the positive rents from issuing dollar assets and investing them in foreign currency assets. Notice that at time \(t\), monopoly rents are 0 but are positive from \(t + 1\) onwards since \(Q_{t+h} < 0\) for some \(h\). Term (b) captures the valuation effects discussed in Gourinchas, Rey, and Govillot (2018). The contemporaneous appreciation of the dollar at time \(t\) lowers the return in dollar terms on foreign assets purchased at \(t - 1\) and, since this was unexpected, it is not reflected in \(\mathcal{E}_{t-1}\) or \(R_{t-1}\).\(^{27}\)

Consider also the outcomes of foreign investors taking the position \(\xi_{t}\). Their portfolio return is given by:

\[
\Pi_{t}^{F} = \xi_{t} \left( R_{t} - R_{t}^{*} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_{t}} \right)
\]

(4.24)

This is the opposite position to financial intermediaries and the return is negative whenever \(Q_{t} < 0\). Foreign investors can also be rebated a share financiers’ profits \(\Pi_{t}^{F}\), but this would not significantly alter my results.

**Rents, the Transfer Problem and Monetary Policy.** The transfer of wealth leads to a contemporaneous dollar appreciation which can lead to trade-offs. At the crux of this trade-off is a version of the transfer problem, first debated in Keynes (1929) and Ohlin (1929).\(^{28}\) Monetary

\(^{26}\)From (4.15), we can derive total profits accruing to the financial intermediation sector,

\[
\Pi_{t}^{F} = \left( \mathbb{E}_{t-1} \left[ \frac{\xi_{t}}{\mathcal{E}_{t-1}} \right] R_{t}^{*} - R_{t} \right) Q_{t-1} = \Gamma_{t-1} R_{t-1}^{*} Q_{t-1}^{2} \geq 0
\]

(4.21)

Additionally, (4.22) can also be rewritten as:

\[
C_{F,t} \leq \mathcal{E}_{t}^{-\lambda} \left\{ \xi_{t}^{\eta} \mathcal{P}_{H}^{1-\eta} + (x_{t} - a_{t}^{F}) - R_{t-1}(x_{t-1} - a_{t-1}^{F}) \Gamma_{t-1} Q_{t-1} a_{t-1}^{F} + R_{t}^{*} \frac{\mathcal{E}_{t-1}[\xi_{t}]}{\mathcal{E}_{t-1}} a_{t-1}^{F} \right\}
\]

(4.22)

showing that monopoly rents are non-zero even if \(R\) is held constant.

\(^{27}\)The losses due to the initial appreciation last only one period because all debt is short-term. The introduction of long maturity debt has important implications for the quantification of monopoly rents and valuation effects, and I leave this to future work.

\(^{28}\)Keynes argued that war reparations paid by Germany to France would impose further costs to the German economy in the form of adverse terms of trade movements, which Ohlin suggested would not materialise if the French spent the reparations on German goods. Relative to the initial debate, as well as the price movements, associated with a transfer, I emphasize the macroeconomic externalities which result from them.
policy in the hegemon has to balance the costs from the dollar appreciation at the onset of the crisis, with the wealth transfer which follows. Note that the hegemon earns rents even if monetary policy keeps interest rates relatively constant, consistent with the relatively narrow interest rate differentials documented in Fig. C.1, but also if interest rates adjust to offset the initial appreciation.\footnote{Monetary policy can determine the magnitude of the rents to the extent that an interest rate movement affects the total supply of dollar debt, away from the \( \sigma = \theta = \zeta = 1 \) limit, akin to a Bernanke and Blinder (1992) credit channel, or the insurance channel in Caballero and Krishnamurthy (2004), Wang (2019). See Appendix C.5.}

### 4.3 Analytical Hegemon’s Dilemma

In this section, I illustrate the trade-off between maximizing monopoly rents and moderating the demand effects of a dollar appreciation, statically, for a given monetary policy stance. I describe how debt issuance and dollar swaps affect equilibrium outcomes.

**Setup.** Consider a two-period version \( t = \{1, 2\} \) of the model described in Section 4.2. At \( t = 0 \), I normalize dollar supply, demand and imbalances to zero \( (x_0 = \xi_0 = Q_0 = 0) \) and I assume inverse dollar liquidity is given by \( \Gamma_0 = \overline{Q}^{-2} \) (dollar swaps are not used). In the final period \( t = 2 \), I assume there is no issuance of new households debt in period 2 \( (x_2 = 0) \) and monetary policy credibly commits to a long-run exchange rate \( \varepsilon_2 = \overline{\varepsilon} \) such that \( \tau_2 = \tau_0 = 0 \). To capture the idea of an increase in the demand for dollars from abroad I assume foreigners’ demand for dollar debt rises to \( \xi_1 = 1 \) at \( t = 1 \).

Monetary policy plays a key role in the mode of transmission of dollar shortages to hegemon allocations. To capture this in a tractable manner, I define the monetary instrument \( \mu_t = \varepsilon_t C_{F,t} + \overline{P}_{H} C_{H,t} \), such that \( R_1 = \beta \frac{\mu}{\mu_t} \). An increase in \( \mu_1 \) implies a fall in interest rates.\footnote{As in, e.g., Corsetti and Pesenti (2001), the quantity \( \mu_t \) is the return on a perpetual bond. This follows from iterating the Euler equation forward and using the identify for \( \mu_t \).}

For simplicity, I further assume \( \beta = \beta^* = 1 \). Rearranging (4.15) and substituting in \( R_1 \), the expression for the exchange rate at time \( t = 1 \) is given by:

\[
\varepsilon_1 = \overline{\varepsilon} \left( \frac{\overline{\mu}}{\mu_1} - \Gamma_1 Q_1 \right)^{-1}
\]  

(4.25)

I specify a monetary policy rule parametrized by a single responsiveness parameter \( s \): (i) if \( s = 0 \), monetary policy maintains a constant \( R_1 \) and the adjustment happens through a dollar appreciation (ii) if \( s > 0 \), the monetary policy response to shortages is expansionary \( (R_1 \downarrow) \) and, in the limit \( (s = 1) \), targets an exchange rate \( \overline{\varepsilon} \). The monetary policy rule is given by:

\[
\frac{\mu_1}{\overline{\mu}} = (1 - s) + s(1 + \Gamma_1 Q_1)^{-1}
\]

(4.26)

**Stabilization and Monopolist Incentives.** Define the period-1 labour wedge \( \tau_1 \) as,

\[
\tau_1 = 1 - \frac{1}{A_1} \kappa \frac{C_{H,1} L_1^\psi}{C_{H,1}^* L_1^\psi},
\]

(4.27)

where \( L_1 = C_{H,1} + C_{H,1}^* \). The labour wedge is frequently considered in the literature as a measure of the output gap, see e.g. Chari, Kehoe, and McGrattan (2007) and Farhi and Werning (2016).
The labour wedge is equal to zero if prices are flexible such that (4.6) holds, but is generally non-zero if prices are rigid. I define periods where \( \tau_t > 0 \) to be periods of recession, since there is involuntary unemployment in the economy and conversely periods where \( \tau_t < 0 \) as boom periods—more specifically, periods when households are over-working relative to the flex-price allocations. Dollar shortages transmit to the labour wedge through two channels. First, the dollar appreciation reduces demand for exports leading to a fall in employment (\( L_1 \downarrow \)). Second, the monetary policy responds by cutting interest rates (\( \mu_1 \uparrow \)) according to the parameter \( s > 0 \) which stimulates domestic consumption (\( C_{H,1} \uparrow \)).

Next, I define \( \Omega_2 \) as the return on a portfolio \( x_1 \) of dollar borrowing, invested in foreign assets and adjusted for the hegemon’s share of intermediaries’ profits. For simplicity, I assume the hegemon forms an arbitrage portfolio in period 1 (\( x_1 = a_1^F \)), earning \( R_1 - R^* \frac{\bar{P}}{\bar{Q}_1} \) in period 2.\(^{31}\) The portfolio return for the hegemon is given by:

\[
\Omega_2 = -\Gamma_1 Q_1 x_1 + \omega \Gamma_1 Q_1^2 \tag{4.28}
\]

I posit that the hegemon planner optimally chooses private debt issuance (\( x_1 \)) in period \( t = 1 \), via an implicit macro-prudential tax, and the level of dollar liquidity \( \Gamma_1 = \frac{1}{Q + Q_1^2} \), via issuance of dollar swaps \( Q_1^s \), to maximize a convex combination over two incentives: employment stabilization and maximization of monopoly rents:\(^{32}\)

\[
\max \{ w^S |\tau_1(x_1, \Gamma_1; \xi_1) - \tau| + (1 - w^S) \Omega_2^M(x_1, \Gamma_1; \xi_1) \} \tag{HD1}
\]

I make explicit the dependence of the period 1 labour wedge and monopoly rents (earned in period 2) on the supply of dollar assets \( x_1 \), (inverse) dollar liquidity \( \Gamma_1 \) and dollar demand \( \xi_1 \). The parameter \( w^S \) captures the preference for stabilization. The optimal allocation is summarised by the first-order conditions for (HD1) with respect to \( x_1 \) and \( \Gamma_1 \) (if the positivity constraint does not bind) and are presented in Appendix C.2.

**Proposition 1 (Analytical Hegemon’s Dilemma)**

(i) A rise in dollar shortages (\( Q_1 < 0 \)) increases monopoly rents (\( \Omega_2 > 0 \)) and widens the labour wedge (\( |\tau_1 - \tau| > 0 \)) as long as \( s \neq \bar{s} \).

(ii) Consider the limit \( w^S = 1 \) (stabilization strategy). The hegemon supplies dollar assets to satisfy demand (\( x_1 = \xi_1 \)) or extends dollar swaps such that \( \Gamma_1 \to 0 \) to perfectly stabilize employment. Instead, if \( w^S = 0 \) (monopolist strategy), the hegemon chooses \( x_1 \) at the top of a ‘returns Laffer’ curve and dollar swaps are not used \( \Gamma_1 = \bar{Q}^{-2} \).

**Proof.** See Appendix C.2.

A surge in capital inflows results in a widening of the labour wedge unless \( s = \bar{s} \), in which case \( R_1 \) moves to exactly offset the effect of \( dQ_1 \) on \( \tau_1 \). Proposition 1 isolates two key channels which drive the hegemon policy response—macroeconomic stabilization and monopoly (financial) rent

\(^{31}\)This assumption imposes that hegemon net foreign assets are zero in every period, further emphasizing the importance of gross flows.

\(^{32}\)This modelling choice is made for clarity and I make no claim that it maps to welfare optimization. Specifically, there is a welfare maximizing level for \( w^* \) and \( s \), but I take these values as given. Nonetheless, when I solve for the welfare maximizing allocation in Section 4.4, I show that stabilization of the labour wedge is approximately attained in the constrained optimal allocation.
Suppose the hegemon is only concerned with closing the labour wedge gap \( w^S = 1 \), i.e a ‘stabilization’ strategy. Then, following a rise in dollar demand \( \xi_1 > 0 \), the planner can either choose debt issuance \( x_1 \) such that for any level of dollar demand \( \xi_1 \), dollar shortages are zero \( Q_1 = 0 \) or extend dollar swaps such that \( \Gamma_1 \rightarrow 0 \) and shortages do not imply any movement in the exchange rate. However, this strategy comes at the cost of a lower price for dollar debt.

Suppose instead that \( w^S = 0 \), corresponding to a ‘monopolist’ strategy. In this case, the hegemon chooses debt \( x_1 \) at the top of a Laffer curve for portfolio returns, detailed in Appendix C.2 and targets a level of dollar shortages \( Q_1 < 0 \). Since monopoly rents are strictly decreasing in dollar liquidity \( \Gamma_1 \), dollar swaps are not used. Figure 4.3 illustrates the locus of \( x_1, \Gamma_1 \) which maximize the hegemon’s objective function in each of the two corner cases. For intermediate values of \( w^S \), the hegemon compromises between the two strategies and the Laffer curve shifts to higher levels of \( x_1 \). In Appendix C.2, I pursue two extensions within this stylized framework. I analyse the implications of an appreciation on the returns to a portfolio formed at \( t = 0 \) (valuation effects) and I look at how the results change when there are competing issuers of dollar assets (or other reserve currencies).

### 4.4 Optimal Policy

In this section, I identify the macroeconomic externalities which arise in the dynamic model, especially due to dollar shortages abroad, and analyse how they impinge on the efficiency of monetary policy. To do so, I first derive the constrained efficient allocation, attained when the hegemon is able to set monetary and macroprudential policy optimally. Macroprudential policy takes the form of a time-varying tax on private borrowing.\(^{33}\) The hegemon planner chooses allocations and prices to maximize domestic household welfare only, subject to the equilibrium conditions detailed in Lemma 2. I assume the planner is endowed with perfect commitment and I restrict the analysis to one-off unanticipated shocks as in Farhi and Werning (2014) and

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\(^{33}\)I distinguish between capital controls and a macroprudential borrowing tax, by assuming that the former would enter as a wedge in the UIP equation. Therefore, capital controls in the model would correspond to a tax on financiers.
others. The planning problem for the hegemon can be summarised as follows:\footnote{The full derivation of both the indirect utility function and the implementation constraints is presented in Appendix C.3. In the main body, I maintain \( \sigma = \theta = 1, \zeta > 1 \) and relegate the generalization to Section C.5.}

\[
\max_{\{C_{F,t},x_t,\xi_t\}_{t \geq 0}} \sum_{t=0}^{\infty} \beta^t V(C_{F,t}, \xi_t) \tag{HD2}
\]

s.t. \((4.22)\),

where I attach multiplier \( \eta_C \) to the implementability condition \((4.22)\). The indirect utility function \( V(C_{F,t}, \xi_t) \) is given by,

\[
V(C_{F,t}, \xi_t) = \chi \log \left( \frac{\chi}{1-\chi} \frac{\xi_t}{\tau_H} C_{F,t} \right) + (1-\chi) \log(C_{F,t}) - \frac{1}{1+\psi} \left( \frac{1}{1-\chi} \left[ \frac{\chi}{1-\chi} \frac{\xi_t}{\tau_H} C_{F,t} + \xi_t \frac{\eta}{\tau_H} \right] \right)^{1+\psi} \tag{4.29}
\]

I assume that the planning problem is convex in the region of interest such that the first-order conditions characterise the equilibrium allocation. I characterize the planner’s allocation as a function of partial derivatives of the indirect utility with respect to \( C_{F,t} \) and \( \xi_t \), denoted by \( V_{C_{F,t}}, V_{\xi_t} \), respectively, and wedges. Key to my analysis is the case where the planner does not have access to the optimal borrowing tax and therefore cannot optimally choose \( \{x_t\} \). Then, the planner also faces households’ Euler \((4.5)\) as a constraint, to which I attach multiplier \( \eta^E \).

I begin by defining a measure of over-borrowing by private households in the economy. By analogy to the labour wedge \( \tau_t \), defined in \((4.27)\), I define the financing (issuance) wedge \( \tau_{\Omega} \):

\[
\tau_{\Omega} = \frac{R_t + \Gamma_t x_t - 2 \omega \Gamma_t Q_t}{R_t} - 1, \tag{4.30}
\]

where the numerator reflects the social cost of issuing an additional unit of dollar debt (i.e the cost faced by the country as a whole) and the denominator reflects the private (individual) cost faced by households. The wedge is positive as long as hegemon (gross) borrowing in dollars is positive \((x_t > 0)\), which is the case when the foreign sector demands dollar debt \((\xi_t > 0)\). The wedge is also increasing in the share of financiers’ profits accruing to the hegemon \((\omega)\), since dollar shortages lead to intermediation profits.

**Proposition 2 (Over-borrowing by private agents)**

*Hegemon households over-borrow in dollar debt as long as:*

\[
1 + \frac{\chi}{1-\chi} \tau_{t+1} (1 + \tau_{\Omega}^t) > 1, \tag{4.31}
\]

*and under-issue otherwise.*

**Proof.** Combine the first order condition (FOC) for the planner with respect to \( x_t \), which characterizes the socially optimal level of private borrowing, with the FOC with respect to \( C_{F,t} \) and the expression for \( V_{C_{F,t}} \), detailed in Appendix C.3. Then, derive the optimal tax \( \tau_t^x \) on private borrowing by comparing the planners’ optimality condition with the Euler equation \((4.5)\), which dictates the privately optimal level of borrowing. Households over-borrow if the optimal borrowing tax is positive \((\tau_t^x < 0)\). \( \square \)
The efficient level of borrowing by hegemon households is determined by the interaction of two key frictions in the model—segmented international financial markets leading to dollar scarcity and nominal rigidities. Financial market segmentation is particularly important because it exposes the hegemon economy (and optimal policy) to fluctuations in the supply and demand of dollar assets abroad. Consider first the case where prices are flexible or monetary policy finds it optimal to target the flexible allocation, such that the labour wedge is zero \( (\tau_t = \tau_{t+1} = 0) \). In this case, over-borrowing still arises because households do not act as monopolists in the market for dollars. Next, suppose that prices are rigid and the monetary authority responds to dollar shortages by lowering the interest rate sufficiently, such that \( \tau_t \leq \tau_{t+1} \). Then, in addition to the issuance externality, private households fail to internalize that the social value of a unit of consumption \( C_{F,t} \) tomorrow is higher due to its effects on employment. So monetary policy can affect the efficient level of borrowing even if \( \sigma = \theta = \zeta = 1 \) and \( x_t \) does not respond, through the labour wedge. Notice that the two externalities which underlie the over-borrowing are dynamic versions of the incentives detailed in (HD1). The following corollary details the borrowing tax required at the constrained efficient allocation.

**Corollary (Optimal tax on borrowing)**

The optimal ex-post borrowing tax is given by:

\[
1 - \tau_t^p = \frac{1 + \frac{1}{1 - \chi} \tau_{t+1}}{1 + \frac{1}{1 - \chi} \tau_t} (1 + \tau_t^\Omega), \tag{4.32}
\]

where \( \tau_t^p < 0 \) denotes a tax on borrowing.

Over-borrowing matters because it compromises the ability of other policy instruments to achieve their objectives. To quantify the effects of over-borrowing, I consider the multiplier on the Euler equation denoted by \( \eta_E \), which is positive whenever households are over-borrowing, i.e \( (4.31) \) is satisfied. Taking the first-order condition of (HD2), with respect to \( x_t \), with the Euler \( (4.5) \) attached as constraint and rearranging,

\[
\eta_E = \left\{ \Gamma_t \frac{1 - g \tau_{t+1}}{1 - \eta C_{F,t+1}} \right\}^{-1} \left\{ \beta \eta_{t+1} C_{t+1} - R_t + \Gamma_t x_t - \frac{2}{\chi} \Gamma Q_t \right\} - \eta C_{t+1} C_t = \eta E - \eta C_{t+1} C_t \tag{4.33}
\]

First, households over-borrow when the cost of borrowing faced by the country as a whole (the term in square brackets) is higher than that faced by an atomistic household \( R_t \), captured by \( \tau_t^\Omega > 0 \). Second, households over-borrow when when the social value of a unit of consumption tomorrow \( \eta_{t+1} C_{t+1} \) is high relative to its private value, as is the case when the labour wedge tomorrow is relatively high.

\[35\]As derived in Appendix C.3, when monetary policy is optimally set,

\[
\eta C_{t+1} = V_{C_{F,t}} = u_{C_{F,t}} (1 + \frac{1}{1 - \chi}) \tau_t, \tag{4.34}
\]

where \( V_{C_{F,t}} \) is the social value of a unit of consumption and \( u_{C_{F,t}} \) is the marginal value. If monetary policy is constrained or unresponsive, then \( \eta C_{t+1} = V_{C_{F,t}} = \eta_C \) which may exacerbate over-borrowing, as detailed in Section 4.4.2.
4.4.1 Monetary policy

In open economies, monetary policy faces a well-understood trade-off between macroeconomic stabilisation and risk-sharing incentives. With flexible exchange rates monetary policy can target the flexible price allocation ($\tau_t = 0$). Generally, however, when markets are incomplete, monetary policy does not target $\tau_t = 0$. I assume monetary policy chooses the exchange rate $E_t$. Combining the FOCs with respect to $E_t$ and $C_{F,t}$ yields a targeting rule for monetary policy,

$$V_{E_t} + X_{E_t}(\eta_t^C) + F_{E_t}(\eta_t^C, \eta_{t+1}^C) + R_{E_t}(\eta_t^E, \eta_{t-1}^E) = 0 \quad (4.35)$$

where $X_{E_t}$ denotes the effect of a depreciation on the foreign demand for exports, $F_{E_t}$ denotes the effect of a depreciation on households’ returns on their financial position and $R_{E_t}$ is the derivative of the implicit formulation of the Euler equation (4.5). Each term depends is detailed in Appendix C.3.

When macro-prudential policy is available ($R_{E_t} = 0$), monetary policy faces familiar trade-offs. The partial derivative $V_{E_t}$ captures the direct effects of a depreciation on households’ utility. This balances the positive effect of an increase in consumption of home goods as they become relatively cheaper and the negative effect that households must work relatively more to afford the same amount of imports. The term $X_{E_t}$ reflects the incentive to depreciate in order to increase export revenues in terms of imports. Together these channels capture the (goods) terms of trade motive of monetary policy. The risk-sharing motive of monetary policy, summarised in $F_{E_t}$, depends on the level of issuance $\{x_t\}$, the level of foreign asset holdings $\{a_F^t\}$ and the level of dollar demand $\{\xi_t\}$. If pass-through to import prices is non-zero ($\lambda > 0$), monetary policy has an incentive to depreciate debt coming due, captured by $F_{E_t}$. Monetary policy also balances the effects of an appreciation on the returns to the hegemon carry trade portfolio.\(^{36}\)

Absent macro-prudential policy ($R_{E_t} \neq 0$), monetary policy no longer efficiently balances the terms-of-trade and risk-sharing incentives and cannot attain the constrained efficient allocation when there are dollar shortages. Consider the case where $\lambda = 1$ (PCP) and the hegemon holds no foreign assets.\(^{37}\) If $\xi_t > 0$, implying a positive issuance externality ($\tau_t^\Omega > 0$), monetary policy will generally be more contractionary. By appreciating the exchange rate and widening the labour wedge ($\tau_t > \tau_{t+1}$), monetary policy can partly offset the inefficient boom caused by households over-borrowing (Proposition 1). This contractionary motive for monetary policy is active even if $\sigma = \theta = \zeta = 1$.\(^{38}\) Relative to the constrained efficient allocation, in the equilibrium with monetary policy alone, the dollar is excessively appreciated, output is still excessively volatile, and there is over-borrowing in equilibrium.

This finding can also be interpreted in terms of the classical Mundellian Trilemma. Using (4.35), I tightly define hegemon monetary policy to be independent when it can achieve the constrained efficient allocation, independent of the level of dollar shortages abroad. Due to

\(^{36}\)Following an increase in $\xi_t$, monetary policy wants to fight the initial appreciation to offset the losses accruing on the U.S. portfolio, but on the other hand, an appreciation increases the amount of imports monopoly rents can buy (if $\lambda > 0$).

\(^{37}\)Allowing for $\lambda < 1$ (DCP) and foreign asset holdings $a_F^t > 0$, monetary policy affects over-borrowing via additional wealth effects acting on the hegemon’s portfolio, see Wang (2019), and relatedly in Itskhoki and Mukhin (2022).

\(^{38}\)Bianchi and Coulibaly (2021) study the scope for monetary policy to address borrowing inefficiencies for different paraterizations of $\sigma$ and $\theta$. If $\sigma < \theta = \eta$, contractionary monetary policy leads to a fall in households borrowing. I detail the effect of monetary policy on over-borrowing for general $\sigma$ in Appendix C.5.
market segmentation, how close the equilibrium with monetary policy is to the constrained efficient equilibrium depends on foreign dollar balances. In other words, U.S. monetary policy is compromised by capital flows driven by dollar demand. This complements the findings of Rey (2015) who shows that a dollar-led global financial cycle compromises monetary policy independence in the rest of the world.39

4.4.2 Dollar Swaps

I now endow the hegemon with the ability to extend dollar swap lines $Q^s > 0$ to financial intermediaries, easing portfolio constraints and increasing dollar liquidity in international markets $(\Gamma = (Q + Q^s)^{-2} \leq Q^{-2})$. I show that dollar swap lines stabilize the economy at the cost of eroding monopoly rents.40 To illustrate the mechanisms driving the choice to extend dollar swaps, I assume the hegemon can indirectly choose the level of liquidity period by period and I consider the first order condition of (HD2) with respect to $\Gamma_t$:

$$-\eta_{t+1}^{ \varepsilon^L \lambda} \{Q_t x_t + \omega Q_t^2\} = - \eta_{t}^{ \varepsilon^L \lambda} \frac{1}{\varepsilon_{t+1}^L C_{t+1}} Q_t$$

The left hand side of (4.36) represents the marginal cost of increasing liquidity by one unit. Suppose there are dollar shortages ($Q_t < 0$). Increasing dollar liquidity erodes monopoly rents from issuance of dollar debt by households, since intermediaries can now issue dollars at a lower cost. The right hand side of (4.36) captures the marginal (social) benefit of increasing liquidity by one unit which relies on the over-borrowing externality. Dollar swaps affect the interest rate and therefore the allocation of private sector borrowing over time. Increasing liquidity by one unit raises the cost of borrowing through a lower exchange rate premium, lowering over-borrowing ($\eta_{t}^{E} \downarrow$). Instead, if the optimal borrowing tax were available, private borrowing would be at an optimal and $\eta_{t}^{E} = 0$. In that case, the net marginal benefit of issuing dollar swaps in the model is negative and the constraint $Q^s \geq 0$ binds.

**Proposition 3 (Dollar Swaps)**

*Faced with dollar shortages, dollar swaps address over-borrowing at the cost of lower monopoly rents from issuance. Dollar swaps are not used if an optimal borrowing tax is available.*

While dollar swaps are an imperfect substitute to macro-prudential taxation for addressing internal objectives in the hegemon, the two policies lead to very different outcomes internationally. On the one hand, the optimal borrowing tax restricts private sector issuance resulting in larger dollar shortages and worse portfolio returns for foreign investors. On the other hand, the provision of dollar swaps narrows the spread in borrowing costs for any level of shortages,
improving outcomes for foreign investors. Since dollar swaps can be Pareto improving globally, this may explain why dollar swaps were preferred to macroprudential policy, which would instead restrict the international supply of dollar assets, during recent crises.

**Lemma 3 (Dollar Swaps vs. Macroprudential Tax)**

Both dollar swaps and macroprudential policy can improve outcomes for the hegemon if $\eta_t^E > 0$. Macroprudential policy leads to worse outcomes for foreign investors, given by $\Pi_t^F$, if (4.31) is satisfied, whereas dollar swaps improve $\Pi_t^F$.

**Unresponsive monetary policy** In addition to assuming that a macro-prudential tax is not available, I now analyze the case where monetary policy is unresponsive:

$$R_t = R$$

Specifically, I define

$$\xi_t^\lambda C_{F,t} = \mu_t (1 - \chi),$$

where $\mu_t$ is a synthetic monetary instrument and $R_t = \beta^{\mu_t+1}/\mu_t$. When $\mu_t$ grows at a constant rate, this ensures nominal interest rates $R_t$ are constant in the absence of macro-prudential policy. For simplicity, I consider the case $\mu_t = \mu$ and attach the multiplier $\eta_t^\mu$ to the monetary policy constraint (4.37). Intuitively, when interest rates don’t adjust, each additional unit of $C_{F,t}$ is also associated with a dollar appreciation which further depresses domestic demand for $H-$ type goods. This pushes down the value of a unit of consumption today and the cost of over-borrowing will tend to rise.

In Section 4.5.3, I detail three extensions of the model which highlight the scope for dollar swaps to improve U.S. welfare. First, I consider an extension of the model with firesale of assets by foreign investors. Then, hegemon households earn lower returns on their holdings of foreign assets when there are dollar shortages abroad. In this case, I show that dollar swaps can be desirable, even if the macroprudential tax is chosen optimally. Secondly, I show that faced with productivity shock ($A_t$), dollar swaps help recover monetary policy independence but cannot themselves offset the effects of the shock. Instead, in the case of a shock to dollar demand $\xi_t$, dollar swaps are able to directly address the shock and achieve stabilisation regardless of monetary policy. Third, I discuss whether public debt issuance can be used to support the monopolistic allocation.

---

41Over the past decade, interest rates have hovered around the zero lower bound (ZLB) and are largely unresponsive to shocks. The analysis in this section coincides with imposing a zero lower bound in the limit $\beta \to 1$. I present the first order conditions associated with this problem in Appendix C.3

42Note that this is true even if the level of over-borrowing, as measured by the required tax (see Corollary 1), falls because $\tau_t > \tau_{t+1}$. 

81
4.4.3 Limited Financial Market Participation

I extend the model to allow for limited financial market participation and I show that dollar shortages in international markets have distributional consequences for households in the hegemon. I consider two types of households. Financially-active households trade in a domestic currency, non-contingent bond with financial intermediaries. I denote active household quantities by an $A$ superscript and the measure of financially active households is exogenously given by $a_t$. Financially inactive households, have allocations denoted by an $NA$ superscript, and consume their wages and profits in every period. I make the following assumptions.

Assumption (Limited Financial Market Participation)

(i.) Labour is rationed equally when the economy is demand constrained: $L_t^A = L_t^{NA}$.

(ii.) Profits from goods’ firms $\Pi^g_t$ accrue equally amongst all households.

(iii.) Profits from ownership of financial firms $\Pi^f_t$ accrue exclusively to active households.

A full exposition of the model is delegated to Appendix C.4. Here, I detail two key features of the model. First, financially active households trade in complete markets domestically and price traded assets:

$$\frac{1}{E_t^{A\lambda}C_{F,t}^A} = \beta R_t \frac{1}{E_{t+1}^{A\lambda}C_{F,t+1}^A},$$

(4.38)

Therefore, only active household allocations appear in the Euler condition. Inactive households consume their wages in each period, and a representative inactive household can be considered because of the absence of idiosyncratic risks. Goods market clearing is given by $Y_{H,t} = a_t C_{H,t}^A + (1 - a_t) C_{H,t}^{NA}$ + $C^*_H$. Second, dollar market clearing now requires:

$$Q_t = \alpha_t x_t - \xi_t$$

(4.39)

The next proposition highlights the distributional implications of dollar shortages abroad for hegemon households.

Proposition 4 (Dollar Shortages and Redistribution)

Consumptions of individual active and inactive households are given by,

$$C_{F,t}^A \leq E_t^{A\lambda} \left[ \zeta P^{1-\eta} x_t + (1 - (1 - a_t) \chi) F_t \right],$$

(4.40)

$$C_{F,t}^{NA} \leq E_t^{A\lambda} \left[ \zeta P^{1-\eta} x_t + a_t \chi F_t \right],$$

(4.41)

In the literature, these households are often referred to as hand-to-mouth, see Aguiar et al. (2015) for an empirical investigation. Alvarez, Atkeson, and Kehoe (2002) and Alvarez, Atkeson, and Kehoe (2009) study models of endogenous financial market segmentation based on fixed costs, analogous to the problems faced by financial intermediaries in Section 3.

82
respectively, where,

\[ F_t = x_t - a_t^F - R^* \frac{E_{t-1}[E_t]}{E_{t-1}} (x_{t-1} - a_{t-1}^F) - \Gamma_{t-1} Q_{t-1} x_{t-1} - R^* \frac{E_{t-1}[E_t]}{E_{t-1}} a_{t-1}^F + \omega_t Q_t^2 \]

In equilibrium, monopoly issuance rents accrue disproportionately to active households if \( \chi < 1 \).

**Proof:** See Appendix C.4

According to the assumptions above, export revenues contribute equally to both active and inactive households’ consumption, but monopoly rents disproportionally accrue to financially-active households as long as \( \chi < 1 \), i.e. active households spend a share of their rents abroad. Active households partly spend monopoly rents on domestic goods, contributing to domestic demand and boosting inactive household consumption but less than one to one. The set-up above resembles a two agent model as in Bilbiie (2020) and Auclert et al. (2021). In these models a spending multiplier arises, equal to \( \frac{1}{1-(1-\alpha)} \), where \( 1-\alpha \) is the measure of hand-to-mouth households. In open economies, financially active households spend a share \( 1-\chi \) income on foreign goods, so the multiplier becomes \( \frac{1}{1-(1-\alpha)\chi} < \frac{1}{1-(1-\alpha)} \). Allowing for redistributive taxes or domestically complete markets (\( a=1 \)), then \( C^{A}_{F,t} = C^{NA}_{F,t} \).

**Optimal policy with limited financial market participation.** I denote the indirect utility function with limited financial market participation by \( V(C^{A}_{F,t}, C^{NA}_{F,t}, E_t; \lambda, a_t) \), where \( \lambda = [\lambda^A, \lambda^{NA}] \) are Pareto weights such that \( a_t \lambda^A + (1- a_t) \lambda^{NA} = 1 \). The planning problem is given by,

\[
\max_{\{C^{A}_{F,t},C^{NA}_{F,t}, E_t, x_t\}} \sum_{t=0}^{\infty} V(C^{A}_{F,t}, C^{NA}_{F,t}, E_t; \lambda, a_t)
\]

s.t. (4.40), (4.41)

where (4.40) and (4.41) are the constraints for active and inactive households respectively. I detail the indirect utility function, the conditions governing the planner’s allocation in Appendix C.4.

In the job market paper version of this chapter, I consider the comparative statics with respect to \( a \). I show that on the one hand, welfare rises with participation since the total size of monopoly rents grows (Proposition 4). On the other hand, a higher \( a \) implies a larger financial externality. Therefore, welfare is rising with \( a \) at the constrained efficient allocation but may be decreasing when macro-prudential policy is not available.

### 4.5 Numerical Exercise

**Calibration.** The calibration is quarterly. I choose \( \beta = \beta^* = 0.99 \) based on an annual natural interest rate of about 4%. I maintain that the CRRA coefficient is \( \sigma = 1 \) and the elasticity of substitution across domestic and imported goods is \( \theta = 1 \), which are not far from literature estimates. Similarly, I set the Frisch elasticity \( \psi \) of substitution to 2.5 and choose \( \kappa \) to target a steady-state labour supply of two-thirds.\(^{44}\) I choose \( \chi = 0.85 \) such that \( C^*_H/Y_H = 0.15, \)

\(^{44}\)See e.g Valchev (2020), Eichenbaum, Johannsen, and Rebelo (2020).
consistent with data from the Bureau of Economic Analysis (BEA) for the U.S and I choose an export demand elasticity $\zeta = 2.5$. I choose $\Gamma = -Q^2 = 0.14$, based on an internal calibration such that a 1% of U.S. GDP change in dollar shortages leads to about a 2% appreciation for the dollar, on impact, holding $R_t$ constant, consistent with evidence of FX dollar swaps vis-a-vis Brazil as identified in Kohlscheen and Andrade (2014). To generate realistic values for monopoly rents in the U.S. economy, I consider a steady state where net foreign assets are zero, but the gross asset and liability position of the U.S. are 100% GDP.\footnote{In the steady state this implies $Q_t = 0$, $\xi_t = a^\xi = \xi$.} A spread of 4% then implies monopoly rents of 0.04$x_t = 4\%$ on impact.

**Dollar demand shock.** I consider a one-off unanticipated shock to dollar demand ($\xi_t$), which follows an AR(1) process with quarterly persistence 0.85, Figure 4.4 (left panel). I choose the size of the dollar demand shock to result in an exchange rate appreciation (on impact) of about 8% if interest rates are held constant, Figure 4.4 (right panel). The implied size of the dollar demand shock is about 7% of U.S. GDP.\footnote{McGuire and Peter (2009) find that European bank’s dollar shortfall (the biggest counterparty for the U.S. in terms of dollar swap lines) at the onset of the GFC was about 1 – 1.2 trillion, or roughly 7-8% of U.S. GDP in 2007, so the size of the dollar shock implied by the model is reasonable.} A spread of 4% then implies monopoly rents of 0.04$x_t = 4\%$ on impact.

![Figure 4.4: Impulse response to dollar demand shock $\xi_t$. Left panel: Dollar demand shock and dollar shortages (% of U.S. GDP). Right panel: Exchange rate appreciation (% deviations from steady state).](image)

**Monetary policy only.** Figure 4.5 contrasts the effects of a dollar demand shock on allocations and prices in the hegemon, and shortages abroad, if interest rates are held constant and if monetary policy is set optimally according to (4.35). In both cases, the demand shock $\xi_t > 0$ leads to an excess demand for dollars ($Q_t < 0$). The middle panel illustrates exchange rate and interest rate movements under the two monetary regimes, expanding on Figure 4.4. The hegemon optimally lowers interest rates such that a smaller dollar appreciation is required to satisfy financiers’ optimality condition (4.15). The right panel illustrates the response of the aggregate labour wedge. When interest rates are held constant, the demand shock leads to a domestic recession ($\tau_t > 0$), driven by a fall in the demand for exported goods and portfolio losses. Instead, if interest rates respond optimally, the hegemon experiences a temporary boom ($\tau_t < 0$), although a recession follows after about 6 quarters.\footnote{Dollar shortages are more prevalent and more persistent when monetary policy is optimally set. This is because households face a smaller recession (or boom) and therefore borrow less in foreign markets since $\eta > 1$.}
Since only a measure $a < 1$ of households in the hegemon participate in financial markets in any given period, dollar shortages have heterogeneous effects on the two groups of households within the hegemon. Inactive households experience involuntary unemployment, but the effect is significantly stronger when interest rates are constant. On the other hand, active households experience involuntary unemployment only if interest rates are held constant, and are overworked otherwise. See Figure C.10 in Appendix C.6.

![Figure 4.5: Impulse response to dollar demand shock $\xi_t$ Comparison of optimal monetary (solid line) policy vs. unresponsive monetary policy (dashed line). Left Panel: Borrowing (deviations from steady state in % GDP). Middle panel: Exchange rate and interest rate movements (% deviations from steady state.) Right panel: Average labour wedge deviations.](image)

**Constrained efficient allocation.** The optimal tax on borrowing is used to postpone consumption to the future, monopolistically restricting the supply of dollars abroad. The left panel in Figure 4.6 shows that total borrowing falls making dollar shortages are larger and more persistent. At the constrained efficient allocation, the interest rate cut is larger (5% vs. 3%), lowering the pressure on the exchange rate to appreciate (middle panel). This difference reflects how much dollar shortages abroad weigh on monetary policy in the absence of a borrowing tax. Monetary and macroprudential policy together are able to almost fully stabilize the aggregate labour wedge. The planner no longer accepts externally induced employment instability and is at the same time able to efficiently maximize the transfer of monopoly rents from abroad.

![Figure 4.6: Impulse response to $\xi > 0$. Comparison of optimal macropru (riveted line) vs. monetary policy alone (solid line). Left Panel: Borrowing (deviations from steady state in % GDP) Middle panel: Exchange rate and interest rate movements (% deviations from steady state). Right panel: Average labour wedge deviations.](image)
4.5.1 Welfare

To assess the welfare implications of a rise in dollar shortages for the hegemon, I denote the present discounted value of welfare for a household \( i \in \{A, NA \} \), following a dollar demand shock \( \{ \xi_t \} > 0 \) when dollar liquidity is \( \Gamma \), by:

\[
W^i(\{\xi_t, \tau^\ast\}; \{\Gamma, \xi_t\})
\]

where I make explicit the dependence of welfare on monetary policy (\( \mathbb{E}_t \)) and macroprudential policy (\( \tau^\ast \)). I next define the Hicksian equivalent variation for consumption,

\[
\sum_{t=0}^{\infty} \beta^t \left[ \frac{C_i^t(1 + \nu_i^t)^{1-\sigma}}{1 - \sigma} - \kappa \frac{L_i^{1+\psi}}{1 + \psi} \right] = W^i(\{\xi_t, \tau^\ast\}; \{\Gamma, 0\}),
\]

where \( \nu_i^t \) is a proportional consumption transfer, calculated over the period of elevated dollar demand, such that household \( i \in \{A, NA \} \) is equally well-off whether or not the dollar demand shock occurs.\(^{48}\) A positive transfer \( \nu_i^t > 0 \) suggests that a one-off unexpected increase in dollar shortages is costly to household \( i \), i.e \( W^i(\{\xi_t, \tau^\ast\}; \{\Gamma, 0\}) > W^i(\{\xi_t, \tau^\ast\}; \{\Gamma, \xi_t\}) \). Table 4.1 details the welfare outcomes from a one-off dollar demand shock for the calibration discussed above.

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Inactive</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unresponsive monetary (no macropru.)</td>
<td>0.25%</td>
<td>0.43%</td>
<td>0.31%</td>
</tr>
<tr>
<td>Optimal monetary (no macropru.)</td>
<td>-0.81%</td>
<td>0.17%</td>
<td>-0.51%</td>
</tr>
<tr>
<td>Constrained Optimal</td>
<td>-2.2%</td>
<td>0.23%</td>
<td>-1.5%</td>
</tr>
</tbody>
</table>

Table 4.1: Hicksian welfare transfers under different policy regimes, in response to a one-off, unanticipated dollar-asset demand shock.

When interest rates do not respond (first row of Table 4.1), dollar shortages cost about 0.31% of consumption equivalent per quarter, in the aggregate, over the 2 year duration of the crisis due to a combination of decreased export demand and valuation effects. These are driven by both losses to financially-active and inactive households, although the latter suffer disproportionately (Proposition 4). Instead if monetary policy responds optimally, which requires an interest rate cut of just under 3%, the aggregate economy gains the equivalent of 0.5% consumption per quarter over the 2 years, but this is only one-third of the gain that could be achieved at the constrained efficient allocation, which additionally requires the optimal tax on borrowing. However, this figure masks welfare losses facing inactive households (0.17%), which are worsened by the use of a borrowing tax.

4.5.2 Revisiting Dollar Swaps.

In practice, dollar swap lines are extended by the FED at a time \( t \), and their take-up in future periods is determined by the demand of foreign central banks. Therefore, the U.S. makes a

\(^{48}\)Such consumption transfers are used Lucas (2003) to evaluate the welfare costs of business cycles. I assume \( \nu_i^t = \nu \) for the first 8 quarters after the shock hits (after which its size becomes negligible) and \( \nu_i^t = 0 \) thereafter.
one-off decision to extend dollar swaps if:

$$\int \lambda^i W^i(\{E_t, \tau^i\}; \{\frac{1}{(1+Q^i)^2}, \xi_t\}) di > \int \lambda^i W^i(\{E_t, \tau^i\}; \{\frac{1}{Q^i}, \xi_t\}) di$$

(4.44)

where $\lambda^i = a^i A$ for $i = A$ and $\lambda^i = (1 - a)\lambda^{NA}$ for $i = NA$.

Dollar demand shocks have muted macroeconomic consequences for the hegemon if dollar liquidity is sufficiently high, therefore swaps are optimal when dollar demand leads to welfare losses. In contrast, since dollar swaps cannot achieve the constrained efficient allocation, dollar swaps are not desirable when dollar shortages improve aggregate welfare for the hegemon. So, dollar swaps are optimal for the hegemon when $R_t = R$ or when $\lambda^{NA}$, the Pareto weight attached to inactive households, is high. Unresponsive monetary policy, possibly due to low rates we have experienced since the GFC, and a preference for redistribution to financially-inactive households are two reasons the model suggests dollar swap lines have become so prominent in recent years.\(^{49}\)

### 4.5.3 Extensions

**Firesales.** Suppose the return on foreign asset holdings ($a_t^F$) is $R^*(1 - \phi(\Gamma_t, \xi_t))$, where $\phi$ denotes a haircut which can accrue on foreign assets.\(^{50}\) This can capture a situation where the foreign sector is selling-off these assets (fire-sales) because of liquidity shortages, leading to lower returns. To reflect that fire-sales are more likely when dollar liquidity is scarce and foreign investors make large losses on their dollar portfolios, I assume $\frac{d\phi(\Gamma)}{d\Gamma} > 0$. Then, dollar swap lines can be desirable even when optimal macro-prudential policy is in place, see (C.49) in Appendix C.7.

**Productivity shocks.** Consider a productivity shock ($A_t$ falls), detailed in Appendix C.6. Households experience an income loss and borrow to smooth their consumption when $\sigma > \theta = \eta$. From Proposition 1, we know that households will over-borrow because they fail to internalise their size in financial markets. Once again, absent a borrowing tax, monetary policy cannot efficiently trade-off internal objectives. Dollar swaps help hegemon monetary policy regain its independence, narrowing the issuance wedge $\tau^\Omega$, and the economy moves closer to the efficient allocation.\(^{51}\)

**Public debt.** In the job market version of this paper, I consider an extension of the model with government spending and public debt issuance. I show that although debt issuance can be chosen to implement the desired level of dollar shortages abroad, this will generally not be the optimal allocation because of domestic fiscal incentives such as smoothing of public spending.

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\(^{49}\)In the job market version of this paper, I consider the comparative statics with respect to $\lambda$, the pass-through of dollar movements to U.S. import prices. I show that when interest rates are constant, welfare is increasing in pass-through since an appreciation allows hegemon households to purchase more imports. Therefore, for a given level of dollar demand, DCP contributes to higher welfare costs from the resulting appreciation due to the presence of real income effects, see e.g Corsetti and Pesenti (2001), Auclert et al. (2021). However, as noted in Farhi and Maggiori (2018), the extent of demand for dollar assets and the associated safety premium is likely to be endogenous to the international pricing paradigm.

\(^{50}\)Firesales by foreign investors leading to asset price crashes were cited as a key concern by the FED when it announced the Dollar Swap Lines. See https://www.federalreserve.gov/newsevents/pressreleases/swap-lines-faqs.htm.

\(^{51}\)As pointed out in Farhi and Werning (2014), controls on capital flows are also required to deal with terms of trade motives so dollar swaps cannot replace the borrowing tax. However, the inefficiency is then not dependent on the level of dollar shortages abroad.
Dollar swaps, instead, have little effect on the public sector balance sheet and directly target the spread in the cost of borrowing in dollars vis-a-vis foreign currency.

Additionally, the extension of the model to consider public debt issuance yields insights on the effects of quantitative easing (QE). QE, by which the FED purchases U.S. treasuries, also results in a reduction in the supply of dollar assets domestically and abroad, manifesting in dollar shortages.\footnote{Krishnamurthy and Lustig (2019) show that quantitative easing where the FED purchased treasuries indeed widened the treasury basis, consistent with larger shortages in my model.}

### 4.6 Conclusion

The prominent role of the dollar in financial markets is not only costly for non-U.S. investors who search for dollar debt despite its poor return, but can also interfere with the efficient working of U.S. monetary policy. Because dollars are scarce, U.S. households and the government earn monopoly rents from issuing domestic-currency denominated debt, but face costs associated with a dollar appreciation. Monetary policy in the hegemon can stabilize the domestic economy, but it cannot achieve the constrained efficient allocation absent a macro-prudential tax because of (inefficient) over-borrowing by households. This arises because atomistic households fail to internalize their size in dollar markets and because of nominal rigidities. Relative to the constrained efficient allocation, I show that with monetary policy alone, U.S. output and prices are more volatile, and monopoly rents are low.

Dollar swaps can improve welfare for the hegemon, in place of a missing macro-prudential tax, but they cannot achieve the constrained efficient allocation. Dollar swaps expand the portfolio limits faced by financial intermediaries who can manufacture dollar debt and alleviate dollar shortages in foreign markets. This addresses the over-borrowing but only at the cost of eroding monopoly rents. Dollar swaps are more desirable if monetary policy is unresponsive and if pass-through to import prices is low (DCP). When a measure of households in the hegemon do not participate in financial markets, dollar shortages abroad lead to distributional consequences which can drive the policy response. Specifically, dollar swaps systematically favour inactive households by stabilizing wages, at the expense of active households who forego excess returns on their portfolio.

In conclusion, this chapter analyses the ability of monetary policy to manage large and volatile capital flows driven by the demand for dollars. Macro-prudential policy, in the form of a tax on borrowing, which exacerbates dollar shortages abroad, can be used to achieve the constrained efficient allocation for the U.S. By restricting the supply of dollars abroad, the U.S. can earn monopoly rents at the expense of foreign investors. Such a policy could however undermine the position of the dollar moving forward or prompt retaliatory action, which may be why it not used in practice. The International Monetary System seems instead to have settled in an uncomfortable equilibrium, where the U.S. provides dollar liquidity via swap lines when needed (acting as a lender of last resort), even though by doing so it foregoes some monopoly rents. A rethinking of the system may be on the horizon, which could entail the use of a new global reserve currency, digital currencies or centralized clearing of financial markets.


93


96
Appendix A

Appendix to Chapter 2

A.1 Data Sources

We use nominal zero-coupon government bond yields at maturities from 6 months to 10 years for 7 industrialised countries: US, Australia, Canada, euro area, Japan, Switzerland and UK. Our benchmark sample spans 1980:01-2017:12, although the panel of interest rates is unbalanced as bond yields are not available from the start of the sample in all jurisdictions. Table A.1 summarises the sources of nominal zero-coupon government bond yields, and the sample availability, for the benchmark economies in our study. In robustness analyses, we also assess results for a broader set of G10 currencies—adding New Zealand, Norway and Sweden—for which zero-coupon government bond yields are available up to 2009:05 from Wright (2011).

Table A.1: Yield Curve Data Sources

<table>
<thead>
<tr>
<th>Country</th>
<th>Sources</th>
<th>Start Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Reserve Bank of Australia</td>
<td>1992:07</td>
</tr>
<tr>
<td>Canada</td>
<td>Bank of Canada</td>
<td>1986:01</td>
</tr>
<tr>
<td>Euro Area</td>
<td>Bundesbank (German Yields)</td>
<td>1980:01</td>
</tr>
<tr>
<td>Japan</td>
<td>Wright (2011) and Bank of England</td>
<td>1986:01</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Swiss National Bank</td>
<td>1988:01</td>
</tr>
<tr>
<td>UK</td>
<td>Anderson and Sleath (2001)</td>
<td>1975:01</td>
</tr>
</tbody>
</table>

Notes: Data from before 1980:01 are not used in this paper.

Exchange rate data is from Datastream, reflecting end-of-month spot rates vis-à-vis the US dollar. Liquidity yields are from Du, Im, and Schreger (2018), available at the 1, 2, 3, 5, 7 and 10-year maturities. The earliest liquidity yields are available from 1991:04 for some countries (e.g. UK). The latest liquidity yields are available from 1999:01 (e.g. euro area). For both exchange rates and liquidity yields, we use end-of-month observations.
A.2 Empirical Results

A.2.1 Full Results from UIP and Yield Curve-Augmented UIP Regressions

Table A.2 presents our benchmark results for regressions (2.1) and (2.2). Column (1) presents the $\beta_{1,\kappa}$ estimates, at different horizons, from the canonical UIP panel regression using pooled monthly data from 1980:01 to 2017:12. Columns (2)-(3) present the $\beta_{1,\kappa}$ and $\beta_{2,\kappa}$ estimates at different horizons from the slope-augmented regression.

A.2.2 Robustness Results for Yield Curve-Augmented UIP Regression

In this Appendix, we report results for the robustness exercises discussed in Section 2.2.3.

Relative curvature. Table A.3 presents results from an extended variant of regression (2.2) which also includes the relative yield curve curvature $C^*_j,t - C_t$. Column (3) indicates that there remains a tent-shaped relationship on relative slope coefficients across horizons. Although the relative curvature coefficients in column (4) appear to have a significant negative tent-shaped relationship, this relationship is not robust. Using more conservative standard errors, we do not find the relative curvature coefficients to be statistically different from zero.

In addition, Figure A.1 demonstrates that the marginal explanatory power from the relative curvature is small in comparison to that of the relative slope. It plots the adjusted $R^2$ from regression (2.1), regression (2.2) and regression (2.2) with the relative curvature. The increase in explanatory power from the relative slope substantially exceeds that of the relative curvature across medium-term horizons, further justifying our focus on the relative yield curve slope.

Figure A.1: Explanatory power of UIP regression and augmented variants at different horizons

Notes: Adjusted $R^2$ from the standard UIP regression (2.1) of ex post exchange rate changes on horizon-specific interest rate differentials (thin, red, crosses), a relative slope-augmented UIP regression (2.2) (thick, black, circles) and a relative slope and curvature-augmented UIP regression (thin, blue, squares) at different horizons $\kappa$ (horizontal axis, in months). Regressions estimated using pooled end-of-month data for six currencies (AUD, CAD, CHF, EUR, JPY and GBP) vis-à-vis the USD from 1980:01 to 2017:12, and include country fixed effects.
<table>
<thead>
<tr>
<th></th>
<th>(1) UIP Regression $r^*_t - r_t$</th>
<th>(2) Augmented Regression $r^*_t - r_t$</th>
<th>(3) $S^* - S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-months</td>
<td>-1.06</td>
<td>-0.53</td>
<td>0.39</td>
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<tr>
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<td>(0.65)</td>
<td>(1.03)</td>
<td>(0.65)</td>
</tr>
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<td>12-months</td>
<td>-0.99**</td>
<td>-0.37</td>
<td>0.86</td>
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<tr>
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<td>(0.50)</td>
<td>(0.83)</td>
<td>(0.98)</td>
</tr>
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<td>0.10</td>
<td>2.02*</td>
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<tr>
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<td>(0.43)</td>
<td>(0.68)</td>
<td>(1.06)</td>
</tr>
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<td>(0.62)</td>
<td>(1.19)</td>
</tr>
<tr>
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<td>0.57</td>
<td>3.58***</td>
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<tr>
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<td>(0.57)</td>
<td>(1.26)</td>
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<td>(1.25)</td>
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<td>0.95**</td>
<td>4.27***</td>
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<td>(0.42)</td>
<td>(1.14)</td>
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<tr>
<td>48-months</td>
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<td>4.14***</td>
</tr>
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<td>(0.34)</td>
<td>(1.11)</td>
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<td>1.31***</td>
<td>4.03***</td>
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<tr>
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<td>(0.28)</td>
<td>(1.13)</td>
</tr>
<tr>
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<td>3.92***</td>
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<tr>
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<td>(1.21)</td>
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<td>1.57***</td>
<td>3.78***</td>
</tr>
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<td>(0.26)</td>
<td>(1.25)</td>
</tr>
<tr>
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<td>1.63***</td>
<td>3.33***</td>
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<td>(0.23)</td>
<td>(1.18)</td>
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<tr>
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<td>2.50**</td>
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<tr>
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<td>(0.21)</td>
<td>(1.08)</td>
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<td>(0.18)</td>
<td>(0.97)</td>
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<td>(0.17)</td>
<td>(0.96)</td>
</tr>
<tr>
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<td>0.93***</td>
<td>-0.09</td>
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<tr>
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<td>(0.17)</td>
<td>(1.06)</td>
</tr>
<tr>
<td>108-months</td>
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<td>0.78***</td>
<td>-0.59</td>
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<td>(0.17)</td>
<td>(0.16)</td>
<td>(1.16)</td>
</tr>
<tr>
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<td>0.70***</td>
<td>-0.78</td>
</tr>
<tr>
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<td>(0.16)</td>
<td>(1.20)</td>
</tr>
<tr>
<td>120-months</td>
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<td>0.65***</td>
<td>-0.83</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.16)</td>
<td>(1.20)</td>
</tr>
</tbody>
</table>

Notes: Column (1) presents coefficient estimates from regression (2.1)—the canonical UIP regression—a regression of the $\kappa$-period exchange rate change $\Delta c_{t+\kappa}$ on the $\kappa$-period return differential $r^*_{t,\kappa} - r_{t,\kappa}$. Columns (2)-(3) document point estimates from (2.2)—the augmented regression—using the relative yield curve slope (measured using a proxy) as an additional regressor. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-a-vis the USD from 1980:01 to 2017:12, including country fixed effects. The panel is unbalanced. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).
Table A.3: Coefficient estimates from canonical UIP regression and regression augmented with relative yield curve slope and curvature

<table>
<thead>
<tr>
<th>Maturity</th>
<th>(1) UIP Regression $r_e^{\kappa} - r_\kappa$</th>
<th>(2) Yield Curve Augmented Regression $r_e^{\kappa} - r_\kappa$</th>
<th>(3) $S^\kappa - S$</th>
<th>(4) $C^\kappa - C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-months</td>
<td>-1.06 (0.65)</td>
<td>-0.40 (1.00)</td>
<td>0.75 (0.70)</td>
<td>-0.61 (0.74)</td>
</tr>
<tr>
<td>12-months</td>
<td>-0.99** (0.50)</td>
<td>-0.22 (0.82)</td>
<td>2.87** (1.31)</td>
<td>-1.25 (1.09)</td>
</tr>
<tr>
<td>18-months</td>
<td>-0.87** (0.43)</td>
<td>0.29 (0.69)</td>
<td>2.87** (1.31)</td>
<td>-1.25 (1.09)</td>
</tr>
<tr>
<td>24-months</td>
<td>-0.67* (0.39)</td>
<td>0.60 (0.62)</td>
<td>4.31*** (1.50)</td>
<td>-2.45 (1.53)</td>
</tr>
<tr>
<td>30-months</td>
<td>-0.47* (0.35)</td>
<td>0.94* (0.56)</td>
<td>5.98*** (1.60)</td>
<td>-3.67** (1.77)</td>
</tr>
<tr>
<td>36-months</td>
<td>-0.25 (0.33)</td>
<td>1.11** (0.52)</td>
<td>6.74*** (1.63)</td>
<td>-4.13** (1.74)</td>
</tr>
<tr>
<td>42-months</td>
<td>0.05 (0.33)</td>
<td>1.31*** (0.44)</td>
<td>7.40*** (1.61)</td>
<td>-5.11*** (1.86)</td>
</tr>
<tr>
<td>48-months</td>
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<td>1.39*** (0.35)</td>
<td>7.04*** (1.68)</td>
<td>-4.89** (2.03)</td>
</tr>
<tr>
<td>54-months</td>
<td>0.67** (0.28)</td>
<td>1.53*** (0.28)</td>
<td>6.63*** (1.83)</td>
<td>-4.51** (2.20)</td>
</tr>
<tr>
<td>60-months</td>
<td>0.90*** (0.25)</td>
<td>1.60*** (0.27)</td>
<td>5.98*** (1.97)</td>
<td>-3.66 (2.31)</td>
</tr>
<tr>
<td>66-months</td>
<td>1.11*** (0.23)</td>
<td>1.64*** (0.26)</td>
<td>4.91*** (2.03)</td>
<td>-2.06 (2.37)</td>
</tr>
<tr>
<td>72-months</td>
<td>1.27*** (0.19)</td>
<td>1.64*** (0.23)</td>
<td>3.61 (1.93)</td>
<td>-0.52 (2.21)</td>
</tr>
<tr>
<td>78-months</td>
<td>1.31*** (0.17)</td>
<td>1.55*** (0.21)</td>
<td>2.54 (1.77)</td>
<td>-0.06 (2.09)</td>
</tr>
<tr>
<td>84-months</td>
<td>1.27*** (0.17)</td>
<td>1.42*** (0.19)</td>
<td>1.89 (1.65)</td>
<td>-0.30 (2.10)</td>
</tr>
<tr>
<td>90-months</td>
<td>1.20*** (0.17)</td>
<td>1.28*** (0.18)</td>
<td>0.93 (1.60)</td>
<td>0.32 (2.07)</td>
</tr>
<tr>
<td>96-months</td>
<td>1.08*** (0.17)</td>
<td>1.10*** (0.16)</td>
<td>0.06 (1.68)</td>
<td>0.90 (2.24)</td>
</tr>
<tr>
<td>102-months</td>
<td>0.94*** (0.17)</td>
<td>0.93*** (0.16)</td>
<td>-0.41 (1.74)</td>
<td>0.63 (2.25)</td>
</tr>
<tr>
<td>108-months</td>
<td>0.81*** (0.17)</td>
<td>0.78*** (0.16)</td>
<td>-0.71 (1.83)</td>
<td>0.25 (2.31)</td>
</tr>
<tr>
<td>114-months</td>
<td>0.73*** (0.17)</td>
<td>0.70*** (0.16)</td>
<td>-0.88 (1.89)</td>
<td>0.20 (2.34)</td>
</tr>
<tr>
<td>120-months</td>
<td>0.68*** (0.16)</td>
<td>0.65*** (0.16)</td>
<td>-0.42 (1.66)</td>
<td>0.79 (2.44)</td>
</tr>
</tbody>
</table>

Notes: Column (1) presents coefficient estimates from regression (2.1)—the canonical UIP regression—a regression of the $\kappa$-period exchange rate change $\Delta r_e^{\kappa}$ on the $\kappa$-period return differential $r_e^{\kappa} - r_\kappa$. Columns (2)-(4) document point estimates from an extended regression (2.2) using the relative yield curve slope and curvature (measured using proxies) as additional regressors. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-á-vis the USD from 1980:01 to 2017:12, including country fixed effects. The panel is unbalanced. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).
Predictability of interest rates. Table A.4 presents results of regressions of exchange rate changes on: (a) the relative yield curve slope; (b) the relative yield curve slope and curvature; and (b) the relative yield curve level, slope and curvature. These specifications differ from our baseline specification by omitting the interest rate differential. In both cases, the tent-shaped pattern of coefficients on the relative slope remains significant.

In specification (c), we proxy the yield curve level using the difference between 10-year zero-coupon yields $L_{t}^{j} = i_{t,10y}^{j}$. This specification replicates that in Chen and Tsang (2013). However, our results differ due to differences in the construction of yield curve factors. Chen and Tsang (2013) capture relative yield curve factors by directly estimating Nelson-Siegel decompositions on relative interest rate differentials. To do this, they assume symmetry of factor structures across countries. We, instead, construct proxies for factors using yield curves estimated on a country-by-country basis, and so do not assume such symmetry.

Long-horizon inference. As discussed in Section 2.2.3, long-horizon forecasting regressions like (2.1) and (2.2) can face size distortions, whereby the null hypothesis is rejected too often. Valkanov (2003) demonstrates that this problem is especially pertinent when samples are small and regressors are persistent. Although the Driscoll and Kraay (1998) standard errors used in the main body of the paper are robust to heteroskedasticity and autocorrelation, we assess the robustness of our findings using alternative inference here.

Following Moon, Rubia, and Valkanov (2004), we use scaled $t$-statistics, whereby standard $t$-statistics are multiplied by $1/\sqrt{\kappa}$. In the context of long-horizon forecasting regressions like ours, Moon, Rubia, and Valkanov (2004) demonstrate that these scaled $t$-statistics are approximately standard normal when regressors are sufficiently persistent. However, because the scaled $t$-statistics can tend to under-reject the null when regressors are not near-integrated, we view these $t$-statistics as providing more conservative inference than the Driscoll and Kraay (1998) standard errors.

Figure A.2 plots the $\beta_{2,\kappa}$ estimates from (2.2) with 90% confidence intervals implied by the scaled $t$-statistics of Moon, Rubia, and Valkanov (2004). Relative to table A.3, point estimates are unchanged. But the error bands implied by the scaled $t$-statistics are wider from 12 months onwards. Nevertheless, point estimates are significantly positive according to the more conservative inference from the 2.5 to 3.5-year horizons, within which the peak of the tent arises.

In addition, Figure A.3 plots the $\beta_{1,\kappa}$ and $\beta_{3,\kappa}$ coefficient estimates from an extended variant of regression (2.2), which includes the relative curvature, alongside the 90% confidence bands implied by the scaled $t$-statistics. While the overall pattern of $\beta_{1,\kappa}$ coefficients is broadly the same as the canonical UIP regression, the confidence bands with these more conservative $t$-statistics are wider. The scaled $t$-statistics also imply that the coefficients on the relative curvature are statistically insignificant at all horizons, justifying our focus on the relative slope in this paper.

Sub-sample stability. To assess the stability of our results, we estimate regression (2.2) on two sub-samples. The first, from 1980:01 to 2008:06, is intended to capture the pre-crisis period. The second, from 1990:01 to 2017:12, includes the post-crisis period.

The slope coefficient estimates from different sub-samples are presented in Table A.5. For comparison, column (1) includes the relative slope coefficient loadings from our benchmark sample presented in the main body of the paper. Columns (2) and (4) include the estimated
Table A.4: Coefficient estimates from regressions of exchange rate change on relative slope, on relative slope and curvature, and on relative level, slope and curvature and regression augmented with relative yield curve slope and curvature

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<th>(2) Slope &amp; Curvature</th>
<th>(3) Level, Slope &amp; Curvature</th>
<th>(4) Level</th>
<th>(5) Slope &amp; Curvature</th>
<th>(6) Curvature</th>
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<td>( \kappa )</td>
<td>( S^* - S )</td>
<td>( S^* - C )</td>
<td>( C^* - C )</td>
<td>( L^* - L )</td>
<td>( S^* - C )</td>
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<td>-0.67</td>
<td>-0.22</td>
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<td>-0.61</td>
</tr>
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<td></td>
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<td>(0.78)</td>
<td>(0.47)</td>
<td>(0.56)</td>
<td>(0.75)</td>
</tr>
<tr>
<td>12-months</td>
<td>1.19**</td>
<td>1.68**</td>
<td>-0.93</td>
<td>-0.20</td>
<td>1.62**</td>
<td>-0.88</td>
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<td>(0.77)</td>
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<td>(1.11)</td>
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<td>(1.25)</td>
</tr>
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<td>24-months</td>
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<td>(1.91)</td>
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<td>(1.74)</td>
</tr>
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<td>(1.99)</td>
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<td>-1.03</td>
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<td>3.62**</td>
<td>-1.76</td>
</tr>
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<td>(2.19)</td>
<td>(1.31)</td>
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</tr>
<tr>
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<td>2.87*</td>
<td>-0.91</td>
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<td>(1.18)</td>
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<td>(2.18)</td>
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<td>(1.79)</td>
<td>(2.30)</td>
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<td>8.32***</td>
<td>1.84</td>
<td>1.76</td>
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<td>(2.34)</td>
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<td>9.11***</td>
<td>0.13</td>
<td>3.13</td>
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<td>(1.29)</td>
<td>(1.73)</td>
<td>(2.15)</td>
</tr>
<tr>
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<td>-2.24</td>
<td>4.02*</td>
<td>9.37***</td>
<td>-0.44</td>
<td>3.13</td>
</tr>
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<td>(1.94)</td>
<td>(2.39)</td>
<td>(1.26)</td>
<td>(1.60)</td>
<td>(2.04)</td>
</tr>
<tr>
<td>84-months</td>
<td>-0.88</td>
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Notes: Column (1) presents coefficient estimates from regression of the \( \kappa \)-period exchange rate change \( \Delta^\kappa \kappa \kappa + \kappa \kappa \kappa \) on the relative yield curve slope \( S^* - S \). Columns (2)-(3) present coefficient estimates from a regression with the relative yield curve slope and curvature \( S^* - C \). Columns (4)-(6) document point estimates from regression on relative yield curve level \( L^* - L \), slope and curvature. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD from 1980:01 to 2017:12, including country fixed effects. The panel is unbalanced. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).
Figure A.2: Estimated relative slope coefficients from augmented UIP regression using more conservative inference

Notes: Black circles denote $\hat{\beta}_{2,\kappa}$ point estimates from regression (2.2). The horizontal axis denotes the horizon $\kappa$ in months. Regressions are estimated using pooled monthly data from 1980:01 to 2017:12, including country fixed effects. 90% confidence intervals, calculated using implied standard errors from scaled $t$-statistics proposed by Moon, Rubia, and Valkanov (2004) standard errors, are denoted by thick black bars around point estimates.

loadings over the pre-crisis and predominantly post-crisis samples, respectively. In both cases the coefficient estimates form a tent shape with respect to maturity, peaking at the 4 and 3.5-year horizons, respectively.

In addition, column (3) presents an additional robustness exercises, where we use available G10 currency and yield curve data, adding Sweden, Norway and New Zealand to our cross-section of countries, for the pre-crisis period only. The relative slope loadings continue to follow a tent-shaped pattern with respect to maturity.

**Country-specific regressions.** Table A.6 presents country-specific estimates of the yield curve augmented-UlP regression. Inference is conducted using Newey and West (1987) standard errors, to account for serial correlation. For comparison, column (1) presents the benchmark relative slope coefficient estimates from the panel regression discussed in the main body of the paper. As noted in the main text, although coefficient estimates vary in size and significance across countries, a relative slope coefficient estimates display a tent shape with respect to horizon $\kappa$ for most of the currencies in our sample (AUD, CHF, EUR, JPY, GBP). A positive tent shape is present for Canada as well, but is insignificant. The peak of the tent realises at 30–42 months for all 6 currency pairs. However, some anomalies arise at long horizons beyond 8 years.
Table A.5: Slope coefficient estimates from augmented UIP regression for pooled regression across different samples

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<th>(2) 1980:01-2008:06 G7 Currencies</th>
<th>(3) 1980:01-2008:06 G10 Currencies</th>
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<td>0.71 (0.89)</td>
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<td>1.80 (1.13)</td>
<td>1.94* (0.99)</td>
<td>0.94 (0.88)</td>
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<tr>
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<td>2.78** (1.12)</td>
<td>1.36 (1.01)</td>
</tr>
<tr>
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<td>3.47** (1.36)</td>
<td>3.68*** (1.18)</td>
<td>2.31** (1.09)</td>
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<td>4.09*** (1.33)</td>
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<td>2.88** (1.11)</td>
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<td>-0.83 (1.20)</td>
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Notes: Coefficient estimates on the relative yield curve slope \( S_t^\kappa - S_t \) from regression (2.2)—the augmented UIP regression—a regression of the \( \kappa \)-period exchange rate change \( \Delta e_{t+\kappa} \), on the \( \kappa \)-period return differential \( r_{t+\kappa}^\kappa - r_{t}^\kappa \), the relative yield curve slope and the relative yield curve curvature \( \kappa^\kappa \). Regressions in columns (1) and (3)-(5) are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples. Column (2) includes three additional currencies—NOK, NZD and SEK—for zero-coupon government bond yield curve data is available prior to the crisis. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.
Table A.6: Slope coefficient estimates from augmented UIP regression for pooled regression and country-specific regressions

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Notes: Coefficient estimates on the relative yield curve slope $S_t - S_{t-1}$ from regression (2.2)—the augmented UIP regression—a regression of the $\kappa$-period exchange rate change $\Delta e_{t+\kappa}$ on the $\kappa$-period return differential $r^*_{t,\kappa} - r_{t,\kappa}$, the relative yield curve slope and the relative yield curve curvature $C^*_{t} - C_{t}$. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD from 1980:01 to 2017:12. Column (1) presents coefficient estimates from a panel regression of all six countries, including country fixed effects. The panel is unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. Columns (2)-(7) report coefficient estimates from country-specific regressions. Newey and West (1987) standard errors (reported in parentheses) are constructed with a maximum lag of 5. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.
Figure A.3: Estimated relative slope coefficients from augmented UIP regression using more conservative inference

Notes: Black circles denote $\hat{\beta}_{1,\kappa}$ (left-hand side) and $\hat{\beta}_{3,\kappa}$ (right-hand side) point estimates from regression (2.2). The horizontal axis denotes the horizon $\kappa$ in months. In regression (2.2), the slope and curvature in each country are measured using proxies. Regressions are estimated using pooled monthly data from 1980:01 to 2017:12, including country fixed effects. 90% confidence intervals, calculated using implied standard errors from scaled $t$-statistics proposed by Moon, Rubia, and Valkanov (2004) standard errors, are denoted by thick black bars around point estimates.

A.2.3 Robustness Results for Risk Premia

In Table A.7, we present the mean return from a simple investment strategy that goes long the Foreign bond and short the US bond when the Foreign yield curve slope is lower than the US yield curve slope, and goes long the US bond and short the Foreign bond when the US yield curve slope is lower than the Foreign yield curve slope. Relative to Lustig, Stathopoulos, and Verdelhan (2019), we present the mean dollar-bond return differences for a range of holding periods $h = 6, 12, ..., 60$ and maturities $\kappa = 6, 12, ..., 120$ (in months).
Table A.7: Mean Excess Returns from Dynamic Long-Short Bond Portfolios

<table>
<thead>
<tr>
<th>Holding Periods</th>
<th>6m</th>
<th>12m</th>
<th>18m</th>
<th>24m</th>
<th>30m</th>
<th>36m</th>
<th>42m</th>
<th>48m</th>
<th>54m</th>
<th>60m</th>
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Notes: Summary return statistics from investment strategies that go long in the Foreign-country bond and short in the US bond when the Foreign yield curve slope is lower than the US yield curve slope, and go long in the US bond and short in the Foreign-country bond when the Foreign yield curve slope is higher than the US yield curve slope. The table reports the mean US dollar-bond excess return difference for different holding periods and different maturities. Returns are annualised and constructed using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different country samples spanning 1980:01-2017:12.

A.2.4 Additional Results for Liquidity Yield-Augmented Regressions

Table A.8 shows coefficient estimates from regression (2.7) for local currency-bond excess returns.
Table A.8: Slope and liquidity yield coefficient estimates from pooled regression of excess returns

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<td>( \kappa_j,t,t ) + ( \eta_R \kappa )</td>
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Notes: Coefficient estimates on the relative yield curve slope \( S^* - S \) (Panel C.i) and cross-country \( \kappa \)-period liquidity yield \( \eta_R \kappa \) (Panel C.ii) from regressions with the log local currency-bond excess return difference as dependent variable. Regressions are estimated using pooled end-of-month data for six currencies—AUD, CAD, CHF, EUR, JPY and GBP—vis-à-vis the USD for different samples within 1991:04-2017:12. The log returns and yield curve slope differentials are annualised. All regressions include country fixed effects. All regressions include country fixed effects. The panels are unbalanced and standard errors (reported in parentheses) are constructed according to the Driscoll and Kraay (1998) methodology. *, ** and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively.

A.3 Derivations for Two-Country Cox, Ingersoll and Ross Model

Bond-pricing recursions. To derive the Home bond price recursions, we guess and verify equation (2.18). We use the fact that \( p_{t,n} = E_t [m_{t,t+1} + p_{t+1,n-1}] + (1/2) \text{var}_t (m_{t,t+1} + p_{t+1,n-1}) \), and combine the guess with equations (2.16) and (2.17).

First, consider the one-period bond, \( n = 1 \):

\[
p_{t,1} = E_t [m_{t,t+1} + \frac{1}{2} \text{var}_t (m_{t,t+1})] = -\alpha - \chi z_{1,t} - \tau z_{2,t} + \frac{1}{2} \gamma z_{1,t} + \frac{1}{2} \delta z_{2,t}
\]

where the first line uses the expression for the bond price for \( n = 1 \), the conditional expectation of equation (2.16) is used in the second line, and the resulting expression is rearranged to yield the third line. The one-period risk-free yield \( y_{t,1} \) is therefore given by:

\[
y_{t,1} = \alpha + \left( \chi - \frac{1}{2} \gamma \right) z_{1,t} + \left( \tau - \frac{1}{2} \delta \right) z_{2,t}
\] (A.1)
Next, consider the general $n$-period bond price:

$$p_{t,n} = \mathbb{E}_t \left[ m_{t,t+1} + p_{t+1,n-1} \right] + \frac{1}{2} \text{var}_t \left( m_{t,t+1} + p_{t+1,n-1} \right)$$

$$= - \alpha - \chi z_{1,t} - \tau z_{2,t} + \mathbb{E}_t \left[ -A_{n-1} - B_{n-1} z_{1,t+1} - C_{n-1} z_{2,t+1} \right]$$

$$+ \frac{1}{2} \text{var}_t \left( -\sqrt{\gamma_{1,t}} u_{1,t+1} - \sqrt{\delta_{2,t}} u_{2,t+1} - B_{n-1} z_{1,t+1} - C_{n-1} z_{2,t+1} \right)$$

$$= - \alpha - A_{n-1} - B_{n-1} (1 - \phi_1) \theta_1 - C_{n-1} (1 - \phi_2) \theta_2$$

$$- \chi z_{1,t} - B_{n-1} \phi_1 z_{1,t} - \tau z_{2,t} - C_{n-1} \phi_2 z_{2,t}$$

$$+ \frac{1}{2} \left( (B_{n-1} \sigma_1)^2 z_{1,t} + 2B_{n-1} \sigma_1 \sqrt{\gamma_{2,t}} + \gamma z_{1,t} + (C_{n-1} \sigma_2)^2 z_{2,t} + 2C_{n-1} \sigma_2 \sqrt{\delta_{2,t}} + \delta z_{2,t} \right)$$

$$= - (\alpha + A_{n-1} + B_{n-1} (1 - \phi_1) \theta_1 + C_{n-1} (1 - \phi_2) \theta_2)$$

$$- z_{1,t} \left[ \left( \chi - \frac{1}{2} \gamma \right) + B_{n-1} (\phi_1 + \sigma_1 \sqrt{\gamma}) - \frac{1}{2} (B_{n-1} \sigma_1)^2 \right]$$

$$- z_{2,t} \left[ \left( \tau - \frac{1}{2} \delta \right) + C_{n-1} \left( \phi_2 + \sigma_2 \sqrt{\delta} \right) - \frac{1}{2} (C_{n-1} \sigma_2)^2 \right]$$

where the second line uses equation (2.16) and the guess; the third line uses equation (2.17); the fourth line rearranges the third; and the fifth line collects like terms. The recursions can be seen in the final line:

$$A_n \equiv A_n(\alpha, \phi_1, \phi_2, \theta_1, \theta_2; A_{n-1}, B_{n-1}, C_{n-1}) = \alpha + A_{n-1} + B_{n-1} (1 - \phi_1) \theta_1 + C_{n-1} (1 - \phi_2) \theta_2$$

$$B_n \equiv B_n(\phi_1, \chi, \gamma, \sigma_1; B_{n-1}) = \left( \chi - \frac{1}{2} \gamma \right) + B_{n-1} (\phi_1 + \sigma_1 \sqrt{\gamma}) - \frac{1}{2} (B_{n-1} \sigma_1)^2$$

$$C_n \equiv C_n(\phi_2, \tau, \delta, \sigma_2; C_{n-1}) = \left( \tau - \frac{1}{2} \delta \right) + C_{n-1} \left( \phi_2 + \sigma_2 \sqrt{\delta} \right) - \frac{1}{2} (C_{n-1} \sigma_2)^2$$

with initial conditions $A_0 = B_0 = C_0 = 0$. So the $n$-period bond price is:

$$p_{t,n} = - (A_n + B_n z_{1,t} + C_n z_{2,t})$$

verifying equation (2.18).

**Bond excess returns.** The *ex ante* $n$-period bond excess return is defined as $\mathbb{E}_t[r_{x(t+1)}^{(n)}] = \mathbb{E}_t[p_{t+1,n-1} - p_{t,1} - y_{t,1}]$. This can be written as:

$$\mathbb{E}_t \left[ r_{x(t+1)}^{(n)} \right] = \mathbb{E}_t \left[ p_{t+1,n-1} - p_{t,1} - y_{t,1} \right]$$

$$= \mathbb{E}_t \left[ -A_{n-1} + A_n - B_{n-1} z_{1,t+1} + B_n z_{1,t} - C_{n-1} z_{2,t+1} + C_n z_{2,t} \right]$$

$$- \alpha - (\chi - \frac{1}{2} \gamma) z_{1,t} - (\tau - \frac{1}{2} \delta) z_{2,t}$$

$$= B_{n-1} (1 - \phi_1) \theta_1 + C_{n-1} (1 - \phi_2) \theta_2 - B_{n-1} \mathbb{E}_t[z_{1,t+1}] + B_n z_{1,t}$$

$$- C_{n-1} \mathbb{E}_t[z_{2,t+1}] + C_n z_{2,t} - (\chi - \frac{1}{2} \gamma) z_{1,t} - (\tau - \frac{1}{2} \delta) z_{2,t}$$
between 10-year and 6-month yields:

\[
E_t \left[ r_{x,t+1}^{(\infty)} \right] = \left[ B_{\infty} \sigma_1 \sqrt{\gamma} - \frac{1}{2} (B_{\infty} \sigma_1)^2 \right] z_{1,t} \] + \left[ C_{\infty} \sigma_2 \sqrt{\delta} - \frac{1}{2} (C_{\infty} \sigma_2)^2 \right] z_{2,t}
\]

(A.2)

where line 2 uses equations (2.18) and (A.1), line 3 uses the recursion for \( A_n \) defined above, line 4 expands the conditional expectation of factors and collects like terms, line 5 uses the recursions for \( B_n \) and \( C_n \) defined above.

Evaluating the expression above in the limit as \( n \to \infty \) yields:

\[
E_t \left[ r_{x,t+1}^{(\infty)} \right] = \left[ B_{\infty} \sigma_1 \sqrt{\gamma} - \frac{1}{2} (B_{\infty} \sigma_1)^2 \right] z_{1,t} \] + \left[ C_{\infty} \sigma_2 \sqrt{\delta} - \frac{1}{2} (C_{\infty} \sigma_2)^2 \right] z_{2,t}
\]

Using the recursions for \( B_n \) and \( C_n \), this can be rearranged as:

\[
E_t \left[ r_{x,t+1}^{(\infty)} \right] = \left[ B_{\infty} (1 - \phi_1) - \chi + \frac{1}{2} \gamma \right] z_{1,t} \] + \left[ C_{\infty} (1 - \phi_2) - \tau + \frac{1}{2} \delta \right] z_{2,t}
\]

Moreover, equation (A.2) can be used to express the *ex ante* bond risk premium:

\[
-\text{cov}(p_{t+1,n-1}, m_{t,t+1}) = E_t \left[ r_{x,t+1}^{(\infty)} \right] + \frac{1}{2} \text{var}(r_{n,t+1})
\]

\[
= B_{n-1} \sigma_1 \sqrt{\gamma} z_{1,t} + C_{n-1} \sigma_2 \sqrt{\delta} z_{2,t}
\]

recovering equation (2.22) in the main body.

**Yield curve slope.** The yield curve slope is defined as the difference between yields on \( n \)- and 1-period bonds:

\[
S_{t,n} = y_{t,n} - y_{t,1} = \frac{1}{n} (A_n + B_n z_{1,t} + C_n z_{2,t}) - \alpha - \left( \chi - \frac{1}{2} \gamma \right) z_{1,t} - \left( \tau - \frac{1}{2} \delta \right) z_{2,t}
\]

Evaluating this expression in the limit as \( n \to \infty \) yields:

\[
S_{t,\infty} = B_{\infty} (1 - \phi_1) \theta_1 + C_{\infty} (1 - \phi_2) \theta_2 - \left( \chi - \frac{1}{2} \gamma \right) z_{1,t} - \left( \tau - \frac{1}{2} \delta \right) z_{2,t}
\]

which arises from the recursions for \( A_n \), \( B_n \) and \( C_n \), where \( B_n \) and \( C_n \) have a finite limit and \( A_n \) grows linearly.

The approximation of the slope by the bond risk premium \( S_{t,\infty} \approx E_t \left[ r_{x,t+1}^{(\infty)} \right] \) is also verified within the CIR model. Over long enough samples, \( E_t[z_{1,t}] = \theta_1 \) and \( E_t[z_{2,t}] = \theta_2 \), yielding the result.

To calibrate the CIR model at a monthly frequency, we define the slope as the difference between 10-year and 6-month yields:

\[
S_t = y_{t,120} - y_{t,6} = \frac{1}{120} (A_{120} + B_{120} z_{1,t} + C_{120} z_{2,t}) - \frac{1}{6} (A_6 + B_6 z_{1,t} + C_6 z_{2,t}) \quad (A.3)
\]

**Exchange rates.** Under complete markets, (log) one-period exchange rate changes are determined as:

\[
E_t[\epsilon_{t+1}] - \epsilon_t = E_t[m_{t,t+1} - m_{t,t+1}^*] = \chi (z_{1,t} - z_{1,t}^*) + \tau (z_{2,t} - z_{2,t}^*)
\]
The $k$-step ahead exchange rate change is then given by:

$$
\mathbb{E}_t[\epsilon_{t+k}^c] - \epsilon_t = \sum_{i=1}^\kappa \mathbb{E}_t[\Delta^1 \epsilon_{t+i}] = \frac{1 - \phi_k^h}{1 - \phi_1^h} \gamma (z_{1,t} - z_{1,t}^*) + \frac{1 - \phi_k^h}{1 - \phi_2^h} \tau (z_{2,t} - z_{2,t}^*)
$$

(A.4)

The one-period ERRP can be derived by combining equations (2.12) and (2.16):

$$
\mathbb{E}_t[r_{X,t+1}^c] = \frac{1}{2} \gamma (z_{1,t} - z_{1,t}^*) + \frac{1}{2} \delta (z_{2,t} - z_{2,t}^*)
$$

Model-implied UIP coefficient. The UIP coefficient is constructed as the scaled conditional covariance of the sum of expected future exchange rate movements and cross-country return differentials across maturities $h$:

$$
\beta_{h}^{UIP} = \frac{\text{cov}_t(\mathbb{E}_t[\epsilon_{t+h}] - \epsilon_t, r_{t,h}^* - r_{t,h})}{\text{var}_t(r_{t,h}^* - r_{t,h})}
$$

$$
= \frac{\chi (1 - \phi_1^h) B_h \text{var}_t(z_{1,t} - z_{1,t}) + \phi_2^h C_h \text{var}_t(z_{2,t} - z_{2,t})}{B_h^2 \text{var}_t(z_{1,t} - z_{1,t}) + C_h^2 \text{var}_t(z_{2,t} - z_{2,t})}
$$

(A.5)

where line 1 is the definition of the univariate regression coefficient, and line 2 uses equation (A.4) and the definition for returns.

A.3.1 Proof to Lemma

Consider the UIP coefficient in equation (A.5) for a general horizon $h$.

Condition (i). For $h = 1$: $\frac{1 - \phi_1^h}{1 - \phi_1^h} B_h = B_1 = \chi - \frac{1}{2} \gamma$ and $\frac{1 - \phi_2^h}{1 - \phi_2^h} C_h = C_1 = \tau - \frac{1}{2} \delta$. Condition (i) follows from requiring the numerator to be negative, since the denominator is strictly positive.

Condition (ii). To rule out permanent innovations to investors’ SDFs, we use the expression for the expected (log) bond excess return, equation (A.2). Lustig, Statopoulos, and Verdelhan, 2019 (Appendix IV.C) show that if there are no permanent innovations, then $\lim_{k \to \infty} \mathbb{E}_t[r_{X,t,h+k}^c]$ must equal half the variance of the SDF $\frac{1}{2} \gamma|z_{1,t}| + \frac{1}{2} \delta|z_{2,t}|$. Condition (ii) follows from this. If this condition is satisfied, $m_{t,h+1}^P$ is constant.

Condition (iii). For UIP to hold approximately in levels, the UIP coefficient must switch sign over horizons, such that the infinite sum of ERRP is small. To achieve this, in tandem with condition (i), the second term in the numerator of equation (A.5) must be positive ($\tau - \frac{1}{2} \delta > 0$) and become sufficiently large, relative to the negative first term, as $h \to \infty$. Note that $\frac{1 - \phi_2^h}{1 - \phi_2^h}$ is an increasing function of $\phi_1$ when $\phi_i < 1$ ($i = 1, 2$), and $|B_n|$ and $|C_n|$ are also increasing functions of $\phi_1$ and $\phi_2$, respectively. Since $B_n < 0$ and $C_n > 0$, it follows that the numerator—which is negative for $h = 1$—becomes positive for large $h$ if $\phi_2$ is sufficiently larger than $\phi_1$. 

A.3.2 Proof to Proposition

The model-implied coefficient from a univariate regression of the cumulative $h$-period exchange rate movement and the cross-country slope differential (defined as the difference between 120-
and 6-month yields) is given by:

\[
\beta_h^{SR} = \frac{\text{cov}_t(\mathbb{E}_t[e_{t+h} - e_t], (y_{t,120}^{*} - y_{t,6}^{*}) - (y_{t,120} - y_{t,6}))}{\text{var}_t((y_{t,120}^{*} - y_{t,6}^{*}) - (y_{t,120} - y_{t,6}))}
\]

\[
= \frac{1-\phi_1}{1-\phi_1} \lambda \left[ \frac{1}{120} B_{120} - \frac{1}{6} B_6 \right] \text{var}_t(z_{1,t}^{*} - z_{1,t}) + \frac{1-\phi_1}{1-\phi_1} \tau \left[ \frac{1}{120} C_{120} - \frac{1}{6} C_6 \right] \text{var}_t(z_{2,t}^{*} - z_{2,t})
\]

(A.6)

where line 1 is the definition of the univariate regression coefficient, and line 2 uses equations (A.3) and (A.4).

To generate a tent-shaped pattern for coefficients across horizons, we require \(\beta_h^{SR} < \beta_{h'}^{SR}\) for some \(h' > h\) and \(\beta_h^{SR} > \beta_{h''}^{SR}\) for \(h'' > h'\). To achieve this, the first term in the numerator, which is associated with the less persistent factor, must be positive such that the term is rising for some \(h < h'\). The second term, associated with the more persistent factor, must be negative.

Conditions (i) and (iii) from the Lemma ensure that: \(\text{sign}(\chi - \frac{1}{2}\gamma) = -\text{sign}(\tau - \frac{1}{2}\delta)\). This implies: \(\text{sign}(\frac{1}{120} B_{120} - \frac{1}{6} B_6) = -\text{sign}(\frac{1}{120} C_{120} - \frac{1}{6} C_6)\). To see this, consider the limit as \(\sigma_i \to 0\) \((i = 1, 2)\) and the recursions for \(B_n\) and \(C_n\). In this limit, the recursion for \(B_n\) collapses to:

\(B_n = (\chi - \frac{1}{2}\gamma) + \phi B_{n-1} = (\chi - \frac{1}{2}\gamma) + \phi_1 (\chi - \frac{1}{2}\gamma) + \ldots + \phi_1^n B_0 = \frac{1-\phi_1^n}{1-\phi_1} (\chi - \frac{1}{2}\gamma) < 0\). Likewise \(C_n\) will collapse to \(\frac{1-\phi_2^n}{1-\phi_2} (\tau - \frac{1}{2}\delta) > 0\). These conditions are also satisfied for \(\sigma > 0\), as long as \(\sigma\) is not too large.

Furthermore, \(\frac{1}{120} B_{120} - \frac{1}{6} B_6 = (\chi - \frac{1}{2}\gamma) \frac{1}{1-\phi_1} \left[ \frac{1}{120} B_{120} - \frac{1}{6} B_6 \right]\). The term in square brackets is negative for all \(\phi_1 < 1\). Therefore the first term in the numerator of \(\beta_h^{SR}\) is positive. By analogy, the second term, involving \(C_n\) loadings, is positive.

Since \(\chi, \tau > 0\) and \(\chi(\chi - \frac{1}{2}\gamma) \text{var}_t(z_{1,t}^* - z_{1,t}) < -\tau(\tau - \frac{1}{2}\delta) \text{var}_t(z_{2,t}^* - z_{2,t})\) from condition (i), the first factor is dominant at short horizons. This implies that \(\beta_h^{SR}\) is increasing for some \(h < h'\). However, as \(\phi_1 < \phi_2\) from condition (iii), \(\beta_h^{SR}\) will be decreasing for \(h'' > h'\). If (i) or (iii) are not satisfied, the tent can not be reproduced.

Furthermore, if risk is only permanent, which would violate condition (ii), the slope is constant and has no predictive power for exchange rates.

\[\square\]
Appendix B

Appendix to Chapter 3

B.1 Derivations and Proofs

B.1.1 Pareto Frontier

This sub-section provides derivations for the Pareto frontier, which is defined in Lemma 1 of Section 3.2.1. The Pareto frontier summarises combinations of consumption allocations \( \{c_{1,t}, c_{2,t}\} \) which are Pareto efficient, given a level of aggregate consumption \( C_t \).

The Home representative household chooses their consumption by minimising expenditure, for a given level of aggregate consumption \( C_t \):

\[
\begin{align*}
\min_{c_{1,t}, c_{2,t}} & \quad p_{1,t} c_{1,t} + p_{2,t} c_{2,t} \\
\text{s.t.} & \quad C_t = g(c_t)
\end{align*}
\]

The first-order conditions for this problem yield the Home relative demand equation:

\[
g_{1,t} \phi(c_{2,t}, c_{1,t}) = p_{1,t} \phi(c_{2,t}, c_{1,t}) = \frac{\alpha_1 - \alpha_1}{\alpha} \phi(c_{2,t}, c_{1,t}) \tag{B.1}
\]

where \( p_{1,t}/p_{2,t} \equiv 1/TOT_t \) and \( TOT_t \) refers to the terms of trade.

To derive the Pareto frontier, note that the analogous Foreign relative demand curve is:

\[
g_{1,t}^* \phi(c_{2,t}^*, c_{1,t}^*) = p_{1,t} \phi(c_{2,t}^*, c_{1,t}^*) = \frac{1 - \alpha}{\alpha} \phi(c_{2,t}^*, c_{1,t}^*) \tag{B.2}
\]

Equating relative prices across countries, equations (B.1) and (B.2) yield:

\[
\frac{c_{2,t}^*}{c_{1,t}^*} = \left( \frac{\alpha}{1 - \alpha} \right)^2 \frac{c_{2,t}}{c_{1,t}} \tag{B.3}
\]

This expression for optimal relative consumption must be consistent with goods market clearing \( (Y_{i,t} = c_{i,t} + c_{i,t}^* \text{ for } i = 1, 2) \). Combining (B.3) with goods market clearing, we attain the following expressions for consumption:

\[
\begin{align*}
c_{1,t} &= \frac{bc_{2,t} Y_{1,t}}{Y_{2,t} - (1 - b)c_{2,t}} \tag{B.4} \\
c_{2,t} &= \frac{c_{1,t} Y_{2,t}}{b Y_{1,t} + (1 - b)c_{1,t}} \tag{B.5}
\end{align*}
\]
where \( b \equiv \left( \frac{\alpha}{1 - \alpha} \right)^2 \).

**Solving for \( dc_t(C)/dC \)** Rearranging the Armington aggregator, we can show that:

\[
c_{1,t}(C_t) = \left[ \frac{C_t^{\frac{\phi-1}{2}} - (1 - \alpha)^{\frac{1}{2}} c_{2,t}^{\frac{\phi-1}{2}}}{\alpha^{\frac{1}{2}}} \right]^{\frac{\phi}{\phi-1}} \tag{B.6}
\]

\[
c_{2,t}(C_t) = \left[ \frac{C_t^{\frac{\phi-1}{2}} - \alpha^{\frac{1}{2}} c_{1,t}^{\frac{\phi-1}{2}}}{(1 - \alpha)^{\frac{1}{2}}} \right]^{\frac{\phi}{\phi-1}} \tag{B.7}
\]

Equating equations (B.5) with (B.7) yields:

\[
\left[ C_t^{\frac{\phi-1}{2}} - \alpha^{\frac{1}{2}} c_{1,t}(C_t)^{\frac{\phi-1}{2}} \right]^{\frac{\phi}{\phi-1}} (b Y_{1,t} + (1 - b) c_{1,t}(C_t)) = c_{1,t}(C_t) Y_{2,t} (1 - \alpha)^{\frac{1}{\phi-1}}
\]

Totally differentiating this expression and rearranging yields:

\[
\frac{dc_{1,t}(C_t)}{dC_t} = \frac{C_t^{-\frac{1}{2}} X_t (b Y_{1,t} + (1 - b) c_{1,t}(C_t))}{Y_{2,t} - c_{2,t}(C_t) (1 - b) + \alpha^{\frac{1}{2}} c_{1,t}(C_t)^{-\frac{1}{2}} X_t (b Y_{1,t} + (1 - b) c_{1,t} C_t)}
\]

where \( X_t \equiv \left[ C_t^{\frac{\phi-1}{2}} - \alpha^{\frac{1}{2}} c_{1,t}(C_t)^{\frac{\phi-1}{2}} \right]^{\frac{1}{\phi-1}} (1 - \alpha)^{-\frac{1}{\phi-1}}. \)

The expression for \( dc_{2,t}(C_t)/dC_t \) can be derived analogously.

**B.1.2 Foreign Household Optimisation**

This sub-section details the representative Foreign consumer’s optimisation problem, which acts as a constraint for the unilateral Home Ramsey planner in Section 3.3.

Foreign households maximise their discounted lifetime utility subject to their inter-temporal budget constraint, given world prices \( p_t \):

\[
\max_{\{c_t\}} U_0^* = \sum_{t=0}^{\infty} \beta^t u^*(c_t(\cdot)) \quad \text{s.t.} \quad \sum_{t=0}^{\infty} p_t \cdot (c_t^* - y_t^*) \leq 0
\]

The first-order conditions for this problem are given by (3.3) and (3.4) in Section 3.3, where \( \lambda^* \) is the Lagrange multiplier on the Foreign inter-temporal budget constraint.

**B.1.3 Proof to Proposition 2**

First, note that any outcome achievable in (P-Unil-FTA) is achievable in (P-Unil-nFTA). Part (i) follows immediately since (P-Unil-nFTA) is a relaxed version of (P-Unil-FTA) therefore the planner achieves weakly better outcomes when the FTA is relaxed. However, we analyse this
further. Equations (3.5), (3.6), and (3.7) satisfy the following total derivative rule:

$$\frac{dL}{dC} = \frac{\partial L}{\partial c_1} c_1'(C) + \frac{\partial L}{\partial c_2} c_2'(C)$$

The solution to (P-Unil-FTA) (when an FTA is in force) satisfies $\frac{dC}{dc_1} = 0$ at the (constrained) optimal allocation. Since $c_1'(C), c_2'(C)$ are positive and increasing functions given by Lemma 1, generally $\text{sign}(\frac{dC}{dc_1}) = -\text{sign}(\frac{dC}{dc_2})$ indicating an incentive to adjust consumption across varieties remains at the constrained optimal allocation.

In contrast, the solution to (P-Unil-nFTA) given by (3.6) and (3.7) implies $\frac{dC}{dc_1} = \frac{dC}{dc_2} = 0$ which necessarily implies aggregate consumption is (unconstrained) optimal as well. Formally, denote,

$$\mathcal{C} = \{C : \max L(C) \mid c_1(C), c_2(C) \text{ on Pareto Frontier}\}, \quad (B.8)$$

where $\mathcal{C}$ is a scalar because $L$ is strictly concave in the region of interest. Then note that $\frac{dC}{dc_1|c_1(C),c_2(C)} \neq 0$. If, e.g., $\frac{dC}{dc_1|c_1(C),c_2(C)} > 0$, then $\frac{dC}{dc_2|c_1(C),c_2(C)} < 0$ and there exists $\epsilon$ perturbation such that a $c_1(\mathcal{C}) \pm \epsilon, c_2(\mathcal{C}) \pm \epsilon$ are preferred.

Furthermore, (ii) follows since it must be then that $c_1'(C), c_2'(C)$ implied by (3.6) and (3.7) violate Lemma 1 (ii) if $\frac{dC}{dc_1|c_1(C),c_2(C)} \neq 0$. Conversely, if $\frac{dL}{dcC} = 0 \implies \frac{dC}{dc_1} = 0, \frac{dC}{dc_2} = 0$ if $c_1'(C), c_2'(C)$ are not binding, i.e. the constraints are identical to the correspondence implied by (3.6) and (3.7).

(iii) The allocations coincide when there is no trade in goods in equilibrium as the households' choice is optimal for the planner.

B.1.4 Derivatives of the Consumption Aggregator

In this sub-section, we define the derivatives of the Arthington, 1969 aggregator which defines aggregate consumption in our computational experiments. We present the expressions for the representative Home consumer only, but they are analogous for the representative Foreign consumer.

The first derivatives of the Home aggregator are given by:

$$g_1(c_t) = \frac{\partial g(c_t)}{\partial c_{1,t}} = \alpha^\phi \frac{\partial c_{1,t}}{\partial c_{1,t}} \left[ \frac{1}{\alpha^\phi} c_{1,t} + (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} \right] = \alpha^\phi c_{1,t}$$

$$g_2(c_t) = \frac{\partial g(c_t)}{\partial c_{2,t}} = (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} \left[ \frac{1}{\alpha^\phi} c_{1,t} + (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} \right] = (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} c_{1,t}$$

The second derivatives are:

$$g_{11}(c_t) = -\frac{1}{\phi} \alpha^\phi \frac{\partial c_{1,t}}{\partial c_{1,t}} \left[ \frac{1}{\alpha^\phi} c_{1,t} + (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} \right] = -\frac{1}{\phi} \alpha^\phi c_{1,t}$$

$$g_{12}(c_t) = -\frac{1}{\phi} \alpha^\phi (1 - \alpha) \frac{1}{\alpha^\phi} c_{1,t} \frac{1}{\alpha^\phi} c_{2,t} \left[ \frac{1}{\alpha^\phi} c_{1,t} + (1 - \alpha) \frac{1}{\alpha^\phi} c_{2,t} \right] = -\frac{1}{\phi} \alpha^\phi c_{2,t} c_{1,t}$$

$$g_{21}(c_t) = g_{12}(c_t)$$

117
\[ g_{22}(c_t) = -\frac{1}{\phi}(1 - \alpha)\frac{1}{\phi} \frac{1}{2} c_{2,t}^{\phi - 1} \left[ \frac{1}{\alpha^{\phi} c_{1,t}^{\phi} + (1 - \alpha)^{\phi} c_{2,t}^{\phi}} \right] \]
\[ + \frac{1}{\phi}(1 - \alpha)\frac{1}{\phi}^{2} c_{2,t}^{\phi - 2} \left[ \frac{1}{\alpha^{\phi} c_{1,t}^{\phi} + (1 - \alpha)^{\phi} c_{2,t}^{\phi}} \right] \]

**B.2 Nash Allocation**

Consider the problem faced by the Foreign planner,

\[ \max_{\{c_t^i\}} \sum_{t=0}^{\infty} \beta^t u(g(c_t^i)) \quad (P1^* \text{ Nash}) \]
\[ s.t \sum_{t=0}^{\infty} [\Pi_{s=0}^{t-1}(1 - \theta_s)] \beta^t u'(g(c_t^i)) \tau_t^{-1} \nabla g(c_t^i) \cdot (c_t^i - y_t^i) \leq 0 \quad (IC^* \text{ Nash}) \]

where,

\[ \tau_t = \begin{bmatrix} 1 & 0 \\ 0 & (1 - \tau) \end{bmatrix} \quad (B.9) \]

The first order conditions for the Foreign country with respect to \( c_{H,t}^i \) and \( c_{F,t}^i \) are given by,

\[ C_t^{-\sigma} g_{1,t}^* = \mu \left[ \Pi_{s=0}^{t-1}(1 - \theta_s) \right] \left\{ C_t^{-\sigma} g_{1,t} + \sigma C_t^{-\sigma - 1} g_{1,t} \left[ \frac{g_{1,t}(c_{1,t}^i - y_{1,t}^i)}{g_{2,t}(1 - \tau) - 1(c_{2,t}^i - y_{2,t}^i)} \right] \right\} \]
\[ \Rightarrow \quad C_t^{-\sigma} g_{1,t}^* = \mu \hat{MC}_{1,t}^* \quad (B.10) \]

and,

\[ C_t^{-\sigma} g_{2,t}^* = \mu \left[ \Pi_{s=0}^{t-1}(1 - \theta_s) \right] \left\{ C_t^{-\sigma} g_{2,t}(1 - \tau) - 1 + \sigma C_t^{-\sigma - 1} g_{2,t} \left[ \frac{g_{1,t}(c_{1,t}^i - y_{1,t}^i) + g_{2,t}(1 - \tau) - 1(c_{2,t}^i - y_{2,t}^i)}{g_{2,t}(1 - \tau) - 1(c_{2,t}^i - y_{2,t}^i)} \right] \right\} \]
\[ \Rightarrow \quad C_t^{-\sigma} g_{2,t}^* = \mu \hat{MC}_{2,t}^* \quad (B.11) \]

**B.2.1 Proof to Proposition 5**

Dividing (3.17) by its \( t + 1 \) analogue yields,

\[ \frac{C_t^{-\sigma} g_{1,t}}{C_{t+1}^{-\sigma} g_{1,t+1}} = \frac{1}{1 - \theta^*_t} \frac{\hat{MC}_{1,t}}{\hat{MC}_{1,t+1}} \quad (B.12) \]

Evaluating the Foreign analogue for \( i = 1 \), i.e. (B.10), and using it to substitute out \( \frac{1}{1 - \theta^*_t} \) above, and using the analogous Home euler to substitute in \( 1 - \theta_t \) yields the expression for the
optimal tax on capital flows levied by the Home country:

\[
1 - \theta_t = \frac{1}{\frac{1}{g_{1,t}} + \frac{1}{g_{1,t+1}}}
\left[\frac{\sigma g_{1,t}^*(c^*_{1,t} - y^*_{1,t}) + g_{2,t}^* (1 - \tau_t^*)^{-1}(c^*_{2,t} - y^*_{2,t})}{\sigma C_t^* g_{1,t}^* + g_{2,t+1}^* (1 - \tau_t+1)^{-1}(c^*_{2,t+1} - y^*_{2,t+1})}\right] -
\]

Dividing (B.10) by its \(t + 1\) analogue yields,

\[
\frac{C_t^* g_{1,t}^*}{C_{t+1}^* g_{1,t+1}^*} = \frac{1}{1 - \theta_t}
\left[\frac{C_t^* g_{1,t}^* + \sigma C_t^{*-1} g_{1,t}}{C_{t+1}^* g_{1,t+1} + \sigma C_{t+1}^{*-1} g_{1,t+1}}\right] -
\]

\[
\frac{C_t^* g_{1,t}^*}{C_{t+1}^* g_{1,t+1}^*} = \frac{1}{1 - \theta_t}
\left[\frac{C_t^* g_{1,t}^* + \sigma C_t^{*-1} g_{1,t}}{C_{t+1}^* g_{1,t+1} + \sigma C_{t+1}^{*-1} g_{1,t+1}}\right] -
\]

and following the analogous steps as for (B.12) yields the expression for the optimal tax on capital flows levied by the Foreign country:

\[
1 - \theta_t^* = \frac{1}{\frac{1}{g_{1,t}} + \frac{1}{g_{1,t+1}}}
\left[\frac{\sigma g_{1,t}^*(c^*_{1,t} - y^*_{1,t}) + g_{2,t}^* (1 - \tau_t^*)^{-1}(c^*_{2,t} - y^*_{2,t})}{\sigma C_t^* g_{1,t}^* + g_{2,t+1}^* (1 - \tau_t+1)^{-1}(c^*_{2,t+1} - y^*_{2,t+1})}\right] -
\]

To reach the conditions characterizing allocations in a Nash equilibrium, combine (B.12) and
Similarly, combining (B.14) and (B.13) yields,

\[
C_t^{-\sigma} g_{1,t} + \sigma C_t^{-\sigma - 1} g_{1,t}' \left[ \frac{g_{1,t}' (c_{1,t} - y_{1,t}) + g_{2,t}' (1 - \tau_t^*)^{-1} (c_{2,t} - y_{2,t})}{g_{11,t} (c_{1,t} - y_{1,t}) + g_{21,t} (1 - \tau_t^*)^{-1} (c_{2,t} - y_{2,t})} \right] - \frac{1 - \tau_t^*}{1 - \tau_t} = \alpha_{1,0},
\]

Similarly, combining (B.14) and (B.13) yields,

\[
C_t^{-\sigma} g_{2,t} (1 - \tau_t^*)^{-1} + \sigma C_t^{-\sigma - 1} g_{2,t}' \left[ \frac{g_{2,t}' (c_{1,t} - y_{1,t}) + g_{2,t}' (1 - \tau_t^*)^{-1} (c_{2,t} - y_{2,t})}{g_{21,t} (1 - \tau_t^*)^{-1} (c_{2,t} - y_{2,t})} \right] - \frac{1 - \tau_t^*}{1 - \tau_t} = \alpha_{2,0}.
\]

The constant \(\alpha_{1,0}\) is given by,

\[
\alpha_{1,0} = \frac{C_0^{-\sigma} g_{1,0} + \sigma C_0^{-\sigma - 1} g_{1,0}' \left[ \frac{g_{1,0}' (c_{1,0} - y_{1,0}) + g_{2,0} (1 - \tau_0^*)^{-1} (c_{2,0} - y_{2,0})}{g_{11,0} (c_{1,0} - y_{1,0}) + g_{21,0} (1 - \tau_0^*)^{-1} (c_{2,0} - y_{2,0})} \right] - \frac{1 - \tau_0^*}{1 - \tau_0}}
\]

and \(\alpha_{2,0}\) is given by,

\[
\alpha_{2,0} = \frac{1 - \tau_0^*}{1 - \tau_0} \frac{C_0^{-\sigma} g_{2,0} (1 - \tau_0^*)^{-1} + \sigma C_0^{-\sigma - 1} g_{2,0}' \left[ \frac{g_{1,0}' (c_{1,0} - y_{1,0}) + g_{2,0} (1 - \tau_0^*)^{-1} (c_{2,0} - y_{2,0})}{g_{12,0} (c_{1,0} - y_{1,0}) + g_{22,0} (1 - \tau_0^*)^{-1} (c_{2,0} - y_{2,0})} \right] - \frac{1 - \tau_0^*}{1 - \tau_0}}
\]
Finally, substituting out $\tau_t$ and $\tau_t^*$ yields,

$$C_t^{\alpha-\sigma}g_{1,t}^* + \sigma C_t^{\alpha-\sigma-1}g_{2,t}^* \left[ \begin{array}{c} g_{1,t}^*(c_{1,t} - y_{1,t}) + g_{1,t}^*S_t(c_{2,t} - y_{2,t}) \\ \end{array} \right] = \alpha_{1,0},$$

and,

$$C_t^{\alpha-\sigma}g_{2,t}^* + \sigma C_t^{\alpha-\sigma-1}g_{2,t}^* \left[ \begin{array}{c} g_{1,t}^*(c_{1,t} - y_{1,t}) + g_{1,t}^*S_t(c_{2,t} - y_{2,t}) \\ \end{array} \right] = \alpha_{2,0},$$

which complete the proof.

To derive the optimal tariffs, divide the Foreign by the Home optimality condition for good 1 and use the Euler to substitute in the Home optimal tariff on the LHS. Use the foreign Euler to substitute out the Foreign optimal tariff:

$$1 - \tau_t = \frac{1}{S_t}$$
and,

\[ C_t^{-\sigma}g_{1,t}S_t + \sigma C_t^{-\sigma-1}g_{2,t} \left[ \frac{g_{1,t}(c_{1,t}^* - y_{1,t})}{g_{1,t}S_t(c_{2,t} - y_{2,t})} \right] - C_t^{-\sigma}g_{12,t}(c_{1,t}^* - y_{1,t}^*) + \frac{g_{11,t}S_t(c_{2,t}^* - y_{2,t}^*)}{g_{2,t}S_t(c_{2,t} - y_{2,t})} \]

\[
1 - \tau_t^* = \frac{1}{S_t} \left( C_t^{-\sigma}g_{1,t} + \sigma C_t^{-\sigma-1}g_{1,t} \right) \left[ \frac{g_{1,t}(c_{1,t} - y_{1,t})}{g_{1,t}S_t(c_{2,t} - y_{2,t})} \right] - C_t^{-\sigma}g_{12,t}(c_{1,t}^* - y_{1,t}^*) + \frac{g_{11,t}S_t(c_{2,t}^* - y_{2,t}^*)}{g_{2,t}S_t(c_{2,t} - y_{2,t})} \]

abroad.

**B.2.2 Nash equilibrium with FTA**

Consider the Nash problem when a FTA is in place for both Home and Foreign planners. If a FTA is in place, \( \tau_t, \tau_t^* = 1 \), the Home planner chooses \( C_t \) and the Foreign \( C_t^* \) and \( c(C_t), c^*(C_t^*) \) are given by Lemma 1. Then the allocations \( C_t, C_t^* \) in a Nash equilibrium must satisfy,

\[
C_t^{\ast -\sigma}(g_{11,t}^*c_{1,t}^*(C_t) + g_{2,t}^*c_{2,t}^*(C_t)) + \sigma C_t^{\ast -\sigma-1}C_t^{\ast'}(C_t) \left[ g_{1,t}^*(c_{1,t} - y_{1,t}) + g_{2,t}^*(c_{2,t} - y_{2,t}) \right] + C_t^{\ast -\sigma} \left[ (g_{11,t}^* + g_{21,t})c_{1,t}^*(C_t)(c_{1,t} - y_{1,t}) + (g_{12,t}^* + g_{22,t})c_{2,t}^*(C_t)(c_{2,t} - y_{2,t}) \right] = \alpha_0^{FTA}
\]

\[
C_t^{\ast -\sigma}(g_{11,t}^*c_{1,t}^*(C_t) + g_{2,t}^*c_{2,t}^*(C_t)) + \sigma C_t^{\ast -\sigma-1}C_t^{\ast'}(C_t) \left[ g_{1,t}^*(c_{1,t} - y_{1,t}) + g_{2,t}^*(c_{2,t} - y_{2,t}) \right] + C_t^{\ast -\sigma} \left[ (g_{11,t}^* + g_{21,t})c_{1,t}^*(C_t)(c_{1,t} - y_{1,t}) + (g_{12,t}^* + g_{22,t})c_{2,t}^*(C_t)(c_{2,t} - y_{2,t}) \right] = \alpha_0^{FTA}
\]

Optimal capital controls levied by the home country are given by,

\[
1 - \theta_t = \frac{(g_{11,t}^*c_{1,t}^*(C_t) + g_{2,t}^*c_{2,t}^*(C_t)) + \sigma C_t^{\ast -1}C_t^{\ast'}(C_t) \left[ g_{1,t}^*(c_{1,t} - y_{1,t}) + g_{2,t}^*(c_{2,t} - y_{2,t}) \right] + C_t^{\ast -\sigma} \left[ (g_{11,t}^* + g_{21,t})c_{1,t}^*(C_t)(c_{1,t} - y_{1,t}) + (g_{12,t}^* + g_{22,t})c_{2,t}^*(C_t)(c_{2,t} - y_{2,t}) \right]}{(g_{11,t}^*c_{1,t}^*(C_t+1) + g_{2,t}^*c_{2,t}^*(C_t+1)) + \sigma C_{t+1}^{\ast -1}C_{t+1}^{\ast'}(C_{t+1}) \left[ g_{1,t}^*(c_{1,t+1} - y_{1,t+1}) + g_{2,t}^*(c_{2,t+1} - y_{2,t+1}) \right] + C_{t+1}^{\ast -\sigma} \left[ (g_{11,t+1}^* + g_{21,t+1})c_{1,t+1}^*(C_{t+1})(c_{1,t+1} - y_{1,t+1}) + (g_{12,t+1}^* + g_{22,t+1})c_{2,t+1}^*(C_{t+1})(c_{2,t+1} - y_{2,t+1}) \right]}
\]

with an analogous condition for the foreign.
B.3 Cooperative Allocation

B.3.1 Proof to Proposition 6

When a FTA is in place, the optimal cooperative allocation satisfies,

\[ u'(g(c_t)) + \kappa u'(g(c_t^*)) \frac{dC^*}{dC} = 0 \]  \hspace{1cm} (B.18)

where \( \frac{dC^*}{dC_t} = -\frac{P_t}{P^*_t} \), yielding the decentralised risk sharing condition (3.10) with \( \kappa = \frac{u'(g(c_{t-1}^*)) P^*_t}{u'(g(c_{t-1}^*)) P_{t-1}} \) implying \( \theta_t = 0 \). Relaxing the FTA does not change the optimal allocation (since goods taxes are zero at the optimal). With FTA, first order condition follows straightforwardly by substituting \( \frac{dC^*}{dC_t} = -\frac{P_t}{P^*_t} \).

Relaxing the FTA, we get two first order conditions,

\[ u'(g(c_t))g_1 + \kappa u'(g(c_t^*))g_1^* \frac{dC^*}{dC_1} = 0, \] \hspace{1cm} (B.19)

\[ u'(g(c_t))g_2 + \kappa u'(g(c_t^*))g_2^* \frac{dC^*}{dC_2} = 0 \]  \hspace{1cm} (B.20)

Note that \( g_1/g_1^* = \frac{dC}{dC_1} \frac{dC^*}{dC} = \frac{dC}{dC_2} \frac{dC^*}{dC_1} = -\frac{dC}{dC^*} \), therefore both of the above conditions imply (B.18), as in the FTA case. \( \square \)
B.4 Computational Appendix

We consider a setup without uncertainty. Our model is therefore simply solved as the following system of equations. Consider the one good case.

The model has $T + 2$ FOCs: $T + 1$ w.r.t. $c_t$ and 1 with respect to the multiplier $\mu_0$

$$c_t^{-\sigma} = \mu_0 \left[ c_t^{* - \sigma} - \sigma c_t^{* - \sigma - 1} (y_t - c_t) \right] \quad \text{for } t = 0, 1, \ldots, T$$

$$0 = \sum_{t=0}^{T} \beta_t c_t^{* - \sigma} (y_t - c_t)$$

In addition we have market clearing in each period:

$$c_t + c_t^* = y_t + y_t^* \quad \text{for } t = 0, 1, \ldots, T$$

Thus we have $2T + 3$ equations in $2T + 3$ unknowns: $\{c_t\}_{t=0}^{T}$, $\{c_t^*\}_{t=0}^{T}$ and $\mu_0$.

Using vector notation, taking $y = [y_0 \ y_1 \ \ldots \ y_T]'$ and $y^* = [y_0^* \ y_1^* \ \ldots \ y_T^*]'$ as inputs, then solving the following system of equations,

$$c^{-\sigma} = \mu_0 \left[ c^{* - \sigma} - \sigma c^{* - \sigma - 1} (y - c) \right]$$

$$c + c^* = y + y^*$$

$$0 = x'(y - c), \quad \text{where } x = b \odot c^{* - \sigma}$$

where $b = [\beta^0 \ \beta^1 \ \ldots \ \beta^T]'$. 
B.5 World Trade Organisation Data

Figure B.1: Decline in Regional Trade Agreements in Recent Years

Notes: Number of regional trade agreements per year (bars, left-hand axis). Cumulative number of regional trade agreements, with cumulation beginning in 1948 (lines, right-hand axis). Source: WTO.
Appendix C

Appendix to Chapter 4

C.1 Supporting Evidence

This appendix provides evidence in support of the motivation and mechanisms of the chapter.

Evidence on deviations from the Uncovered Interest Parity  Figure C.1 documents the recurrent patterns of returns on a portfolio long in foreign currency bonds, funded by borrowing in U.S. treasuries. The sample considers all G10 and EM7 currencies. Figure C.2 splits the sample intro the two country groups. Both G10 and EM7 currency-denominated debt trades at a higher (realized) return during crises. The portfolio returns for EM7 currencies are larger, and significantly so in the most recent COVID-19 episode. However, the spread exists for G10 countries too.

Evidence on dollar demand. Next, I discuss evidence on the correlation of capital flows and portfolio returns. As is clear from Figure C.1, the difference in the returns on foreign currency and dollar debt is small outside of crises. At the onset of crises, the dollar appreciates resulting in a higher realised cost of borrowing in dollar debt. Borrowing in dollar debt is however much cheaper during crises, generating the monopoly rents at the core of this paper. Figure C.3 plots gross trade volumes and the peak occurs during the GFC. Specifically, Krishnamurthy and Lustig (2019) show that gross flows are strongly negatively correlated with the changes in the spread. The correlation between gross purchases of Treasuries by foreigners and the change in the 3-month spread is -0.58 at monthly frequencies, so foreign investors go long in treasuries \(-\xi_t > 0\) in the model– when it is least profitable to do.

Related to this, Figure C.4, from Corsetti, Lloyd, and Marin (2020), plots emerging market capital flows and exchange rate risk premia as 6-month moving averages. While the correlation of these two variables is close to zero when calculated over the whole period, it becomes strongly positive around periods of significant financial distress and low liquidity. Over a 2005:01-2020:03 sample, the correlation between non-resident portfolio flows to EMs and the EM PPP-weighted exchange rate risk premium, at monthly frequency, is just 0.08, consistent with a \(\Gamma_t\) close to zero. This result is often highlighted by the literature on the ‘exchange rate disconnect’, stressing the apparent weak relationship between currency valuation and economic fundamentals, including capital flows, see e.g. Meese and Rogoff (1983). However, a rolling correlation between these series over a 6-month window highlights that this correlation rises to above 0.75 during periods of financial distress: the Great Financial Crisis, the 2013 Taper Tantrum and the recent COVID
Figure C.1: (a) 3-month forward sum of ex-post deviations from the uncovered interest rate parity (UIP) based on a trade-weighted average of G10 and EM7 currencies in p.p. (b) 3-month Interest rate differentials, 3-month dollar index movements. Shaded regions reflect periods when dollar swap facilities exceeded $600,000 million. Source: Global Financial Data, Federal Reserve and author’s calculations.

Figure C.2: Source: Federal Reserve

crisis—all of which are characterised by large capital movements and low international liquidity. In these periods, through the lens of the model, the data suggests that the level of liquidity – \( \Gamma_t \) in the model— that is substantially high.

Lemma 1 suggests that within the model, dollar demand is proportional to the up-take of dollar swap lines. C.5 below plots dollar swap up-take and suggests that dollar demand peaked during the GFC, the European sovereign debt crisis and after COVID-19, consistent with the evidence above.
Figure C.3: Evidence on timing of purchases of U.S. bonds by foreigners. Purchases by foreign investors and sales to foreign investors normalised by the foreign holdings of Treasuries. Source: Krishnamurthy and Lustig (2019).

Figure C.4: Capital flows and *ex post* exchange rate risk premia for EMs

*Note:* 6-month moving average of: non-resident portfolio flows to EMs, and 1-month *ex post* EM exchange rate risk premia vis-à-vis US dollar (PPP-weighted). Capital flows cumulated over each calendar month, with negative value implying an outflow from EMs. Moving averages plotted at end-date of period. Shaded areas denote periods in which 6-month rolling correlation of raw capital flows and exchange rate risk premia exceed 0.75. Unconditional correlation of raw series equal to 0.08 over the sample. *Dates:* January 2005 to March 2020. *Data Sources:* Datastream, IIF, IMF International Financial Statistics.

Figure C.5: Weekly outstanding dollar swaps (Wednesday level). Source: Federal Reserve
Evidence on U.S. Carry Trade Portfolio. In the model, monopoly rents for the U.S. accrue even in the absence of interest rate adjustments through its holdings of foreign currency assets. Figure C.6 (left panel) plots the net investment position of the U.S., as a % of GDP, from 2006Q1 to 2021Q4, calculated as the difference in gross external assets and liabilities (right panel), and has rapidly worsened over time. Data from Bénétrix, Lane, and Shambaugh (2015) suggests that over 80% of external liabilities are dollar denominated, and over 60% of external assets are foreign currency denominated, so the U.S. holds a large carry trade portfolio consistent with the mechanisms in the paper.

![Figure C.6](image)

Figure C.6: Left Panel: Net Investment Position for the United States in as % GDP. Right panel: Gross assets and liabilities as % GDP. Source: BEA and author’s calculations.

Evidence of Wealth Inflows to the U.S. during the GFC. The final figure contrasts the calculation of the U.S. net foreign asset position around the GFC by Maggiori (2017) and Jiang, Krishnamurthy, and Lustig (2020). The latter consider a wider set of assets and find evidence of a net transfer to the U.S. from abroad, even though the position deteriorated in absolute value. – consistent with the mechanism in this paper. Specifically, they consider equities, bonds, and deposits issued in the U.S., held by both U.S. and non-U.S. agents, plotted by the black-dashed line. The red line measures the same quantity for Canada, Germany, France, Great Britain and Japan.

![Figure C.7](image)

Figure C.7: Left panel: Figure 5 from Maggiori (2017). Right panel: Figure 5 from Jiang, Krishnamurthy, and Lustig (2020).
C.2 Further derivations for Section 3: Analytical Hegemon’s Dilemma

For convenience, I repeat below the expression for the exchange rate,

\[ E_1 = \tilde{E} \left( \frac{\bar{\mu}}{\mu_1} - \Gamma_1 Q_1 \right)^{-1} \] (C.1)

for a given monetary policy \( \mu_1 \). The monetary policy rule determining \( \mu_1 \) is given by:

\[ \mu = (1 - s)\bar{\mu} + s\bar{\mu} (1 + \Gamma_1 Q_1)^{-1} \] (C.2)

For \( s < 1 \), dollar shortages \( (Q_1 < 0) \) lead to an appreciation.

The derivatives \( \frac{d\mu_1}{dQ_1} \) and \( \frac{d\mu_1}{d\Gamma_1} \) characterize monetary decisions in response to dollar imbalances and liquidity and, in turn, these determine \( \frac{dE_1}{dQ_1} \), \( \frac{dE_1}{d\Gamma_1} \). Specifically,

\[ \frac{dE_1}{dQ_1} = -E \left( \frac{\bar{\mu}}{\mu_1} - \Gamma_1 Q_1 \right)^{-2} \left[ -\frac{\bar{\mu}}{\mu_1^2} \frac{d\mu_1}{dQ_1} - \frac{\Gamma_1}{\mu_1} \right], \] (C.3)

\[ \frac{dE_1}{d\Gamma_1} = -E \left( \frac{\bar{\mu}}{\mu_1} - \Gamma_1 Q_1 \right)^{-2} \left[ -\frac{\bar{\mu}}{\mu_1^2} \frac{d\mu_1}{d\Gamma_1} - 1 \right], \] (C.4)

where the first term in the square brackets is the standard "UIP channel" by which interest rates affect exchange rates and the second term is the risk premium channel, akin to a Bernanke and Blinder (1992) "credit channel".

Consider the labour wedge \( \tau_1 \), given by (4.27). The derivatives with respect to \( Q_1 \) and \( \Gamma_1 \) are given by:

\[ \frac{d\tau_1}{dQ_1} = -\frac{1}{A_1} \frac{\kappa}{\bar{P}_H} \left\{ \frac{d\mu_1}{dQ_1} \bar{L}^\psi + \mu_1 \psi L^\psi - 1 \left[ \frac{\chi}{\bar{P}_H} \frac{d\mu_1}{dQ_1} \frac{\zeta}{\bar{P}_H} \frac{\xi_1}{\eta} \frac{d\xi_1}{dQ_1} \right] \right\}, \] (C.5)

\[ \frac{d\tau_1}{d\Gamma_1} = -\frac{1}{A_1} \frac{\kappa}{\bar{P}_H} \left\{ \frac{d\mu_1}{d\Gamma_1} \bar{L}^\psi + \mu_1 \psi L^\psi - 1 \left[ \frac{\chi}{\bar{P}_H} \frac{d\mu_1}{d\Gamma_1} \frac{\zeta}{\bar{P}_H} \frac{\xi_1}{\eta} \frac{d\xi_1}{d\Gamma_1} \right] \right\}, \] (C.6)

where \( \frac{d\mu_1}{dQ_1} = -s\bar{\mu} \frac{\Gamma_1}{(1 + \Gamma_1 Q_1)^2} \), and \( \frac{d\mu_1}{d\Gamma_1} = -s\bar{\mu} \frac{Q_1}{(1 + \Gamma_1 Q_1)^2} \).

Consider next the portfolio returns \( \Omega_2 \), which can be rewritten as:

\[-\Gamma_1 x_1^2 + \Gamma_1 \xi_1 x_1 + \omega \Gamma_1 (x_1 - \xi_1)^2 \] (C.7)

An additional unit of \( x_1 \) lowers the return on the portfolio by eroding the scarcity of dollar abroad but, for a given size of dollar shortages, an additional unit of \( x_1 \) expands the size of the portfolio—so (C.7) captures the ‘returns Laffer curve’.

The derivatives of monopoly rents \( \Omega_2 \) with respect to \( x_1 \) and \( \Gamma_1 \) are as follows:

\[ \frac{d\Omega_2}{dx_1} = -2\Gamma_1 x_1 + \Gamma_1 \xi_1 + 2\omega \Gamma_1 Q_1, \] (C.8)

\[ \frac{d\Omega_2}{d\Gamma_1} = -x_1^2 + \xi_1 x_1 + \omega Q_1^2 \] (C.9)

where (C.7) describes the returns Laffer curve faced by the hegemon. For low values of \( x_1 \), each additional unit issued increases \( \Omega_2 \) but for high values of \( x_1 \), \( \frac{d\Omega_2}{dx_1} \) turns negative.
Proof to Proposition 1.

Trade-off- part (i): The relationship between the labour wedge and dollar shortages is given by (C.5) and depends on the responsiveness parameter \( s \) through \( \frac{d\mu_{1}}{d\xi_{1}} \). The level of \( s \) which stabilises the labour wedge \( \bar{s} \) is implicitly defined by setting \( \frac{d\tau_{1}}{d\xi_{1}} = 0 \). Notice that for \( s = 0 \), \( \frac{d\mu_{1}}{d\xi_{1}} > 0 \) since the appreciation lowers exports and \( \mu_{1} \) is constant. Instead, if \( s = 1 \), \( \frac{d\mu_{1}}{d\xi_{1}} < 0 \), since exchange rates are stabilised but monetary policy is expansionary. Given that \( \frac{d\mu_{1}}{d\xi_{1}} \) is a continuous function, \( s \) exists by the intermediate value theorem.

The relationship between the hegemon’s portfolio returns and dollar shortages is given by (C.8) and is strictly increasing \( \frac{d\Omega_{2}}{d\xi_{1}} < 0 \) as long as there are dollar shortages \( Q_{1} < 0 \).

Optimality- part (ii): The first-order conditions for (HD1) with respect to \( x_{1} \) and \( \Gamma_{1} \) respectively are given by

\[
\omega S \text{sign}(\tau - \tau_{1}) \frac{d\tau_{1}}{dx_{1}} + (1 - \omega S) \frac{d\Omega_{2}}{dx_{1}} = 0, \tag{C.10}
\]

\[
\omega S \text{sign}(\tau - \tau_{1}) \frac{d\tau_{1}}{d\Gamma_{1}} + (1 - \omega S) \frac{d\Omega_{2}}{d\Gamma_{1}} = 0, \tag{C.11}
\]

where \( \frac{d\tau_{1}}{dx_{1}} \), \( \frac{d\Omega_{2}}{dx_{1}} \), \( \frac{d\tau_{1}}{d\Gamma_{1}} \) and \( \frac{d\Omega_{2}}{d\Gamma_{1}} \) are given by (C.5), (C.6), (C.8) and (C.9). If the planner chooses \( \Gamma_{1} \geq \frac{1}{Q_{1}} \), then (C.11) is replaced by \( \frac{d\Omega_{2}}{d\Gamma_{1}} \). Combining (C.10) and (C.11) with (C.5), (C.6), (C.8) and (C.9) yields the optimal allocation \( \{x_{1}, \Gamma_{1}\} \).

Consider the case where the planner only cares to stabilize the labour wedge, captured by \( \omega S = 1 \). If \( \Gamma_{1} \) is bounded from below above zero, perfect stabilization can only be achieved if \( dx_{1} = -d\xi_{1} \), i.e the hegemon satisfies dollar excess demand by issuing dollar bonds. If \( \Gamma_{1} = 0 \) can be reached with dollar swaps, stabilization can be achieved using either dollar swaps or issuance.

Instead, consider the case where the planner only cares about maximizing its portfolio returns \( \omega S \to 0 \). Then, rearranging (C.10):

\[
x_{1} = \xi_{1} \frac{1 - 2\omega}{2 - 2\omega} \tag{C.12}
\]

which is the level of \( x_{1} \) at the top of the Laffer curve (C.7). From this, it follows that \( 0 < \frac{dx_{1}}{d\xi_{1}} < 1 \) leading to \( \frac{dQ_{1}}{dx_{1}} < 0 \). In other words, the optimal allocation does not entail perfectly stabilising shortages. Additionally, \( \frac{d\Omega_{1}}{d\Gamma_{1}} > 0 \) as long as \( x_{1} > 0 \) and \( Q_{1} < 0 \) therefore dollar swaps are not used.

For intermediate values of \( \omega S \), the hegemon trades off monopoly rent maximization for macroeconomic stabilization requiring inefficiently high \( x_{1} \), relative to (C.12). Given \( \frac{d\tau_{1}}{d\tau_{1}} > 0 \), \( \frac{d\Omega_{2}}{d\Gamma_{1}} > 0 \) if \( Q_{1} < 0 \) then, from (C.11) we see that dollar swaps become useful as \( |\tau - \tau_{1}| \) grows.

The following figure plots the objective function when \( w S = 0.2 \). Notice that the Laffer curve is now shifted to higher levels of \( x_{1} \).

Exorbitant privilege vs. valuation effects. Monopoly rents represent a wealth inflow to the U.S. during crises, when demand for dollars is high. However, the return on the U.S. portfolio of assets initially falls due to the sharp appreciation, documented in Figure C.1. This
initial fall in portfolio returns is referred to as ‘valuation effects’, see e.g. Gourinchas and Rey (2007) and Gourinchas, Rey, and Govillot (2018) and contributes to a wealth outflow at the onset of crises. To analyze the two-way relationship between issuance policy and dollar swaps on valuation effects, I consider the return on a portfolio \((x_1 = a^F)\) formed at time 0. From this, the hegemon earns \(R^*E_1 - R_0\) in period 1. An unanticipated appreciation of the dollar lowers the dollar-return of the time 0 portfolio at \(t = 1\). For all values of \(w^S\), the hegemon has a stronger incentive to prevent an appreciation at \(t = 1\), either by issuing more debt or by extending dollar swaps.

\[ x_1 = \xi_1 - x_1 - \sum_{i>0}^{N-1} x_i, \]

Imposing symmetry \((x_i = x_1 \forall i)\) yields the optimal issuance chosen by the planner when there are \(N\) competing issuers:

\[ x_1 = \frac{\xi_1 - \sum_{i>0}^{N-1} x_i}{N}, \quad Q_1 = \frac{\xi_1 - x_1 - \sum_{i>0}^{N-1} x_i}{N}. \]

As the number of competing issuers becomes large, dollar shortages go to zero. In the case \(w^S = 1\), as detailed above, each individual issuer finds \(Q_1 = 0\) optimal.

---

\(^1\)Notice that this return can be re-written using (4.15) as \(-\Gamma_0 Q_0 - (E_0|\xi_1 - \xi_1|)/E_0\), where \(\Gamma_0 Q_0 = 0\) and \(E_0|\xi_1 - \xi_1| > 0\). Then, \(Q_2 = -\Gamma_1 Q_1 x_1 + \omega \Gamma_1 Q_1^2 - \left(1 - \frac{\xi_1}{E_0}\right) x_0\). Since \(\frac{\xi_1}{E_0} < 1\) for all \(s < 1\), \(Q_2\) falls relative to before for \(Q_1 < 0\).
C.3 Further derivations for Section 4: Constrained Optimal Allocation

C.3.1 Deriving indirect utility function

To derive the indirect utility function, start from (4.1) and substitute in (4.7) and (4.9):

\[ V(C_{F,t}, \mathcal{E}_t) = \chi \log \left( \frac{\chi}{1 - \chi} \frac{P_{F,t}}{P_{H,t}} C_{F,t} \right) + (1 - \chi) \log(C_{F,t}) \]

\[ -\kappa \left[ \frac{\chi}{1 - \chi} \frac{P_{F,t}}{P_{H,t}} C_{F,t} + (1 - \chi) \frac{P^*_{F,t}}{P_{H,t}} C_{F,t} \right] \]

Assuming prices are perfectly rigid, \( P_{H,t} = \bar{P}_H \), and normalizing foreign prices to 1, \( P_{F,t} = \bar{P}_F \mathcal{E}_t^\lambda \). With perfectly rigid prices, the firms' pricing condition (4.11), is not a constraint in equilibrium on the planning problem, but is instead only used to back out prices. Note also that,

\[ C^*_H = (1 - \chi) \left( \frac{P^*_F}{P_H} \right)^{\eta} C^* = (1 - \chi) \mu^* \left( \frac{\mathcal{E}_t}{P_H} \right)^{\eta}. \]

The partial derivatives with respect to \( C_{F,t} \) and \( \mathcal{E}_t \), are given by,

\[ V_{C_{F,t}} = \frac{1 - \chi}{C_{F,t}} \left( 1 + \frac{\chi}{1 - \chi} \tau_t \right) \]

\[ V_{\mathcal{E}_t} = \frac{1 - \chi}{C_{F,t}} \left( \tau_t \left( \frac{\chi}{1 - \chi} \lambda \mathcal{E}_t^{1-\lambda} C_{F,t} + \zeta \eta \frac{P_H^{1-\eta}}{\mathcal{E}_t^{\eta-\lambda-1}} + \frac{\chi G}{1 - \chi} \lambda \mathcal{E}_t^{1-\lambda} G_{F,t} \right) - \zeta \eta P_H^{1-\eta} \mathcal{E}_t^{\eta-\lambda} \right) \]

\[ -\frac{\chi G}{1 - \chi} \lambda \mathcal{E}_t^{1-\lambda} G_{F,t} \] + \omega G \frac{1 - \chi}{G_{F,t}} \frac{\chi G}{1 - \chi} \lambda \mathcal{E}_t^{1-\lambda} G_{F,t}, \]

where I have used that \(-\kappa L^*_t = (\tau_t - 1) A \frac{1 - \chi}{C_{F,t}} \frac{P_H}{\mathcal{E}_t}\).

The planner's first order conditions for (HD2), with respect to \( C_{F,t}, \mathcal{E}_t, x_t \), respectively, are given by:

\[ C_{F,t} : \quad V_{C_{F,t}} - \eta^C_t - \eta^\mu_t + \frac{1}{\mathcal{E}_t^2 C_{F,t}^2} [\eta^E_t - R_{t-1} \eta^E_{t-1}] = 0, \]

\[ \mathcal{E}_t : \quad V_{\mathcal{E}_t} + \eta^C_t \zeta (\eta - \lambda) \mathcal{E}_t^{\eta-\lambda-1} \frac{P_H^{1-\eta}}{\mathcal{E}_t^{\eta-\lambda-1}} \]

\[ -\lambda \mathcal{E}_t^{1-\lambda} (x_t - a_t^F) - (1 - \lambda) \frac{R^* \mathcal{E}_t^{1-\lambda}}{\mathcal{E}_t^{1-\lambda}} (x_{t-1} - a_t^F) + \lambda \mathcal{E}_t^{1-\lambda} \Gamma_{t-1} Q_{t-1} (x_{t-1}) \]

\[ + \beta \eta^C_{t+1} \left\{ \frac{R^* \mathcal{E}_t^{1-\lambda}}{\mathcal{E}_t^{1-\lambda}} (x_t - a_t^F) \right\} \]

\[ + \eta^E_t \left\{ \frac{1}{C_{F,t}} \lambda \mathcal{E}_t^{1-\lambda} - \frac{1}{C_{F,t+1}} \beta R^* \mathcal{E}_t^{1-\lambda} \right\} + \eta^E_{t-1} \frac{1}{C_{F,t}} \left( 1 - \lambda \right) R^* \mathcal{E}_t^{1-\lambda} - \lambda \mathcal{E}_t^{1-\lambda} \Gamma_{t-1} Q_{t-1} \]

\[ - \eta^\mu_t \lambda \mathcal{E}_t^{1-\lambda} \mu (1 - \chi) = 0, \]

\[ x_t : \quad \eta^C_t \mathcal{E}_t^{1-\lambda} - \beta \eta^C_{t+1} \mathcal{E}_t^{1-\lambda} \left[ R_t + \Gamma_t (x_t) - 2 \omega \Gamma_t Q_t \right] + \eta^E_t \beta \Gamma_t \frac{1}{\mathcal{E}_t^{1-\lambda} C_{F,t+1}} = 0, \]
Next, I focus on deriving the monetary policy rule (4.35). Using (C.46) the monetary policy targeting rule can be written as:

\[ V_E^t + \eta_t^C \frac{dC^*_H}{dE_t^t} + \left\{ \eta_t^C \frac{dF_t}{dE_t^t} + \eta_{t+1}^C \frac{dF_{t+1}}{dE_t^t} \right\} + \left\{ \eta_t^E \frac{dR_t}{dE_t^t} \right\} + \left\{ \eta_{t-1}^E \frac{dR_{t-1}}{dE_t^t} \right\} = 0, \]

where,

\[ \frac{dC^*_H}{dE_t^t} = \zeta(\eta - \lambda)\xi_t^{\eta-\lambda-1}F_H^{-\eta}, \quad (C.21) \]

\[ \frac{dF_t}{dE_t^t} = -\lambda\xi_t^{-\lambda-1}(x_t + B_t - a_t^F) - (1 - \lambda)\frac{R^e\xi_t^{-\lambda}}{\xi_{t-1}^{-1}}(x_{t-1} - a_{t-1}^F), \quad (C.22) \]

\[ \frac{dF_{t+1}}{dE_t^t} = \beta R^e\frac{\xi_{t+1}^{-\lambda}}{\xi_t^{-1}}(x_t - a_t^F), \quad (C.23) \]

\[ \frac{dR_t}{dE_t^t} = \frac{1}{C_{F,t}} \lambda\xi_t^{-\lambda-1} - \frac{1}{C_{F,t+1}} \beta R^e\frac{\xi_{t+1}^{-\lambda}}{\xi_t^{-1}}, \quad (C.24) \]

\[ \frac{dR_{t-1}}{dE_t^t} = \frac{1}{C_{F,t}} \left\{ (1 - \lambda)\frac{\xi_t^{-\lambda}}{\xi_{t-1}^{-1}} - \lambda\xi_t^{-\lambda-1}\Gamma_{t-1}Q_{t-1} \right\}, \quad (C.25) \]

In the main body, (4.35) follows from grouping the terms in (C.27) as follows:

\[ V_{E_t} + \eta_t^C \frac{dC^*_H}{dE_t^t} + \left\{ \eta_t^C \frac{dF_t}{dE_t^t} + \eta_{t+1}^C \frac{dF_{t+1}}{dE_t^t} \right\} + \left\{ \eta_t^E \frac{dR_t}{dE_t^t} \right\} + \left\{ \eta_{t-1}^E \frac{dR_{t-1}}{dE_t^t} \right\} = 0, \quad (C.26) \]

If \( \eta_t^E > 0 \), the hegemon has an incentive to appreciate the exchange rate (higher interest rates) so that households delay consumption to the future. Since policy is set with commitment this is anticipated. Households at \( t \) expecting an appreciation at time \( t + 1 \), would instead increase their consumption and borrowing.

### C.4 Further Derivations for Section 5: Limited Financial Market Participation

**Proof to Proposition 4.**

Consider the market clearing equation (4.9) with \( C_{H,t} = a_tC_{A,t} + (1 - a_t)C_{NA,t} \). Assume equal rationing of goods’ firm profits, employment and lump-sum taxes such that \( \Pi^{g,i} = \Pi^g, L^i = L \) but assume that financiers profits accrue fully to active households. We can express inactive households’ consumption by,

\[ C_{F,t}^{NA} \leq \frac{a_t\chi}{1 - (1 - a_t)\chi} \xi_t^\lambda C_{F,t}^A + \frac{1 - \chi}{1 - (1 - a_t)\chi} \left( (1 - 1)\xi_t^\eta F_H^{-\eta} \right), \quad (C.27) \]
Similarly, evaluating the budget constraint (C.48) for active households’ and substituting (4.9) yields,

\[
\mathcal{E}_t^\lambda C^A_{F,t} \left(1 + \frac{\chi}{1-\chi} (1 - a_t)\right) \leq (1 - a_t) \frac{\chi}{1-\chi} \mathcal{E}_t^\lambda C^N_{A,F,t} + \zeta \mathcal{E}_t^{-\eta} P_H^{1-\eta} + F_t,
\]

where,

\[
F_t = x_t - a_t^F - R_{t-1}(x_{t-1} - a_{t-1}^F) - \Gamma_{t-1} Q_{t-1} a_{t-1}^F - R^* \mathcal{E}_{t-1}^\lambda \mathcal{E}_{t-1} + \omega \Gamma_t Q_t^2.
\]

Solving (C.27) and (C.28) jointly yields:

\[
C^A_{F,t} \leq \mathcal{E}_t^{-\lambda} \left[ \zeta \mathcal{E}_t^{-\eta} P_H^{1-\eta} + (1 - (1 - \alpha)) F_t \right],
\]

as detailed in (4.40). Substituting back into (C.27) yields:

\[
C^N_{A,F,t} \leq \mathcal{E}_t^{-\lambda} \left[ \zeta \mathcal{E}_t^{-\eta} P_H^{1-\eta} + \alpha \chi F_t \right].
\]

The total private portfolio return is given by \[a_t(1 - (1 - a_t)\chi) + (1 - a_t)\alpha \chi F_t = a_t F_t\] and total export revenues are given by \[(a_t + (1 - a_t))\zeta \mathcal{E}_t^{-\eta} P_H^{1-\eta} = \zeta \mathcal{E}_t^{-\eta} P_H^{1-\eta} \].

With limited financial market participation, the indirect utility function for the hegemon planner is given by,

\[
V \left(C^A_{F,t}, C^N_{A,F,t}, \mathcal{E}_t; \lambda, a_t\right) = a_t \lambda^A \mathcal{U} \left( \frac{\chi}{1-\chi} \frac{P^*_t \mathcal{E}_t^A}{P_H^t} C^A_{F,t}, C^A_{F,t}, L_t \right) + \left(1 - a_t\right) \lambda^{NA} \mathcal{U} \left( \frac{\chi}{1-\chi} \frac{P^*_t \mathcal{E}_t^{NA}}{P_H^t} C^N_{A,F,t}, C^N_{A,F,t}, L_t \right)
\]

where \(\lambda = [\lambda^A, \lambda^{NA}]\) are the Pareto weights the planner attaches to \(A\) and \(NA\) households respectively and satisfy \(a_t \lambda^A + (1 - a_t) \lambda^{NA} = 1\). Moreover, \(C^A_{F,t}\) is given by (C.28), \(C^N_{A,F,t}\) is given by (C.30) and \(L_t^A = L_t^{NA}\) is given by market clearing and \(L_t = Y_t/A_t\). The partial derivatives of the indirect utility function with respect to \(C^A_{F,t}\), \(C^N_{A,F,t}\) and \(\mathcal{E}_t\) are given, respectively, by:

\[
V_{C^A_{F,t}} = a_t \lambda^A \frac{1 - \chi}{C^A_{F,t}} \left(1 + \frac{\chi}{1-\chi} \tau_t^A\right),
\]

\[
V_{C^N_{A,F,t}} = (1 - a_t) \lambda^{NA} \frac{1 - \chi}{C^{NA}_{F,t}} \left(1 + \frac{\chi}{1-\chi} \tau_{t}^{NA}\right),
\]

\[
V_{\mathcal{E}_t}(C_{F,t}, \mathcal{E}_t; a_t) = a_t \lambda^A \frac{1 - \chi}{C^A_{F,t}} \left\{ \frac{\chi}{1-\chi} C^A_{F,t} \lambda \mathcal{E}_t^{-1} + (\tau_t^A - 1) \left( \frac{\chi}{1-\chi} \lambda \mathcal{E}_t^{-1} [a_t C^A_{F,t} + (1 - a_t) C^{NA}_{F,t}] + \zeta \eta \mathcal{E}_t^{-\lambda - 1} \right) \right\};
\]

\[
(1 - a_t) \lambda^{NA} \frac{1 - \chi}{C^{NA}_{F,t}} \left\{ \frac{\chi}{1-\chi} C^{NA}_{F,t} \lambda \mathcal{E}_t^{-1} + (\tau_t^{NA} - 1) \left( \frac{\chi}{1-\chi} \lambda \mathcal{E}_t^{-1} [a_t C^A_{F,t} + (1 - a_t) C^{NA}_{F,t}] + \zeta \eta \mathcal{E}_t^{-\lambda - 1} \right) \right\}.
\]

With limited financial market participation, the interest rate reflects the marginal rate of
substitution for \( A \) households only, see (4.38)) Therefore, the condition characterising unresponsive monetary policy is given by,

\[
P^*_t \lambda^C E^A C^A F_t = \mu_t (1 - \chi), \tag{C.35}
\]

where \( \mu \) is a synthetic monetary instrument. If \( \mu_t / \mu_{t+1} \) is constant, \( R_t = \frac{1}{\beta} \).

The hegemon planner now maximizes (C.31) subject to (C.28) and (C.30). I assume \( a_t = a \)
and I attach multipliers \( \eta^A_t \) and \( \eta^N_A \) to (C.28) and (C.30) respectively. The optimal allocation is characterized by the following first order conditions:

\[
C^A_{F,t} : \quad V_{C_{F,t}} - a \eta^A_t - \eta^F_t + a \frac{1}{\lambda^C E^A C^2_{F,t}} \left[ \eta^E_t - R_t \eta^E_{t-1} \right] = 0, \tag{C.36}
\]

\[
C^N_{F,t} : \quad V_{C^N_{F,t}} - (1 - a) \eta^N_A = 0, \tag{C.37}
\]

\[
\mathcal{E}_t : \quad V_{\mathcal{E}_t} + [a \eta^A_t + (1 - a) \eta^N_A] \zeta (\eta - \lambda) \mathcal{E}^{-\lambda-1} H_t + \mathcal{P}_{H(t)} + \lambda \mathcal{E}_t^{-\lambda-1} \Gamma_{t-1} Q_{t-1} (x_t) + \beta [a \eta^A_{t+1} + (1 - a) \eta^N_{A,t+1} \chi] \left[ - \lambda \mathcal{E}_t^{-\lambda-1} (x_t - a_t^F) + (1 - \lambda) \mathcal{P}_{H(t)} + \mathcal{R}_{t+1} \mathcal{E}_{t+1}^{-\lambda} \mathcal{E}^t_{t+1} \mathcal{E}_t^{-\lambda-1} \Gamma_{t-1} Q_{t-1} \right] + \frac{1}{C^A_{F,t+1}} \beta R \mathcal{E}^t_{t+1} + \frac{1}{C^A_{F,t}} \left[ (1 - \lambda) \mathcal{E}_{t-1}^{-\lambda} - \lambda \mathcal{E}_t^{-\lambda-1} \Gamma_{t-1} Q_{t-1} \right]
\]

\[
x_t : \quad [a \eta^A_t + (1 - a) \chi] + (1 - a) \eta^N_A \chi] \left[ \mathcal{E}^{-\lambda-1} H_t + \mathcal{P}_{H(t)} + \lambda \mathcal{E}_t^{-\lambda-1} \Gamma_{t-1} Q_{t-1} (x_t) + \beta [a \eta^A_{t+1} + (1 - a) \eta^N_{A,t+1} \chi] \mathcal{E}_t^{-\lambda} \right] + a \eta^E_{t} \left[ \mathcal{E}^{-\lambda} H_t + \mathcal{P}_{H(t)} + \lambda \mathcal{E}_t^{-\lambda-1} \Gamma_{t-1} Q_{t-1} \right] = 0, \tag{C.39}
\]

### C.5 Generalizing preferences

In this subsection, I consider the generalisation of the model beyond the Cole-Obstfeld (C-O) specification, specifically allowing for \( \sigma \neq 1 \), such that a movement in \( R_t \) has an effect on households’ borrowing decisions \( x_t \). For completeness, I present the indirect utility function and its derivatives for general \( \sigma \) and \( \theta \), and then specify \( \theta = 1 \). I focus on this case because it retains the tractability of the C-O parameterization.\(^2\)

The indirect utility function is given by:

\[
V(C_{F,t}, \mathcal{E}_t) = \frac{1}{1 - \sigma} \left[ \chi^\theta \left( \frac{1}{1 - \chi} \left( \frac{P^*_t \lambda^C E^\lambda C^\lambda F_t}{P^*_{H(t)}} \right)^{\theta - 1} \mathcal{E}^{\lambda - 1} E_{t+1} + (1 - \chi) \mathcal{E}^{\lambda - 1} E_{t+1} \right) \right]^{\theta - 1 - \sigma} \tag{C.40}
\]

\(^2\)In the job market version of this paper, I explore the case of \( \theta \neq 1 \) as well, but qualitatively, the results are unchanged.
where

\[ V_{C,F,t} = C_t^{1-\theta} \left\{ \chi^{\theta} \left[ \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\theta \right] C_{H,t}^{-1} + (1-\chi)^\beta C_{F,t}^{-1} \right\} - \kappa L_t^{\psi} \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\eta, \]

\[ V_{\varepsilon_t} = C_t^{1-\theta} \left\{ \left[ \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\theta \right] \lambda \varepsilon_t^{\lambda-1} C_{F,t} + \zeta(\varepsilon_t, \eta) \right\} \]

The partial derivatives with respect to \( C_{F,t} \) and \( \varepsilon_t \) are given as follows:

\[ V_{C,F,t} = C_t^{1-\theta} \left\{ \chi^{\theta} \left[ \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\theta \right] C_{H,t}^{-1} + (1-\chi)^\beta C_{F,t}^{-1} \right\} - \kappa L_t^{\psi} \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\eta, \]

\[ V_{\varepsilon_t} = C_t^{1-\theta} \left\{ \left[ \frac{\chi}{1-\chi} \left( \frac{P_{F,t}^\sigma \varepsilon_t^\lambda}{P_{H,t}^\sigma} \right)^\theta \right] \lambda \varepsilon_t^{\lambda-1} C_{F,t} + \zeta(\varepsilon_t, \eta) \right\} \]

Focusing on \( \theta = 1 \), the implementability condition is still given by (4.22), but the Euler equation becomes:

\[ \frac{1}{P_t C_t^\sigma} = \beta R_t \frac{1}{E_t[\eta_{t+1}^\sigma C_{t+1}^\sigma]} \]

where \( P_t = \chi^{-\chi}(1-\chi)^{\lambda-1} P_{H,t}^\sigma \varepsilon_t^{\lambda(1-\chi)} \). The Euler condition can be re-expressed as:

\[ \frac{1}{E_t^{\lambda(1-\chi+\lambda \sigma)} C_{F,t}^\sigma} = \beta R_t \frac{1}{E_t[\eta_{t+1}^{\lambda(1-\chi+\lambda \sigma)} C_{F,t+1}^\sigma]} \]

If \( R = R_t \), I additionally attach the constraint \( \varepsilon_t^\lambda C_{F,t}^\sigma = \mu(1-\chi) \).

The first order conditions associated with the planning problem are given by:

\[ C_{F,t} : \quad V_{C,F,t} - \eta_t^C - \eta_t^H + [\varepsilon_t^{\lambda(1-\chi+\lambda \sigma)} C_{F,t}^\sigma]^{-2} \sigma C_{F,t}^{-1} \left[ \eta_t^E - R_t - \eta_t^E_{t-1} \right] = 0, \]

\[ \varepsilon_t : \quad V_{\varepsilon_t} + \eta_t^C \zeta(\eta, \lambda) \varepsilon_t^{\eta-\lambda-1} P_{H,t}^{1-\eta} + \left( -\lambda \varepsilon_t^{\lambda-1}(x_t - a_t^F) + (1-\lambda) \frac{R_t \varepsilon_t^{\lambda-1}}{\varepsilon_t^{\lambda-1}} (x_t-1 - a_{t-1}^F) + \lambda \varepsilon_t^{\lambda-1} \Gamma_{t-1} Q_{t-1} (x_{t-1}) \right) \]

By substituting these equations, we can derive the final result.

138
\[ x_t : \eta_t^C e^{-\lambda t} - \beta \eta_{t+1}^C e^{-\lambda(t+1)} [R_t + \Gamma_t(x_t + B_t) - 2\omega \Gamma_t Q_t] + \eta_t^E \beta \Gamma_t \frac{1}{e^{\lambda(1-\chi+\chi\sigma)}} C_{F,t+1} = 0 \]

(C.47)

All the expressions in this section coincide with the main body counterparts in the limit \( \sigma, \theta \to 1 \). The expressions for the \( a < 1 \) case follow from expanding on the relevant conditions in Appendix C.4.

**Monetary policy stabilization when \( \sigma \neq 1 \).** Figure C.9 below plots the effect of a one period increase in interest rates for stabilization when \( \sigma = \{0.5, 1, 2\} \). Specifically, this section mirrors the findings in Bianchi and Coulibaly (2021) that for \( \sigma < \theta \), contractionary monetary policy can contribute to a reduction in borrowing and address the over-borrowing externality which arises when \( \xi_t \) rises. Instead, borrowing rises in response to \( R \uparrow \) if \( \sigma > \theta \) and is unresponsive at \( \sigma = \theta = \eta = 1 \).

![Figure C.9: Impulse response to a monetary policy shock (decrease in \( \mu \)). Variables plotted as deviations from steady state. Parametrization as in C.1 except \( \eta = 1, \xi = a^F = 0 \), and variable \( \sigma \).](image)
C.6 Further Results for Numerical Exercise

The table below details the parametrization used in Section 4.5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta = \beta^*$</td>
<td>0.99</td>
<td>Discount factor, quarterly calibration</td>
<td>4% annual interest</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>1</td>
<td>Coefficient of relative of risk aversion</td>
<td></td>
</tr>
<tr>
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<td>Macro elasticity of substitution</td>
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<td>Size of foreign economy</td>
<td>Normalisation</td>
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<tr>
<td>$\kappa$</td>
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<td>Disutility from labour</td>
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<tr>
<td>$P_F^* = 1$</td>
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<td>Price of foreign goods</td>
<td>Normalisation</td>
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<tr>
<td>$\omega$</td>
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<td>Home ownership of financiers</td>
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<td>$\chi$</td>
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<td>Share of Home goods</td>
<td>$\frac{C_H}{Y} = 15%$ BEA data</td>
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<td>$\lambda$</td>
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<td>Pass-through for U.S. imports</td>
<td>Matarazzi et al. (2019)</td>
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<tr>
<td>$\lambda^*$</td>
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<td>Elasticity of financiers’ demand</td>
<td>$\frac{d\tau}{dQ} \approx 2$</td>
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</tr>
<tr>
<td>$a^F$</td>
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<td>Steady state FC assets</td>
<td>Gross ext. assets (100% GDP)</td>
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<td>$\alpha$</td>
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<td>Share of inactive households</td>
<td>Survey Cons. Finances</td>
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Table C.1: Benchmark Model Calibration.

Figure C.10 below shows that $NA$ households experience worse outcomes than $A$ households following an increase in $\xi$. Specifically, since by assumption, $L_t^A = L_t^{NA}$, a higher $\tau_t^{NA}$ reflects lower $NA$ consumption. The aggregate labour wedge in Figure 4.5 is calculated as $\tau_t = a\tau_t^A + (1-a)\tau_t^{NA}$.

![Figure C.10: Impulse response to dollar demand shock $\xi_t$. Labour wedge deviations.](image)
C.7 Extensions

**Firesales.** Consider an extension of the model where there is a haircut $\phi(\Gamma)$ on foreign asset returns. Assuming $\mathbf{a} = 1$, the budget constraint for hegemon households is given by,

$$P_{F,t}C_{F,t} + P_{H,t}C_{H,t} \leq \Pi_t + W_tL_t + x_1 - R_{t-1}x_{t-1} - a_t^F + R_{t-1}^s(1 - \phi(\Gamma_{t-1})) \frac{\bar{\varepsilon}_{t-1}}{\bar{\varepsilon}_{t-1}} a_{t-1}^F \tag{C.48}$$

The optimality condition for dollar swap lines, replacing (C.11) in the main body, is given by:

$$- \eta_{t+1}^C \varepsilon_t^{-\lambda} \{Q_t x_t + \omega Q_t^2\} - R^s \frac{\varepsilon_{t+1}}{\varepsilon_t} \frac{d\phi(\Gamma_t)}{d\Gamma_t} a_{t-1}^F = - \eta_t^F \frac{1}{\varepsilon_{t+1}^C C_{F,t+1}} Q_t \tag{C.49}$$

When the hegemon levies the optimal macroprudential tax, $\eta_t^F = 0$. However, when $\frac{d\phi(\Gamma_t)}{d\Gamma_t} > 0$, dollar swaps can be desirable as the hegemon trades off foregone monopoly rents against improved returns on foreign assets.

**Productivity Shocks** Figure C.11 below plots the impulse response to a negative productivity shock, contrasting the $\sigma = 1$ and $\sigma = 2$ allocations. As is standard, following a negative productivity shock, monetary policy raises interest rates leading to an appreciation. When $\sigma > \theta$, this leads to increased borrowing due to an income effect. This in turn increases the supply of dollars in foreign markets, eroding the hegemon’s monopoly rents.

The right panel illustrates the effect of dollar swaps on the issuance wedge $\tau^\Omega$. Extending dollar swaps is analogous to considering a lower $\Gamma$ and this narrows the issuance wedge. Since the issuance wedge weighs negatively on welfare, dollar swaps promote efficient stabilization, alongside monetary policy.

Figure C.11: Impulse response to a 10% fall in $A_t$. Variables plotted as deviations from steady state. The dashed line assumes the standard parameters above, zero steady state gross positions, and $\sigma = \theta = \zeta = 1$. The solid line considers $\sigma = 2$ and the solid line with rivets in the right panel considers $\Gamma = 0.1$ (as opposed to $\Gamma = 0.14$).