Currency Risk and Capital Accumulation*

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Abstract

Capital-output ratios are negatively correlated with currency premia. I investigate the quantitative link between currency risk, currency premia and capital-output ratios across countries by building a heterogeneous country general equilibrium model of capital accumulation. To generate large and persistent differences in currency premia as in the data, my model has two key features: heterogeneous loadings on a global shock and external habit. Heterogenous loadings induce cross-country variations in currency riskiness. When a negative global shock hits, currencies of high-loading countries appreciate, making them a good hedge against global downturns and thus safe. In equilibrium, such countries offer lower currency premia, have lower risk-free rates and accumulate more capital. External habit, on the other hand, enables my model to quantitatively boost the heterogenous-loading induced cross-country variations in currency premia and capital-output ratios to empirical levels without generating counter-factual movements in expected change in exchange rates. When I estimate the model using GDP data from countries issuing the G10 currencies, I find that the estimated loadings are highly correlated with currency premia and capital-output ratios across countries, and model generated capital-output ratios account for roughly 50% of the cross-country variations in the data.

Keywords: currency risk, currency premia, capital-output ratio, external habit, safe currency

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1. Introduction

Differences in capital-output ratios are large and persistent across countries, a phenomenon known as the "Lucas Paradox" (Lucas (1990)). Everything else being equal, this is suggesting that there is significant and long-lasting cross-country differences in returns to capital, and capital is not flowing across borders to eliminate such differences. Existing explanations include various frictions that prevent capital from moving freely, heterogeneity in the production functions, and misallocation of resources. In this paper, I argue that currency risk induces persistent differences in expected returns to capital across countries and is a quantitatively important driver of cross-country variations in capital-output ratios.

A growing literature have established that some currencies are "safer" in the sense that they appreciate in global bad times and offer a good hedge against global downturns[1]. In equilibrium, these currencies offer lower returns and feature permanently lower risk-free rates. Currency risk thus drives persistent cross-country variations in currency returns and risk-free rates[2]. On the other hand, expected return to capital $\mathbb{E}(r)$ can be written as

$$\mathbb{E}(r) = r_f + \text{risk premium}$$

where r_f is the risk-free rate. If currency risk induces systematic variations in r_f across countries, it should pass through to expected returns to capital[3], and also have implications for capital-output ratios. Indeed, assuming that firms are price takers and use a Cobb-Douglas production function, if we equate marginal product of capital to its marginal cost, we have

$$\mathbb{E}(Y/K) = \frac{\mathbb{E}[r]+\delta}{\alpha} = \frac{r_f + \delta + \text{risk premium}}{\alpha} \tag{1}$$

where Y is output, K is the capital stock, α is capital share of output and δ is the depreciation rate. As is clearly shown in equation (1), cross-country variations in risk-free rates and currency returns induced by currency risk should have important implications for capital-output ratios.

In this paper, I study the importance of the currency risk channel to explain the Lucas Paradox by endogenizing capital accumulation within a quantitative heterogenous country

[1] Examples are Lustig and Verdelhan (2007), Lustig et al. (2011),Lustig et al. (2014), Hassan (2013), Richmond (2019), Farhi and Gabaix (2016), Maggiori (2017), Ready et al. (2017), Colacito et al. (2018a), Wiriadinata (2021), Jiang (2021), among others.

[2] Empirically, risk-free rate differences across countries are large and persistent, and they are linked to safeness of the corresponding currency. See Lustig et al. (2011),Hassan and Mano (2018), for example.

[3] Richers (2021) finds direct empirical evidence for this. Specifically, he finds that violation of the uncovered interest rate parity strongly passes through to firm borrowing and cost of capital.

international asset-pricing model with external habit. To induce different responses to global downturns and thus currency riskiness, I follow Lustig et al. (2011) and Colacito et al. (2018a) and allow countries to differ in their loadings on a global shock. Under this setup, currencies of high-loading countries are safer in the sense that they appreciate when a negative global shock hits, making them a good hedge against global risk. In addition, agents are sensitive to currency risk because of external habit, which enables the model to generate large cross-country variations in currency premia and capital-output ratios as in the data. When I calibrate my model to GDP data of countries (regions) issuing the G10 currencies, I find that the model generated capital-output ratios can account for roughly 50% of the cross-country variations in the data.

To better motivate the model and to confirm the conjecture that cross-country variations in capital output ratios and risk-free rates are tightly linked, I first explore the cross-country variations in capital-output ratios and currency premia, and the correlations between them in the data. I define currency premium of country i relative to the US, $\mathbb{E}_t(rx^i_{t+1})$, as the expected return a US investor would get if she borrows at the risk-free rate in the US and invests it in a foreign risk-free bond:

$$\mathbb{E}_t(rx^i_{t+1}) = r^i_{f,t} - \mathbb{E}_t[\Delta ex_{t+1}] - r^{US}_{f,t}$$

where $r^i_{f,t}$ and $r^{US}_{f,t}$ denote the risk-free rates of country i and the US respectively, and Δex_{t+1} is the change in exchange rates quoted in units of country i currencies per US dollar. Note that although change in exchange rate does not show up explicitly in equation (1), agents choosing where to invest their capital should take it into consideration, so instead of looking at cross-country variations in risk-free rates, I focus on currency premia[4]. In the data, expected change in exchange rate is close to zero unconditionally[5], so cross-country variations in risk-free rates and currency premia are quantitatively very similar anyway.

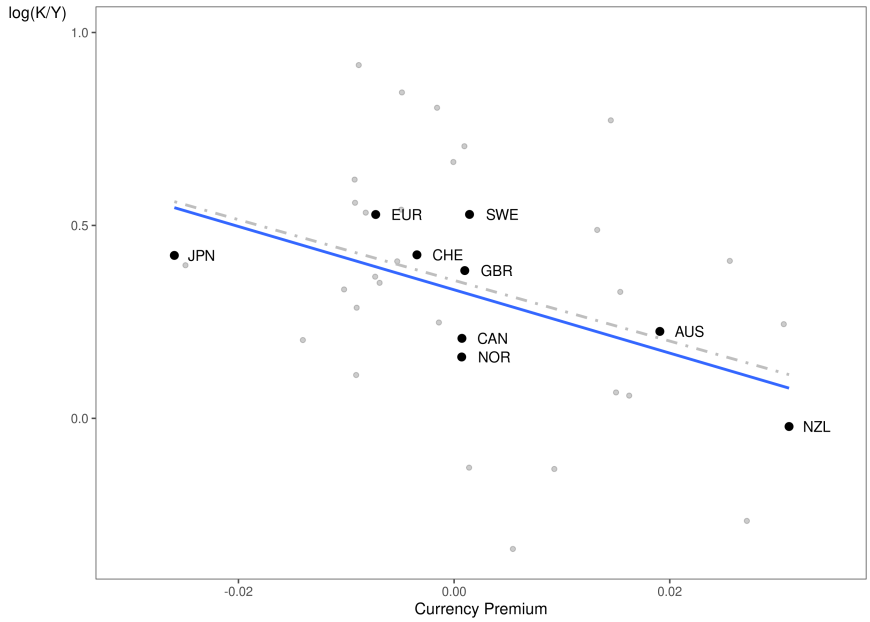
Figure 1 plots log capital-output ratios relative to the US against US-based currency premia for countries (regions) issuing the G10 currencies[6] (Australia, Canada, the Euro area, Great Britain, Japan, Norway, New Zealand, Sweden, Switzerland and United States. Throughout the paper, I treat the Euro area as one country). We can clear see that there is indeed large variations in capital-output ratios and currency premia across countries. For example, capital-output ratio in Japan is 44% higher than New Zealand while currency

[4]It has the additional advantage that under complete market, inflation cancels out when we think about currency premia, so we don't need to worry about nominal v.s. real returns.

[5]See Table 3. Also see Hassan and Mano (2018).

[6]Throughout this paper, I always use G10 to refer to countries issuing the G10 currencies (the most traded ten currencies), not the usual The Group of Ten countries.

Figure 1: Negative Correlation between Log Capital Output Ratios and Currency Premia



This figure plots unconditional log capital-output ratios relative to the US against unconditional currency premia relative to the US for countries issuing the G10 currencies (black dots) and a broader sample of 37 currencies(grey dots). The line of best fit has a slope of -8.21(s.e. 3.12) for G10 (solid blue line) and -7.87 (s.e. 3.36) for the broader sample (dashed grey line). All moments are annual.
Data source: capital stock and output are from PWT 10.0. Currency premia and interest rate differences are from Verdelhan's website. Data ranges from 1994 to 2019. Details on the data construction can be found in section 4.1 and Appendix C.

premia between the two countries is 5.70%. In addition, consistent with equation (1), there is a clear negative relationship between capital-output ratios and currency premia (solid blue line): countries with lower currency premia and thus lower risk-free rates accumulate more capital. To the extend that currency premia are tightly connected to currency risk, Figure 1 empirically links currency risk to capital-output ratios.

Although the Lucas Paradox is often referred to as a phenomenon between developed (rich) and developing (poor) countries, Figure 1 shows that it is also evident within the developed world, which is perhaps even more puzzling. I consciously restrict my sample to countries issuing the G10 currencies[7] for two reasons: (1) all the countries (regions) in this group are western developed countries and are relatively homogeneous in terms of institutions, tax systems and market structures, which mitigates the concern that these

[7] Note that as the base country, US does not show up in Figure 1 so my sample has effectively 9 countries. I make this choice because (1) currency premia need a base country to calculate, and the US dollar is the standard choice; and (2) it is well known that as the center of the global trade, financial, and political network, the US is special in terms of capital accumulation, so I leave the proper treatment of the US for future research.

factors might confound my analysis[8]; and (2) this set of countries closely resembles complete market, which I am going to assume in my model. Nevertheless, if I extend my sample to a set of 37 countries (grey dots in Figure 1), the same pattern persists: there is large cross-country variations in capital-output ratios and currency premia across countries, and there is a clear negative relationship between the two. In fact, the line of best fit (dashed grey line) has almost the same slope as the G10 currencies (solid blue line). In general, capital-output ratios and currency premia vary a lot across countries and they are negatively correlated with each other in the data.

Motivated by the empirical fact and recognizing that currency premia is connected to currency risk, I extend a standard international asset pricing model of currency risk to incorporate capital accumulations and study the quantitative effect of currency risk on capital-output ratios. There are two key ingredients in the model. First, I allow countries to have different loadings on a global productivity shock and agents feature home bias towards their country-specific good; second, agents in my model extracts utility from an exogenously given habit level.

Heterogeneous loadings on a global shock is widely used in the international asset pricing literature to link currency risk to cross-country variations in currency premia[9]. Extending this framework to a general equilibrium model of capital accumulation, my model generates cross-country variations in capital-output ratios in addition to currency premia in a way that is consistent with the data. Intuitively, the country-specific good of the high loading country becomes relatively more expensive when a global negative shock hits. With home bias, the price of the consumption bundle of said country increases, which translates to appreciation of the real exchange rate. In this sense, the high loading currency appreciates in global bad times and is safe. In equilibrium, global investors require a lower return on assets of high-loading countries, including risk-free assets and investments in capital, and high-loading countries feature lower risk-free rates, lower expected return to capital, and install more capital. Heterogeneous loadings on a global shock thus induce cross-country variation in currency safeness, currency premia, expected returns to capital, and capital-output ratios.

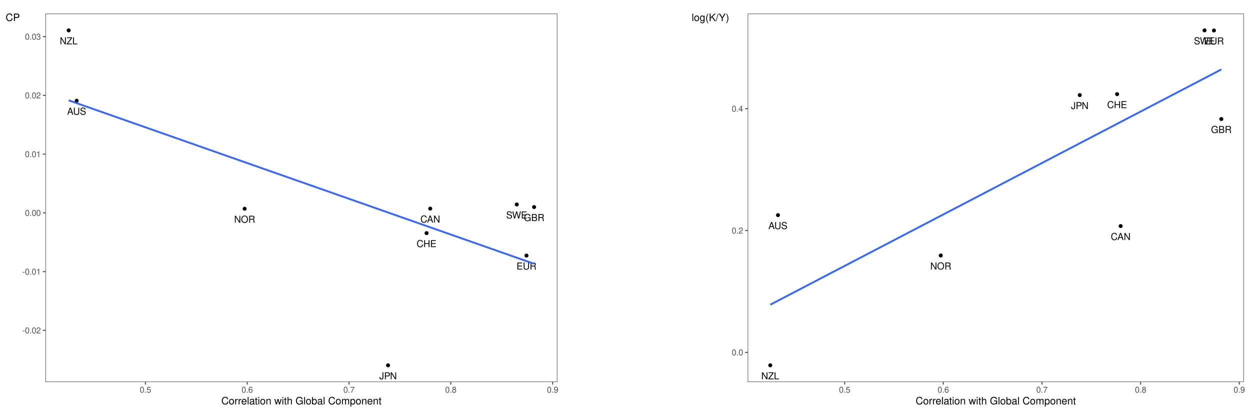
The mechanism can also be analyzed from the perspective of a social planner. The social planner finds it optimal to install more capital in the high loading country for two reasons. The first is from a domestic perspective. The high loading countries feature a more volatile

[8]In Appendix A, I show that the negative correlations between capital-output ratios and currency premia is robust to controlling for financial development, governance efficiency and financial openness, suggesting that these factors are not main drivers of cross-country variation in capital-output ratios within the countries issuing G10 currencies.

[9]Examples are Lustig et al. (2011, 2014), who assume SDFs load differently on a global shock, and Colacito et al. (2018a), who assume long-run endowment processes load differently on a global shock.

productivity profile by construction because they are more sensitive to the global shock. To insure against such risk, it is optimal for the social planner to install more capital there out of precautionary saving motive. The second reason is from an international risk-sharing perspective. Because different countries loads differently on the global shock, when a negative global shock hits, the social planner reallocates resources from low loading countries to high loading countries out of a risk-sharing motive. By installing more capital in the high loading countries, all countries are better off in global bad times: for the high loading countries, they have more to consume; for the low loading countries, less resources need to be taken from them to compensate the suffering high loading countries. Overall, the social planner finds it optimal to install more capital in the high loading countries.

Figure 2: Correlations with Global Component



(a) Currency Premium

(b) Capital-Output Ratio

This figure plots currency premia (Panel(a)) and log capital-output ratios (Panel(b)) relative to the US against correlations of each country's HP-filtered log GDP with the cross-country average. The line of best fit has a slope of -0.06 (s.e. -0.02) for currency premium and a slope of 0.84 (s.e. 0.22) for log capital-output ratio.
Source: capital stock and output data is from PWT 10.0. Currency premia data is from Verdelhan's website. GDP data is from OECD National Accounts Statistics. Data ranges from 1994 to 2019. Details on the data construction can be found in section 4.1.

Moreover, there is empirical evidence for heterogenous loadings on a global shock and their link to currency premia and capital output ratios. Figure 2, Panel (a) plots currency premia against the correlation of each country's HP-filtered log GDP with a global component (the cross-country average of HP-filtered log GDP); Figure 2, Panel (b) plots the same figure for capital-output ratios. As we can see clearly, if a country correlates more with the world, it features lower currency premium and higher capital-output ratios. Motivated by this empirical fact, in my calibration exercise, I extract the loadings on the global shock solely from GDP data.

Another crucial feature in my model is external habit (Campbell and Cochrane (1999)). While there are multiple attempts at generating cross-sectional variations in currency premia across countries in the literature, most of them are either reduced form (e.g., Lustig et al. (2011), Lustig et al. (2014)) or qualitative (e.g., Hassan (2013), Ready et al. (2017), Richmond (2019)). The reason is that as a risk premium, currency premium tend to be quantitatively tiny under standard CRRA preferences, a challenge similar to the well-known equity premium puzzle[10]. I thus use external habit, which is proven to be successful in resolving the equity premium puzzle, to boost currency premia and cross-country variations in capital-output ratios to their empirical levels. In my model, agents extract utility from their consumption over an externally given habit level, which is approximately a geometric average of the history of consumption. Thus, their marginal utility of consumption are jointly determined by consumption and the habit level. Because the habit level is also sensitive to consumption, overall, agents' marginal utility of consumption is much more responsive to changes in consumption than without habit. This feature effectively makes them very risk-averse to consumption risk and helps to generate large risk premium. Following Chen (2017), I assume constant sensitivity of habit with respect to changes in consumption, as opposed to time varying sensitivity in standard habit models[11], and I set the sensitivity parameter to be the same across countries. Under this setup, my model generates unconditional cross-country variations in currency premia and capital-output ratios comparable to the data.

To my knowledge, the only alternative quantitative international asset pricing framework that generates large unconditional cross-country variations in currency premia is Colacito et al. (2018a). Instead of habit, they use Epstein and Zin (1989) preference and long-run risk to boost currency premia. However, the currency premia generated from their framework come predominately from expected change in exchange rates, and cross-country variations in risk-free rates are very modest (p.18 in their paper). In the data, the opposite is true: the main source of currency premia is risk-free rate differences and expected change in exchange rate is close to 0. My model with external habit generates large currency premia without inducing counterfactual movements in expected change in exchange rates and thus provide an alternative framework to quantitative international asset pricing that better matches the data.

Using a simplified two period model, I examine the mechanism of my model and derive four theoretical results in closed form. First, there is indeed a tight link between currency premia and capital-output ratios in the model; second, habit helps to generate large currency premia by effectively making agents very averse to consumption risk; third, expected change

[10]See Hassan and Zhang (2021) for a broad discussion of how the cross-country "currency premium puzzle" and the equity premium puzzle are related. For detailed discussion of the issue, see ongoing work Hassan et al. (2021).

[11]Chen (2017) made this choice for convenience because the sensitivity function in standard Campbell and Cochrane (1999) external habit models are reverse engineered, which is not possible when capital accumulation is considered. In Section 3.2, I show that in my setup, this choice is actually economically important in terms of generating large currency premia.

in exchange rate is 0, and high loading currencies appreciate in global bad times; fourth, high loading currencies feature lower risk-free rates, lower expected return to capital and accumulate more capital.

I then take the full model to the the data and estimate the loadings on the global shock for each country. Motivated by Figure 2, I use quarterly GDP data for countries issuing the G10 currencies and target the correlation of each country's HP-filtered GDP with the cross-country average. The estimated loadings are highly correlated with currency premia and capital-output ratios in the data. Existing frameworks that attempts at estimating the loadings typically rely on asset price data. For example, Lustig et al. (2011) uses currency portfolios, and Colacito et al. (2018a) uses dividend data. Compared to these approaches, my findings that these loadings can be extracted from only GDP data suggest that the economic forces behind the heterogeneity in loadings on the global shock is quite fundamental.

I then simulate the model taking the estimated loadings as given and contrast the simulated capital-output ratios with the data. In a variance decomposition exercise, I find that the estimated model accounts for roughly 50% of the cross-country variations in capital-output ratios in the data. I conduct robustness check by exploring how the degree of home-bias and the elasticity of substitution between different goods affects my results, and find that the model is robust to these changes.

The conclusion of my analysis is that currency risk induced by heterogenous loadings on a global shock jointly determines currency premia and capital-output ratios, and can go a long way towards explaining the Lucas Paradox. However, I recognize one caveat towards my approach. My model is silent on the economic origins of the heterogeneity on loadings on the global shock. This approach, while convenient and general, is subject to problem of endogeneity. In particular, capital-output ratios could affect the loading of a country through some other channel. I argue that because of the homogeneity of countries in my sample in terms of financial development, governance, and market efficiency, the scope of the endogeneitity problem is limited. In Appendix A, I confirm that cross-country variations in financial development, financial openness and governance efficiency has little impact on the relationship between currency premia and capital-output ratios. In addition,while I can not rule out the possibility of endogeneity, I argue that the mechanism studied in this paper is still relevant even with endogeneity: it becomes an amplification mechanism, and its interaction with other mechanisms provide interesting venues for future research.

My paper makes contributions to three strands of literature. First, it contributes to the large body of work rationalizing the significant, persistent difference in capital-output ratios across countries. Existing explanations include heterogeneity in the protection of property rights (Hall and Jones (1997)), in the capital share of output (Karabarbounis and

Neiman (2014)), in the misallocation of resources (Hsieh and Klenow (2009)), in natural resource endowments (Caselli and Feyrer (2007) and Monge-Naranjo et al. (2019)), and in institutional quality (Alfaro et al. (2008)). However, all of these explanations assume risk-free rates to be the same across countries, at least in the long-run. By allowing countries to differ in their riskiness, I show that risk-free rates can permanently differ across countries even under complete markets. This difference is an important channel that can be used to explain the capital-output ratio variations. David et al. (2014) links capital-output ratios to correlations of returns to capital with the US stock market. They find that the emerging markets covary more with the US stock market and is thus risky, and returns to capital are high as a result. I focus on currency risk instead and show that currency risk is a key driver of capital-output ratio among the developed countries.

Second, this paper complements the literature on currency risk with a quantitative approach. While various risk-based explanations exist on why some countries have lower interest rates than others, almost all of them are either reduced form (Lustig et al. (2011, 2014), Verdelhan (2018)) or qualitative (e.g., Hassan (2013), Richmond (2019), Ready et al. (2017), Maggiori (2017)). I adapt external habit preferences to a heterogenous country set-up and show that such preferences boost the difference in the volatility of stochastic discount factors across countries, and thus generate currency premia and risk-free rate differences comparable to the data. In addition, unconditionally change in exchange rate is exactly 0 in my model, which is consistent with the data and differentiates my approach from Colacito et al. (2018a).

Also, the majority of the currency risk literature only focus on asset prices and don't consider capital accumulation, and this paper is one of the few that studies the real impications of the advancements in international asset pricing. Colacito et al. (2018b) studies capital flow patterns in a international set-up with long-run and short-run risk and Epstein and Zin (1989) preferences, but they only study symmetric countries and focus on capital flow instead of capital stock. Hassan et al. (2016) studies a model where countries feature different sizes and real exchange rate volatilities, and find that countries are either larger or more volatile tend to accumulate more capital. But their model is qualitative and can only generate tiny differences in capital-output ratios. My model features heterogeneous loadings on a global shock and external habit, and can generate economically significant variations in capital-output ratios comparable to the data.

Third, this paper is also related to several others applying external habit models to international setups. Verdelhan (2010) uses external habit with time-varying risk-free rates to explain the UIP puzzle. Stathopoulos (2017) further allows for risk-sharing and home bias across countries, and resolves the Backus and Smith (1993) puzzle. Heyerdahl-Larsen (2014) uses deep habit to rationalize a series of puzzles in the international finance literature.

However, all of these papers feature symmetric countries and thus yield no unconditional difference in risk-free rates. They also feature endowment economies and thus do not endogenize capital accumulation. Chen (2017) studies an external habit model with capital accumulation, but he only studies closed economy. I extend his framework to a heterogeneous-country setup, and study its implications for cross-country variations in capital accumulations.

The rest of my paper is organized as follows.In Section 2, I set up the model and derive the optimality conditions. In Section 3 , I solve a simplified two-period, two-country version of the model to study the mechanisms. In Section 4, I solve and estimate the full model. I conclude in Section 5.

2. The Model

In this section, I extend a standard multi-country international asset pricing model to incorporate capital accumulation and heterogeneous countries, as well as external habit. The basic structure of the model largely follows Colacito et al. (2018a), except that instead of using Epstein and Zin (1989) preference, I use external habit, and I endogenize capital accumulation. The economy within each country closely resembles the closed-economy model of Chen (2017).

2.1. Setup

2.1.1. Households

There are N countries indexed by $i = \{1, 2, \ldots, N\}$, each populated by a unit measure of households. Households in country i extract utility from consumption over an externally given habit level H_t^i, and maximize

$$\mathbb{E}_0 \sum_{t=0}^{T} \eta^t \frac{(C_t^i - H_t^i)^{1-\gamma} - 1}{1-\gamma}$$

where η is the time discount factor, C_t^i denotes consumption, and γ governs relative risk aversion. T is a terminal period (which I set to 1 in Section 3 and ∞ in all other sections). Following Campbell and Cochrane (1999), instead of directly specifying an exogenous process for H_t^i, I assume that the surplus consumption ratio, $S_t^i = \frac{C_t^i - H_t^i}{C_t^i}$, follows

$$s_{t+1}^i = (1-\rho_s)\bar{s} + \rho_s s_t^i + \lambda_s(\Delta c_{t+1}^i - \mu) \tag{2}$$

where $s_t^i = \log(S_t^i)$. Throughout the paper, lower case letters denotes logs so that $x = \log(X)$. $\bar{s}$ is the steady state level of s_t^i, ρ_s governs the persistence, and μ is the steady state growth rate of technology. $\bar{s}$, ρ_s and μ are assumed to be the same across countries.

$\lambda_s \geq 0$ governs the sensitivity of the log surplus consumption ratio to consumption growth. Following Chen (2017), I deviate from the standard external habit model by setting λ_s to be a constant instead of a function. In particular,

$$\lambda_s = \frac{1}{\bar{S}} - 1$$

is set to be the steady state level of Campbell and Cochrane (1999). There are two reasons for this deviation. First, the sensitivity function $\lambda(\cdot)$ in Campbell and Cochrane (1999) is reverse engineered to ensure a constant risk-free rate. Once capital accumulation is introduced, reverse-engineering in no longer feasible[12]. Second, as we will see in Section 3.2, setting λ_s to be a constant and to be the same across countries helps with generating large currency premium.

The households supply 1 unit of labor inelastically so that $N_t^i = 1$ in equilibrium.

2.1.2. Firms

Each household owns a firm. Each firm produces a country specific good Y_t^i under the production function:

$$Y_t^i = e^{z_t^i}(K_t^i)^{\alpha}(e^{\mu t} N_t^i)^{1-\alpha} \tag{3}$$

where K_t^i denotes capital and N_t^i denotes labor. α is the capital's share of output. The productivity process z_t^i follows

$$z_{t+1}^i = \rho z_t^i + \beta_z^i \sigma_g \varepsilon_{z,t+1}^g + \sigma^i \varepsilon_{z,t+1}^i \tag{4}$$

where ρ governs the persistence of the productivity process and is assumed to be the same across countries. z_t^i is subject to two shocks: a country specific shock $\varepsilon_{z,t+1}^i \overset{i.i.d.}{\sim} N(0,1)$ and a global shock $\varepsilon_{z,t+1}^g \overset{i.i.d.}{\sim} N(0,1)$. σ^i and σ_g are the corresponding volatilities. Each country have a different loading β_z^i on the global shock. I assume that $\forall i, j$, $\text{corr}(\varepsilon_{z,t+1}^i, \varepsilon_{z,t+1}^g) = \text{corr}(\varepsilon_{z,t+1}^i, \varepsilon_{z,t+1}^j) = 0$, so that each country specific shock are orthogonal to each other and to the global shock.

[12]See Chen (2017) for a complete analysis on the advantage and disadvantages of setting λ_s to be a constant. In particular, Chen (2017) shows that the habit level H_t^i is approximately a geometric average of the history of consumption, and risk-free rates remain stable because capital offers an alternative way of transferring resources across time. I confirm that my model generated smooth risk-free rates in Appendix B.

Capital accumulation follows

$$K_{t+1}^i = \Phi(I_t^i/K_t^i)K_t + (1-\delta)K_t^i \tag{5}$$

where δ is the depreciation rate and I_t^i is investment. Following Jermann (1998), I assume that firms face a convex capital adjustment cost:

$$\Phi(\frac{I}{K}) = a_1 + \frac{a_2}{1-\frac{1}{\xi}}\left(\frac{I}{K}\right)^{1-\frac{1}{\xi}}$$

where ξ governs the elasticity of investment-capital ratio with respect to Tobin's Q. $a_1 = \frac{\exp(\mu)-1+\delta}{1-\xi}$ and $a_2 = (\exp(\mu)-1+\delta)^{\frac{1}{\xi}}$ are chosen so that at the steady state, $\Phi(I/K) = \exp(\mu)-1+\delta$ and $\Phi'(I/K) = 1$.

2.1.3. Final Good and Resource Constraints

Households produce a final good F_t^i according to a Cobb-Douglas aggregator[13]:

$$F_t^i = (X_{i,t}^i)^\nu \prod_{j=1}^N \left(X_{j,t}^i\right)^{\frac{1-\nu}{N}} \tag{6}$$

where $X_{j,t}^i$ denotes the amount of country-j good used by a typical household in country i. Following a large literature surveyed by Lewis (2011), I assume households feature home bias and have extra preference for their own good, which is governed by $\nu > 0$. Home bias is important for the model to generate real exchange rate dynamics and differences in returns, which will become clear in Section 3.

The final good can be used for consumption or investment, so the resource constraint for it is given by

$$F_t^i = C_t^i + I_t^i \qquad \forall i,t. \tag{7}$$

The goods market clears for each country specific good

$$Y_t^i = \sum_{j=1}^N X_{i,t}^j \qquad \forall i,t \tag{8}$$

I assume complete market and I solve the model by solving a social planner's problem.

[13] I use a Cobb-Douglas aggregator for simplicity and for comparison with Colacito et al. (2018a). In Section 4.4, I conduct robustness check using a constant elasticity of substitution (CES) aggregator.

2.2. *Solving the Model*

For simplicity, I assume unit Pareto weights for all households and abstract away from the effect that heterogeneous loadings may have on the initial distribution of wealth across countries. The social planner solves

$$\max \sum_{i=1}^{N} \left[\left(\mathbb{E}_0 \sum_{t=0}^{T} \eta^t \frac{(C_t^i - H_t^i)^{1-\gamma} - 1}{1-\gamma} \right) \right]$$

subject to the resource constraints (7) and (8). We can easily obtain the following first order conditions:

$$(S_t^i)^{-\gamma}(C_t^i)^{-\gamma} = \Lambda_{C,t}^i \qquad \forall i, t \tag{9}$$

$$\Lambda_{C,t}^i(\nu + \frac{1}{N}(1-\nu))\frac{F_t^i}{X_{i,t}^i} = \Lambda_{X,t}^i \qquad \forall i, t \tag{10}$$

$$\Lambda_{C,t}^j \frac{1}{N}(1-\nu)\frac{F_t^j}{X_{i,t}^j} = \Lambda_{X,t}^i \qquad \forall i, j \neq i, t \tag{11}$$

where $\Lambda_{C,t}^i$ and $\Lambda_{X,t}^i$ are shadow prices of consumption and country specific good of country i, respectively. And we can derive the Euler equation as

$$1 = \mathbb{E}_t(M_{t+1}^i R_{t+1}^i) \tag{12}$$

where the the stochastic discount factor (SDF) is given by

$$M_{t+1}^i = \eta \frac{\Lambda_{C,t+1}^i}{\Lambda_{C,t}^i} \tag{13}$$

The required return to capital is given by

$$R_{t+1}^i = \frac{1}{Q_t^i}\left[(\nu + \frac{1}{N}(1-\nu))\frac{F_{t+1}^i}{X_{i,t+1}^i}\alpha\frac{Y_{t+1}^i}{K_{t+1}^i} - I_{t+1}^i/K_t^i + Q_{t+1}^i(\Phi(I_{t+1}^i/K_{t+1}^i) + 1 - \delta)\right] \tag{14}$$

where $Q_t^i = \frac{1}{\Phi'(I_t^i/K_t^i)}$ is Tobin's Q.

Now we have a recursive system of $(11+N)N$ equations (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), (14), which determines policy functions for $(11+N)N$ endogenous variables $\{s_{t+1}^i, Y_t^i, z_{t+1}^i, K_{t+1}^i, I_t^i, F_t^i, C_t^i, \Lambda_{C,t}^i, \Lambda_{X,t}^i, M_t^i, R_t^i, \{X_{j,t}^i\}_{j=1,\ldots,N}\}_{i=1,\ldots,N}$.

3. Examining the Mechanism: A Simplified Model

In this section, I examine in the model how capital accumulation relates to currency premium (Subsection 3.1), how habit helps towards the quantitative success of the model (Subsection 3.2), and how heterogenous loadings on the global shock induces currency risk and cross-country variations in currency premium, capital accumulation and expected returns to capital (Subsection 3.3 and 3.4). To that end, I consider a two country, two period, simplified version of the model and utilize log-linearization (with risk adjustments) to get closed form solutions.

In particular, in addition to setting $N = 2$ and $T = 1$, I shut down capital adjustment cost so that $\Phi(\frac{I}{K}) = \frac{I}{K}$, I set $\delta = 1$ so that capital fully depreciates between periods, and I set $\sigma^\star = \sigma$ so that the only source of heterogeneity between the home and foreign country is the loadings β_z and $\beta_z^\star$. To simplify notation, in this section, I omit the country indicator i and simply denote the foreign country with a star $\star$. I also omit the time indicator for period 1. I assume that the economy is at its deterministic steady state at period 0 and study agents' incentive to accumulate capital for production in period 1.

Under this set-up, the return to capital (14) simplifies to

$$R = \frac{\Lambda_X}{\Lambda_C} \alpha \frac{Y}{K}$$

Substituting back to the Euler equation (12), moving capital to the left hand side and taking logs, we have

$$k = \log(\alpha\eta) + \log\left[\mathbb{E}\left(e^{\lambda_X + y - \lambda_{C,0}}\right)\right]$$

Assuming log-normality, we can already see that the risk plays a role in choosing the optimal level of capital:

$$k = \log(\alpha\eta) + \mathbb{E}\left(\lambda_X + y - \lambda_{C,0}\right) + \underbrace{\frac{1}{2}\operatorname{var}\left(\lambda_X + y - \lambda_{C,0}\right)}_{\text{risk adjustment}}$$

The last term is a risk adjustment term and represents the effect of risk on agent's incentive to accumulate capital. Higher variance induces higher precautionary saving motive, and thus leads to more capital.

To get closed form solution and make the link between capital accumulation and currency risk explicit, I log-linearize the system around its deterministic steady state[14] where all shocks are 0 and all households hold a capital stock that is fixed at its steady state level. That is, I

[14] The log-linearized system can be found in Appendix D.

study households' incentive to accumulate different levels of capital while holding the initial capital stock fixed[15].

3.1. Tight link between currency premium, capital accumulation and return to capital

We start by linking capital accumulation to currency premia. Substituting in the solution for λ_X and y, we have

$$k \approx \frac{1}{2}\nu \left(1 - \frac{1}{(1+\lambda_s)\gamma}\right)^2 \operatorname{var}(m) + const \tag{15}$$

where I use *const* to denote constants that are common across countries throughout the paper. I use $\approx$ to highlight the fact that the result relies on log-linear approximation[16]. Equation (15) links capital accumulation to consumption risk. Intuitively, if $\operatorname{var}(m)$ is high and marginal utility of consumption is volatile, precautionary motive incentivizes households to accumulate more capital.

Naturally, we would expect expected return to capital to be closely related to consumption risk as well. Indeed,

$$\mathbb{E}(r) \approx -\frac{1}{2}\nu \left(1 - \frac{1}{(1+\lambda_s)\gamma}\right)^2 B \operatorname{var}(m) + const \tag{16}$$

where $0 < B = \frac{\gamma(1+\lambda_s)(1+\nu(1-\alpha))(1-\nu)+\nu^2(1-\alpha)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}$. Higher consumption risk ($\operatorname{var}(m)$) induces higher capital, which result in lower return to capital.

As shown in the seminal paper by Backus et al. (2001), under complete market and log-normality of the SDF, currency premium can be written as differences between variance of the log SDF:

$$\begin{aligned} \mathbb{E}(rx) &= r_f^\star - \mathbb{E}(\Delta ex) - r_f \\ &= -\frac{1}{2}(\operatorname{var}(m^\star) - \operatorname{var}(m)) \end{aligned} \tag{17}$$

Since variance of log SDF shows up in (15) and (16), it is obvious that there is a tight link between capital accumulation, expected return to capital, and currency premium. In fact,

[15] Fixing the initial capital stock avoids solving for a quadratic system of equations and makes closed-form solutions feasible.

[16] Alternatively one can denote $\hat{x} = x - \bar{x}$ for all endogenous variables and replace all $\approx$ with $=$.

taking the difference between foreign and home country, we have

$$k^\star - k \approx -\nu \left(1 - \frac{1}{(1+\lambda_s)\gamma}\right)^2 \mathbb{E}(rx) \tag{18}$$

$$\mathbb{E}(r^\star - r) \approx \nu \left(1 - \frac{1}{(1+\lambda_s)\gamma}\right)^2 B\,\mathbb{E}(rx) \tag{19}$$

So differences between capital and expected returns to capital across countries are approximately proportional to currency premium. If a country features higher currency premium, it accumulates less capital and has higher expected return to capital. I summarize this result in the following proposition.

Proposition 1. *In the simplified set-up, capital accumulation and expected return to capital are tightly linked to currency premium as in* (18) *and* (19) *. In particular,if the currency of a country features higher currency premium,*

- *it accumulates less capital.*
- *it features higher expected required rate of return to capital.*

Proof. See Appendix D. ☐

Proposition 1 shows that currency premium is indeed directly linked to capital accumulation and expected return to capital. This result does not rely on external habit (it holds even when $\lambda_s = 0$) [17], but it does require that the home bias parameter $\nu \neq 0$. The intuition is simple: if there is no home bias, the two countries would consume the same consumption bundle, which would feature the same stochastic property (riskiness) and there is no incentive to accumulate different levels of capital. With home bias, the model generates a tight link between currency premia and capital-output ratios as in the data.

3.2. Generating large currency premium: the role of external habit

We then turn to the role of external habit. While external habit is not essential to generate the link between capital accumulation and currency premium, it is crucial for the quantitative success of the model. As shown in (17), currency premium can be written as differences between the variances of log SDFs. To study the role of external habit, recall that under

[17] This is consistent with the findings in Hassan et al. (2016), who use CRRA preferences. In fact, this result is perhaps quite general and does not rely on a specific functional form of the utility function. I leave the formal proof of this more general result for future research.

standard CRRA preference, $\text{var}(m) = \gamma^2 \,\text{var}(\Delta c)$, so

$$\mathbb{E}(rx) = -\gamma^2(\text{var}(\Delta c^\star) - \text{var}(\Delta c))$$

We face a quantitative challenge that is similar to the well-known equity premium puzzle. The equity premium puzzle states aggregate consumption is too smooth to account for the observed Sharpe ratio of the stock market (Hansen and Jagannathan (1991)), while here the *difference* between aggregate consumption growth volatilities is too small ($\text{var}(\Delta c) \in [0.005\%, 0.03\%]$ for G10[18]) to match the observed large currency premium (e.g. 5.70% between New Zealand and Japan) in the data. Under CRRA, resolving both quantitative puzzles requires implausibly large risk aversion γ, which would lead to risk-free rates that are too high compared to the data (Weil (1989)).

To see how habit helps in terms of resolving the puzzle, notice that under the simplified set-up, it can be shown that[19]

$$\text{var}(m) = \text{var}(-\gamma s - \gamma c) = \gamma^2(1 + \lambda_s)^2 \,\text{var}(\Delta c) \tag{20}$$

Under standard calibration used in the external habit literature, λ_s is a large number[20], so it is obvious that habit is effective in generating large $\text{var}(m)$: it boosts the variance of consumption growth by a factor of $(1 + \lambda_s)^2$. In fact, the effective relative risk aversion is given by

$$-\frac{U_{CC}(C, S) \cdot C}{U_C(C, S)} = (1 + \lambda_s)\gamma$$

so external habit increases the effective risk-aversion by a factor of $(1 + \lambda_s)$. The intuition is as follows. Households care about the difference between their consumption level and the externally given habit and hate states when consumption is close to the habit level. Because consumption affects habit level through the sensitivity parameter (see equation (2)), habit provides an additional channel through which consumption could affect marginal utility (this is evident in equation (9)). As a result, marginal utility is much more sensitive to consumption growth than without habit, and the effective risk-aversion is much higher. In fact, the effectiveness of external habit is exactly determined by how sensitive the habit level

[18]Data source: PWT 10.0.

[19]This can be easly seen from (2) holding c_0 constant and assuming $s_0 = \bar{s}$.

[20]For example, $\lambda_s = 16.54$ in Campbell and Cochrane (1999) and $\lambda_s = 13.29$ in Verdelhan (2010).

is to consumption growth shocks [21].

Taking difference across countries and assuming λ_s is the same across countries, we can easily see how external habit helps to generate large currency premium.

Proposition 2. *If countries share the same constant sensitivity parameter λ_s, currency premium is given by*

$$\mathbb{E}(rx) = -\frac{1}{2}\gamma^2(1+\lambda_s)^2(var(\Delta c^\star) - var(\Delta c))$$

Proof. Substitute (20) into (17). □

Proposition 2 is straight forward to understand. If effective risk-aversion are boosted by the same factor in the two countries, then obviously the difference in volatility of consumption growth would be multiplied by this factor. Habit thus generates large currency premium even with mild differences in consumption growth volatilities. Setting λ_s to be constant[22] and to be the same across countries is important for this result. In Appendix E, I show that in an endowment economy as in Verdelhan (2010) where λ_s takes the functional form used in standard habit models and is not constant across countries, currency premium is always 0 even if countries feature heterogeneous variance of consumption growth. In that sense, while in closed-economy asset pricing (Chen (2017)) setting λ_s to constant is a choice of convenience, the same trick is economically important in an international setup because it boosts the difference between variances of SDFs across countries and helps with generating large currency premium.

Because of the tight link with the equity premium puzzle, it is natural to adapt other successful approaches in the equity premium literature to resolve the international puzzle, in particular the long-run risk model of Bansal and Yaron (2004). Colacito et al. (2018a) studies a heterogenous economy similar to mine with Epstein and Zin (1989) preference and long-run risk , but most of the currency premia generated in their model are from predicted appreciation of the high interest rate currency instead of interest rate differences, which is at odds with the data[23]. In the data, currency premia come primarily from interest rate

[21] Note that this intuition is different from what is often used in the standard habit model, where effective risk-aversion is time varying and gets much larger when consumption is close to the habit level (Campbell and Cochrane (1999)) . Here because λ_s is constant, effective risk-aversion is also constant.

[22] In an endowment economy, setting λ_s to be a constant typically induces excess risk-free rate volatilities (see Campbell and Cochrane (1999)), but once capital accumulation is introduced, risk-free rates remain stable even with constant λ_s because agents have another channel (capital) to smooth their consumption profile. See Chen (2017) for a detailed analysis. I confirm that risk-free rates are stable in my model in Appendix B.

[23] In ongoing work Hassan et al. (2021), we show that this undesirable feature is embedded in Epstein and Zin (1989) utility functions.

differences and expected change in exchange rate is close to 0. In the following subsection, I study the real exchange rate in the simplified economy and show that expected change in exchange rate is indeed 0 in my model and all the currency premia comes from interest rate differences as in the data.

3.3. Real exchange rate

Under complete market, change in log real exchange rate (quoted in units foreign currencies per home currency) is given by the difference between log SDFs.

$$\Delta ex = m - m^\star$$

Substituting in the log-linear solutions for the log SDFs, we have the real exchange rate given by

$$\Delta ex \approx \frac{\nu\gamma(1+\lambda_s)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}[(\beta_z^\star - \beta_z)\sigma_g\varepsilon_g + \sigma(\varepsilon^\star - \varepsilon)] \tag{21}$$

Obviously $\mathbb{E}(\Delta ex) = 0$, which is consistent with the data. The reason is that the first moment of the log SDFs does not depend on the loadings β_z and $\beta_z^\star$. This property, while being simple, is not satisfied under Epstein and Zin (1989) preferences[24] and is essential for the model's ability to match unconditional change in exchange rate in the data. Together with Propsition 2, my model generates large currency premium with expected change in exchange rate being 0, which is consistent with the empirical evidence.

Expression (21) also shows how different loadings β and $\beta^\star$ are connected to currency risk and induce one currency to be safer than the other. Without loss of generality, assume $\beta > \beta^\star$ so that the home country has a higher loading on the global shock. When a negative global shock hits ($\varepsilon_g < 0$), it is easy to see that $\Delta ex > 0$ so that the home currency appreciates. The intuition is as follows: when a negative global shock hits, the higher loading home country experiences a deeper drop in its productivity and produces less of its country-specific good, which becomes relatively expensive. Because of home bias, its consumption bundle also becomes relatively expensive, resulting in appreciation of the home currency because real exchange rate is defined to be the relative price of the final consumption good. The higher loading home currency thus appreciates in global bad times and is perceived to be safer by global investors.

I summarize the properties of the real exchange rate in the following proposition.

[24]See Appendix F for a brief discussion. For a complete analysis, see ongoing work Hassan et al. (2021).

Proposition 3. *Under the simplified set-up, real exchange rate is given by* (21)*. Suppose* $\beta_z > \beta_z^\star$*, we have*

- *expected change in exchange rate is 0.*
- *the real exchange rate increases (appreciation of the high loading home currency) when a negative global shock hits.*

Proof. See Appendix D. □

3.4. *Effects of heterogenous loadings*

In Proposition 3, we have established that heterogenous loadings on the global shock induces one country to be safer than the other in the sense that its currency appreciate in global bad times. Intuitively, such countries should feature lower currency premium, lower expected return to capital, and accumulate more capital. In this subsection, I confirm these intuitions with closed form solutions and show that heterogenous loading induced currency risk jointly determines currency premia, expected return to capital, and capital accumulation.

Proposition 4. *Under the simplified specification, the higher loading country*

- *...features lower currency premium and risk-free rates .*

$$\begin{aligned}\mathbb{E}(rx) &= r_f^\star - r_f - \underbrace{\mathbb{E}(\Delta ex)}_{\approx 0}\\ &\approx -\frac{1}{2}\frac{\nu\gamma^2(1+\lambda_s)^2}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\left[(\beta_z^\star)^2-(\beta_z)^2\right]\sigma_g^2\end{aligned}$$

- *...features lower expected return to capital*

$$\begin{aligned}\mathbb{E}(r^\star - r) \approx &-\frac{1}{2}[\gamma(1+\lambda_s)(1+\nu(1-\alpha))(1-\nu)+\nu^2(1-\alpha)]\\ &\times\frac{\nu^2(1-\gamma(1+\lambda_s))^2}{(\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2)^2}\left[(\beta_z^\star)^2-(\beta_z)^2\right]\sigma_g^2\end{aligned}$$

- *...accumulates more capital.*

$$k^\star - k \approx \frac{1}{2}\frac{\nu^2(1-\gamma(1+\lambda_s))^2}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\left[(\beta_z^\star)^2-(\beta_z)^2\right]\sigma_g^2$$

Proof. See Appendix D. □

From an asset pricing perspective, Proposition 4 is intuitive: the higher loading country's currency appreciate in global bad times (Proposition 3), it is thus a good hedge against global risk. Investors require a lower rate of return on assets from this country, thus it features lower currency premium, lower expected return to capital, and accumulates more capital.

It is also intuitive from a social planner's perspective. Installing more capital in the high loading country is desirable for two reasons. First, because the high loading country features a more volatile productivity profile by construction and they prefer their own good, the social planner finds it optimal to install more capital there out of precautionary saving motive. Second, installing more capital in the high loading country also benefits the low loading country because when facing a negative shock, less resources needs to be transferred to the high loading country. To understand this, notice that because of heterogenous loadings, there exists risk-sharing and transfer of resources even when the shock is global. If more capital is installed in the high loading country, their marginal utility of consumption does not drop as much when a negative global shock hits. They need less help from abroad, which makes the low loading country better off as well. In this sense, installing more capital in the high loading country insures the world from downturns as a whole, so the social planner finds it optimal to do so.

Proposition 4 also confirms the findings of Proposition 1 and 2. Obviously there is a tight link between currency premium, expected returns to capital, and capital accumulation. Home bias $\nu > 0$ is essential for generating any cross country differences in these variables, and habit is crucial for quantitative success of the model ($\mathbb{E}(rx)$ is increasing in $(1 + \lambda_s)$).

I summarize the main findings in the simplified model as follows. First, there is a tight link between currency premium, expected return to capital, and capital accumulations; Second, external habit generates large currency premium while keeping expected change in exchange rate at 0; Third, the currency of high loading country appreciate in global bad times. Fourth, high loading country features safer currency, lower currency premium, lower expected return to capital and accumulates more capital.

4. Estimation of the Full Model

We have established a list of theoretical predictions from the simplified model in the last section. In this section, I take the full model to the data and estimate the loadings on the global shock for countries issuing the G10 currencies and investigate the quantitative implications of the model.

4.1. Data

I consider countries(regions) issuing the G10 currencies: Australia, Canada, the Euro area, Japan, New Zealand, Norway, United Kingdom, Sweden, Switzerland, and United States. I use quarterly GDP (in 2015 US dollars) data from the OECD National Account Statistics starting from 1994Q1 (when data for all countries becomes available) to 2019Q4 (before COVID-19). Estimation of the loadings are based solely on GDP data. I generate capital-output ratios from Pen World Table 10.0 (Feenstra et al. (2015)) by dividing capital stock by GDP and then averaging across the sample periods[25]. I get currency premium and exchange rate data from Verdelhan's website[26] by annualizing monthly returns and then taking average across the sample periods.

4.2. Estimation

I begin by externally calibrating a set of parameters to standard values used in the literature, summarized in Table 1. These parameters are set to be the same across countries. The model is quarterly so one period represents a quarter.

Table 1: Externally Calibrated Parameters (Quarterly)

Description		
Preference and Production:		
Relative risk aversion [γ]	4	
Time discount factor [η]	0.995	Chen (2017)
Degree of home bias [ν]	0.98	Colacito et al. (2018a)
Capital Share [α]	0.35	Chen (2017)
Depreciation Rate [δ]	0.016	Chen (2017)
Elasticity of I/K wrt Tobin's Q [ξ]	0.7	Kaltenbrunner and Lochstoer (2010)
TFP:		
Mean of TFP growth(%) [μ]	0.45	Chen (2017)
Persistence of TFP [ρ]	0.98	Chen (2017)
Habit:		
Mean surplus consumption ratio(%) [$\bar{S}$]	7	Verdelhan (2010)
Persistence [ρ_s]	0.995	Verdelhan (2010)

The value of relative risk aversion γ is larger than what is typically used in standard habit models, but is lower than Van Binsbergen (2016) and is well within the standard values used

[25]For the Euro area, I divide the total capital of all countries in the Euro area by their total GDP.
[26]Verdelhan (2018): http://web.mit.edu/adrienv/www/Data_for_AugmentedUIP_allcountries.xls

in macro models. I follow Colacito et al. (2018a) and set home bias ν to 0.98 so that stochastic properties of the country specific good passes through strongly to consumption. I discuss the effect of changing this parameter in Section 4.4. All other variables are standard.

I estimate the remaining 20 parameters $\Theta = \{\sigma_g^i, \sigma^i\}_{i=1,\ldots,N}$ using simulate method of moments. Here I estimate $\sigma_g^i = \beta_z^i \sigma_g$ because β_z^i and σ_g can not be estimated separately. I assume the average country has a loading of 1 on the global shock and set $\sigma_g = \frac{1}{N}\sum \sigma_g^i$, then calculate β_z^i for each country accordingly.

I target 20 data moments: the standard deviations of HP-filtered GDP and the correlation of each country's HP-filtered GDP with the sample average across countries. I estimate the parameter vector $\hat{\Theta}$ by minimizing the distance between data moments and model simulated moments:

$$\hat{\Theta} = \arg\min_{\Theta} \left(\frac{H(\Theta) - H_D}{H_D}\right)' \left(\frac{H(\Theta) - H_D}{H_D}\right)$$

where H_D is a vector of the target moments in the data and $H(\Theta)$ is a vector of simulated moments for a given parameter vector Θ. I get $H(\Theta)$ by solving the model using second order perturbation and then simulate the model for 10000 periods[27], then extract the target moments.

Because I have the same number of target data moments as the number of parameters to be estimated, the parameters are exactly identified[28]. The estimated parameter values are summarized in Table 2.

Table 2: Estimated Parameters

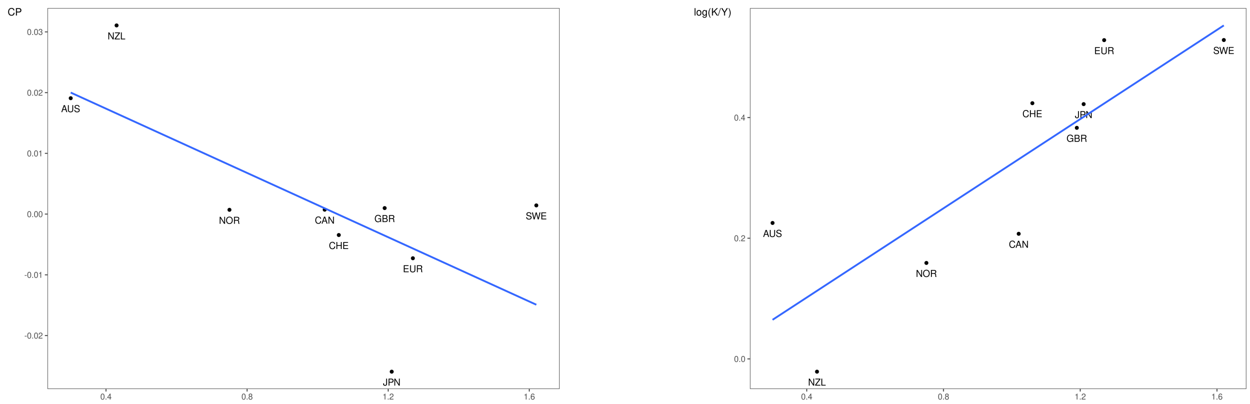
Country	AUS	CAN	CHE	EUR	GBR	JPN	NOR	NZL	SWE	Global
β_z^i	0.30	1.02	1.06	1.27	1.19	1.21	0.75	0.43	1.62	1
$\sigma_z^i(\%)$	0.42	0.53	0.58	0.40	0.37	0.81	0.73	0.73	0.59	0.61

The estimated loadings β_z^i are largely inline with common examples of safe and risky currencies. For example, Japan has a loading of 1.21 and New Zealand has a loading of 0.43 while Japanese yen is widely conceived as a safe haven currency and the New Zealand dollar is considered risky.

[27] I use Dynare 4.6.4 to achieve this. I use second order approximation for efficiency and because for the purpose of this paper, I only focus on unconditional moments and does not consider time-variations.

[28] See Appendix G for the list of target moments and the moment matching results.

Figure 3: Estimated Loadings



(a) Currency Premium (b) Capital-Output Ratio

This figure plots currency premia(Panel(a)) and log capital-output ratios (Panel(b)) relative to the US against estimated loadings on the global shock. The line of best fit has a slope of -0.03 (s.e. -0.01) for currency premium and a slope of 0.37 (s.e. 0.09) for log capital-output ratio. All moments are annualized.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

4.3. Properties of the Estimated Model

In this subsection I take the estimated loadings as given and simulate the model to evaluate its performance. I first confirm that the estimated loadings are indeed highly correlated with currency premia and capital-output ratios. Then I directly compare moments in the data with its corresponding model simulations to evaluate the model's performance. I also discuss the role of habit, home bias and conduct robustness checks with a CES aggregator for the final good.

4.3.1. Correlation between loadings and key variables

I first explore the correlation of the estimated loadings with currency premia and capital-output ratios in the data. To that end, I plot currency premia (Panel (a)) and capital-output ratios (Panel (b)) against the estimated loadings in Figure 3. Consistent with the predictions of Proposition 4, countries with higher loadings on the global shock features lower currency premium and higher capital-output ratios. The R^2 is 0.49 for currency premia and 0.70 for capital-output ratios[29]. The estimated loadings are indeed highly correlated with currency premia and capital-output ratios across countries.

The fact that the loadings on the global shock are estimated solely from GDP data is worth highlighting. While several papers have estimated these loadings and found that they are closely related to currency premia, most of them rely on asset prices for estimation[30].

[29] It is not surprising that R^2 is lower for currency premia because as an asset price, currency premia are much more volatile and harder to estimate precisely compared to capital-output ratios.

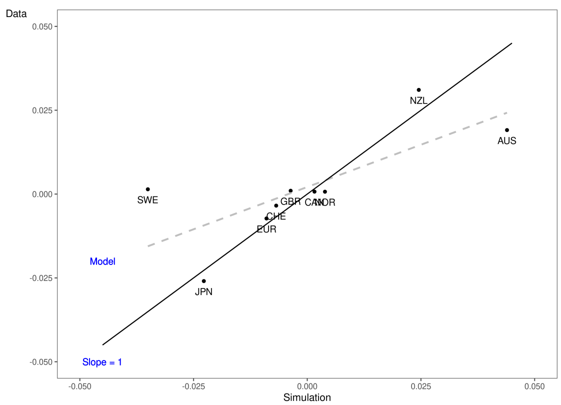
[30] For examples, Lustig et al. (2011) uses portfolios of currencies and Colacito et al. (2018a) use dividend data.

The fact that the loadings can be extracted from GDP data alone is suggesting that the forces that drives the heterogenous loadings on the global shock is quite fundamental.

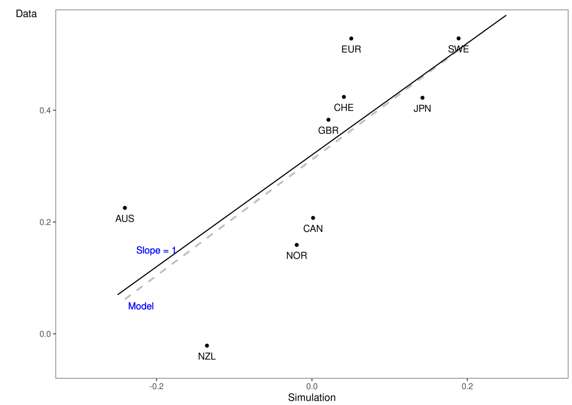
4.3.2. Data Moments v.s. Model Simulations

I investigate the quantitative performance of the model by plotting moments in the data against model generated moments for currency premia (Panel (a)) and capital-output ratios (Panel (b)) in Figure 4.

Figure 4: Data v.s. Simulations



(a) Currency Premium



(b) Capital-Output Ratio

This figure plots currency premia(Panel(a)) and log capital-output ratios (Panel(b)) relative to the US against their simulated counterparts. The line of best fit has a slope of 0.50 (s.e. 0.17) for currency premium and a slope of 1.04 (s.e. 0.37) for log capital-output ratio. Model simulated moments are obtained by simulating the model for 10000 periods and then taking average. All moments are annualized.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

If the model perfectly matches the data, we would expect the model simulated moments and the data moments to be identical across countries and all points should lie on the 45° line. In Figure 4, Panel (a), we can see that except for Sweden and Australia, all countries lie almost perfectly on the 45° line (solid line), suggesting that the model does quite well in terms of matching the currency premia. The line of best fit (dashed line) has a slope of 0.50 (s.e. 0.17), which is mostly driven by under prediction of currency premium for Sweden and over prediction for Australia.

As for capital-output ratios, the model also does quite well in terms of matching the data. As shown in Figure 4, Panel (b), all points are closely aligned along the 45° line (solid line). The line of best fit has a slope of 1.04 (s.e. 0.37), suggesting that on average, the model does a good job at matching the cross-country variations in capital-output ratios [31].

[31] One caveat of the model shows up in Panel (b). Capital-output ratios are all relative to the US. In the data, they range from 0 to 0.5 while in the model, they range from -0.2 to 0.2. This is suggesting that the model does poorly in predicting the capital-output ratio of the reference country, i.e., the US. This is perhaps not surprising because the US enjoys a very special role in the global financial, trade and political network. I leave proper treatment of the US for future research.

To quantify the model's performance in matching the observed cross-country variations in capital-output ratios, I perform the following variance decomposition. Let $\kappa_D^i = k_D^i - y_D^i$ denote the log capital-output ratio in the data for country i and κ_M^i denote the same variable predicted by the model, and write

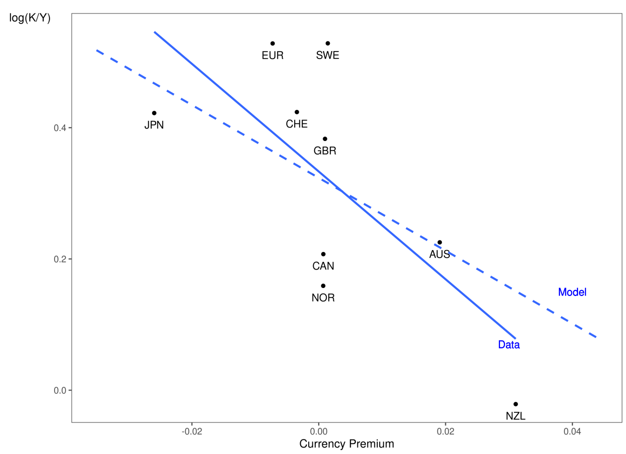
$$\kappa_D^i = \kappa_M^i + e^i$$

where e^i is the prediction error of the model. Taking variances across countries on both side, we have

$$\underbrace{\mathrm{var}(\kappa_D^i)}_{0.0345} = \underbrace{\mathrm{var}(\kappa_M^i)}_{0.0171} + \underbrace{\mathrm{var}(e^i)}_{0.0161} + \underbrace{2\,\mathrm{cov}(\kappa_M^i, e^i)}_{0.0013}$$

Under this decomposition, $\frac{\mathrm{var}(\kappa_M^i)}{\mathrm{var}(\kappa_D^i)} = 49.60\%$, so the model roughly accounts for 50% of the cross-country variations in capital-output ratios.

Figure 5: Regression Line of K/Y on Currency Premium, Data v.s. Model



This figure plots the regression line of capital-output ratios on currency premia for the G10 currencies in the data and the same regression line implied by the model simulations. The points represents the data. The regression line in the data has slope of -8.21 (s.e. 0.3.12). The regression line implied by the model simulations has a slope of -5.55 (s.e. 0.10). Model simulated moments are obtained by simulating the model for 10000 periods and then taking average. All moments are annualized.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

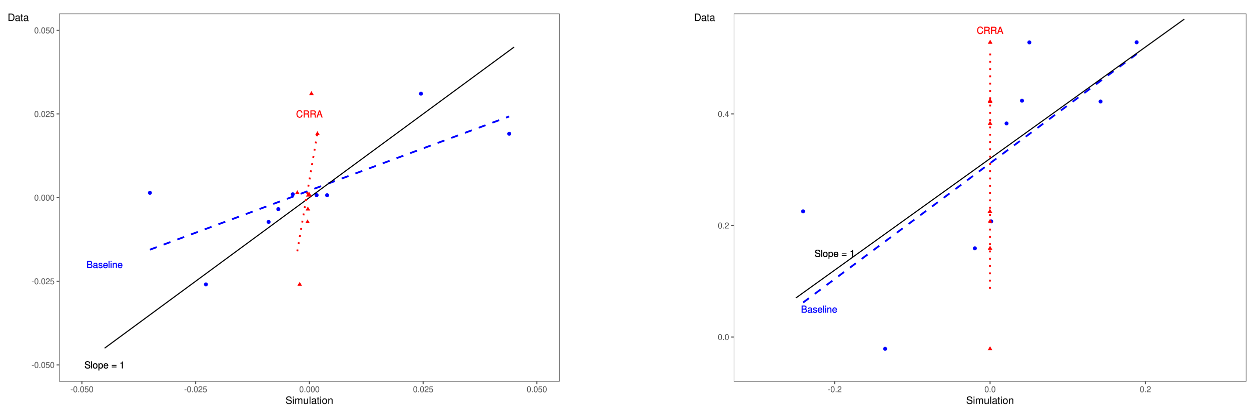
The model also have predictions for the relationship between capital-output ratios and currency premia. Figure 5 compares the regression line of capital-output ratios on currency premia in the data (solid line) with the regression line implied by model simulations (dashed line). The model predicts a slope of -5.55, compared to -8.21 in the data. The model under-predicts the slope, but still explain a significant portion. This result also confirms the findings of Proposition 1, which states that there is a tight link between currency premia and capital-output ratios in the model.

Overall, taken the estimated loadings as given, the model does remarkably well in predicting cross-country variations in capital-output ratios, explaining around 50% of it. The model also does a fairly good job at matching the currency premia, but it predicts currency premia that is too high for Australia and too low for Sweden. This is not surprising because as asset prices, currency premia is much more volatile than capital-output ratios and are harder to predict, especially with macro shocks. The model also does fairly well on predicting the correlations between capital-output ratios and currency premia.

4.3.3. The role of habit

To highlight the role of habit in the quantitative success of the model, I compare the simulated results generated from our baseline habit model with standard CRRA preferences.

Figure 6: Habit v.s. CRRA



(a) Currency Premium (b) Capital-Output Ratio

This figure plots currency premia(Panel(a)) and log capital-output ratios (Panel(b)) relative to the US against their simulated counterparts. Blue dots represent the baseline model with habit, and red triangles represent the CRRA model. The dashed blue line represents the line of best fit for the baseline model with habit, and features a slope of 0.50 (s.e. 0.17, $R^2 = 0.55$) for currency premium and a slope of 1.04 (s.e. 0.37, $R^2 = 0.53$) for log capital-output ratio. The dotted red line represents the line of best fit for the CRRA model, and features a slope of 7.99 (s.e. 3.46, $R^2 = 0.43$) for currency premium and a slope of 1182 (s.e. 533, $R^2 = 0.41$) for log capital-output ratio. All moments are annualized.
Model simulated moments are obtained by simulating the model for 10000 periods and then taking average.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

Figure 6 is generated by adding simulated moments from the CRRA model (red triangles) to Figure 4. In both panels, the CRRA model does poorly on the quantitative front. The lines of best fit are both close to being vertical, and are far away from the 45° line. This confirms our findings in Proposition 2, which states habit is crucial for the quantitative success of the model.

One interesting fact is that although the model with CRRA preference fails miserably on the quantitative front, its predictions are still qualitatively consistent with the data. Under CRRA, the R^2 for currency premium is 0.43 and for capital-output ratio is 0.41, suggesting that the model generated relative patterns are still highly correlated with the data. This is consistent with the findings of Hassan et al. (2016), who study a model with CRRA preference and heterogeneous country sizes and find similar patterns. Because the estimated loadings are highly correlated with currency premia and capital-output ratios (Figure 3), they would induce different responses to the global shock as long as agents are risk averse and feature home bias. The level of sensitivity to risk then governs the quantitative importance of this mechanism. With external habit, the model generates large differeces in currency premia and capital-output ratios, which is consistent with the data.

4.3.4. Exchange rates

Proposition 3 predicts that the model generated expected change in exchange rates are 0 as in the data. We confirm these predictions with our estimated model in this subsection.

Table 3: Expected Change in Exchange Rates, Data v.s. Model

	AUS	CAN	CHE	EUR	GBR	JPN	NOR	NZL	SWE
Data(%)	-0.13	-0.07	-1.64	0.05	0.42	-0.11	0.60	-0.72	0.44
	(11.65)	(0.17)	(10.72)	(9.72)	(8.36)	(11.58)	(10.68)	(12.26)	(10.52)
Model(%)	0.02	0.00	0.02	-0.00	0.00	0.01	0.00	0.00	0.00
	(17.41)	(13.66)	(13.92)	(11.31)	(10.88)	(16.40)	(17.85)	(20.97)	(12.68)

Standard deviations in brackets. Model moments are obtained by simulating the model for 10000 periods and then taking the corresponding moments. All moments are annualized.

Table 3 compares expected change in exchange rates between data and the model simulations. As is well known, exchange rates are very volatile and unconditionally, they are close to 0. The model replicates both empirical patterns, although it over-predicts the volatility of the exchange rates[32]. Combining with Figure 4, Panel (a), the model generates large cross-country variations in currency premia while matching the unconditional moments of change in exchange rates.

To summarize, the estimated loadings are highly correlated with currency premia and capital-output ratios. The model simulated currency premia and capital-output ratios lines up nicely with the data. Variance decomposition suggests the model explains roughly 50% of the cross-country variations in capital-output ratios. The simulated data also replicates the negative relationship between currency premia and capital-output ratios in the data. External habit is crucial for the quantitative success of the model, and helps generating large currency premia with 0 expected change in exchange rates, which is consistent with the data.

[32] Verdelhan (2010) shows that if one allow trade costs, exchange rate volatility can be reduced without affecting currency premia dynamics. Excess volatility of exchange rates is also present in frameworks using Epstein and Zin (1989) utilities and long-run risk, for example, Colacito et al. (2018a). See Brandt et al. (2006) for a general discussion.

4.4. Robustness: CES and Home Bias

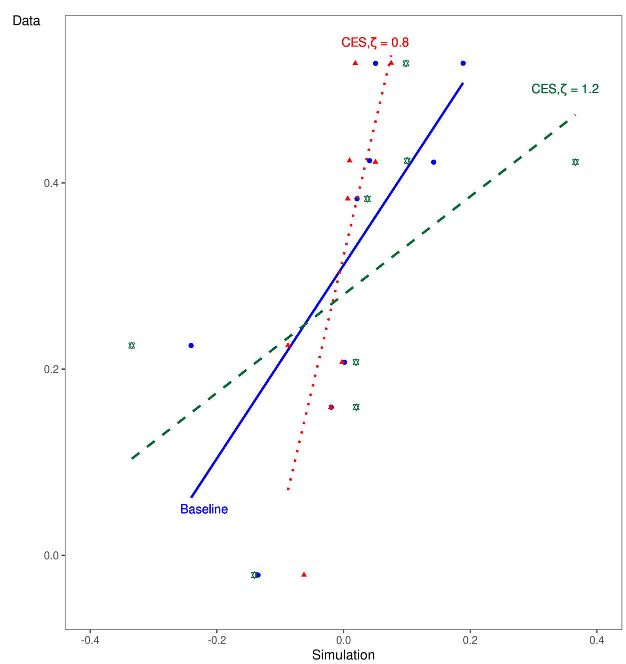
In this section, I test how the quantitative predictions of the model reacts to (1) using a CES aggregator for the final good; (2) changes in the home bias parameter ν.

I start by changing the production function of the final good (6) to the following CES aggregator:

$$F_t^i = \left(\nu (X_{i,t}^i)^{\frac{\zeta-1}{\zeta}} + \sum_{j=1}^{N} \frac{1}{N} (1-\nu) \left(X_{j,t}^i\right)^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}}$$

where ζ governs the elasticity of substitution between the country-specific goods. In my baseline specification, I use Cobb-Douglas aggregator so that $\zeta = 1$. To see how the model predictions change with respect to ζ, in Figure 7 I re-produce Figure 4, Panel (b) for $\zeta = 0.8$ and $\zeta = 1.2$ and put them in the same figure as my baseline specification with $\zeta = 1$.

Figure 7: Changing Elasticity of Substitutions



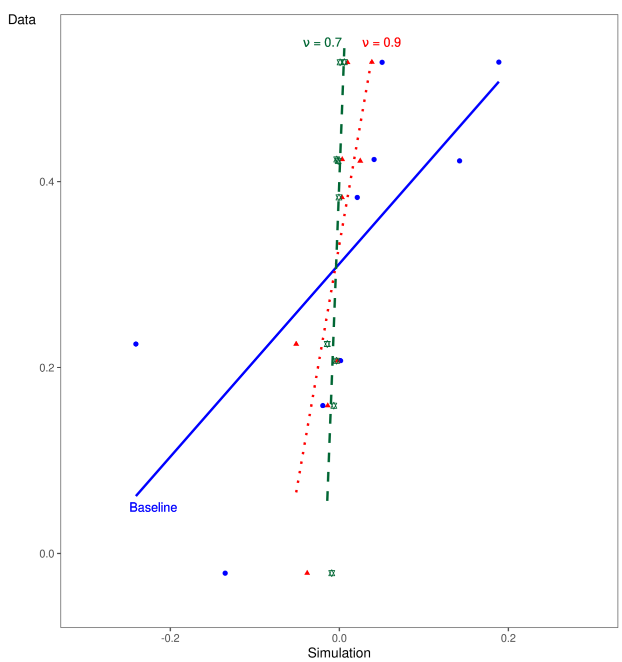
This figure plots log capital-output ratios relative to the US against their simulated counterparts for the baseline model and the model with CES aggregators ($\zeta = 0.8$ and $\zeta = 1.2$). Blue dots represent the baseline model, red triangle represents $\zeta = 0.8$ and green stars represent $\zeta = 1.6$. The line of best fit has a slope of 1.04 (s.e. 0.37, $R^2 = 0.53$) for the baseline model (solid blue line), a slope of 2.86 (s.e. 0.85, $R^2 = 0.61$) for $\zeta = 0.8$ (dotted red line) and a slope of 0.53 (s.e. 0.21, $R^2 = 0.46$) for $\zeta = 1.2$ (dashed green line). Model simulated moments are obtained by simulating the model for 10000 periods and then taking average. All moments are annualized.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

I use the slope of the lines of best fit as a rough measure on how alternative specifications compare to the baseline. A steeper slope indicates the alternative model over-predicts the cross-country variations in capital-output ratios across countries relative to the baseline model and vice versa. As shown in Figure 7, as the elasticity gets larger ($\zeta = 1.2$, green dashed line), the model generated cross-country variations are larger, and the opposite is also true ($\zeta = 0.8$, red dotted line).

This result is intuitive. As elasticity of substitution becomes larger, goods become more substitutable and agents optimally choose to consume more of their home good because it has a higher weight. Higher ζ thus enhances the effect of home bias. When a negative global shock hits and ζ is high, the increase in the price of high-loading country's good passes through more to the price of its final good, leading to more pronounced appreciation. As a result, more capital is installed in the high loading country.

I next turn to the home bias parameter, ν. In international asset pricing models with Cobb-Douglas aggregators, a high degree of home bias is typically assumed[33]. In my baseline calibration, I follow Colacito et al. (2018b) and set $\nu = 0.98$. I illustrate how changing ν affects the results in Figure 8.

Figure 8: Changing Degree of Home Bias



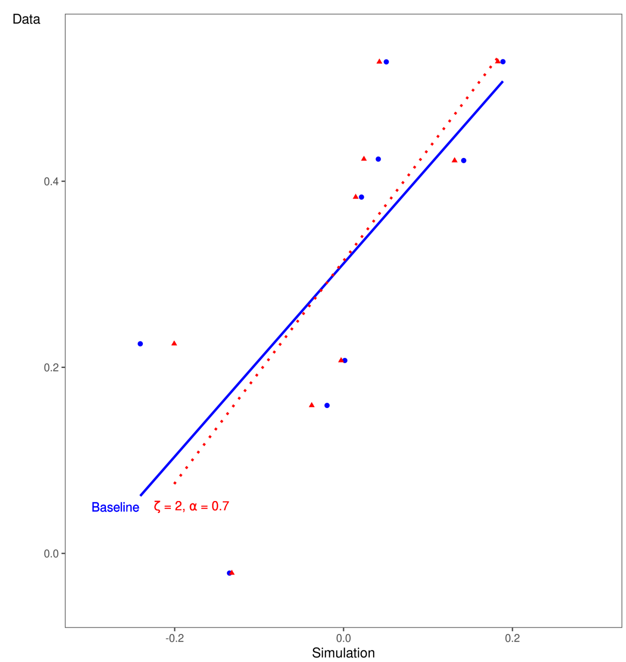
This figure plots log capital-output ratios relative to the US against their simulated counterparts for the baseline model and the model with $\nu = 0.9$ and $\nu = 0.7$). Blue dots represent the baseline model, red triangle represents $\nu = 0.9$ and green stars represent $\nu = 0.7$. The line of best fit has a slope of 1.04 (s.e. 0.37, $R^2 = 0.53$) for the baseline model (solid blue line), a slope of 5.22 (s.e. 1.51, $R^2 = 0.63$) for $\nu = 0.9$ (dotted red line) and a slope of 24.13 (s.e. 7.69, $R^2 = 0.58$) for $\nu = 0.7$ (dashed green line). Model simulated moments are obtained by simulating the model for 10000 periods and then taking average. All moments are annualized. Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

When using Cobb-Douglas aggregator, it is important to use large home bias. As we lower home bias, the model generated cross-country variations becomes much smaller (dotted red line and dashed green line) compared to the baseline (solid blue line). Because Cobb-Douglas

[33] For example, Stathopoulos (2017) uses $\nu = 0.952$, Colacito and Croce (2013) uses $\nu = 0.97$.

aggregator restricts elasticity of substitution to 1, a high level of home bias is needed so that price changes in country specific goods are sufficiently passed through to prices of final goods, which represents real exchange rates. Interestingly, Figure 7 and 8 suggests that we can set ν to lower levels if we use CES aggregators and set $\zeta > 1$. Figure 9 confirms this conjure by showing that a model with $\zeta = 2$ and $\alpha = 0.7$ generates results very similar to the baseline.

Figure 9: High Elasticity with Low Home Bias



This figure plots log capital-output ratios relative to the US against their simulated counterparts for the baseline model and the model with $\zeta = 2$, $\nu = 0.7$). Blue dots represent the baseline model, red triangle represents $\nu = 0.7$, $\zeta = 2$. The line of best fit has a slope of 1.04 (s.e. 0.37, $R^2 = 0.53$) for the baseline model (solid blue line) and a slope of 1.20 (s.e. 0.38, $R^2 = 0.58$) for $\nu = 0.7$, $\zeta = 2$. Model simulated moments are obtained by simulating the model for 10000 periods and then taking average. All moments are annualized.
Data Source: PWT 10.0 and Verdelhan's Dataset. Data Range: 1994-2019. Details on the data construction can be found in section 4.1.

To summarize, the model predicted variations in capital-output ratios are increasing in elasticity of substitutions between goods, ζ, and are decreasing in degree of home bias ν. All specifications in this section feature high R^2s, confirming that the estimated loadings and thus currency risk is tightly linked to capital-output ratios. While the exact variation depends on parameterization, one can achieve similar results to the baseline model with a high ζ and a low ν.

4.5. Endogeneity

The loadings on the global shock are extracted from GDP and correlations of GDP with the world average. While the model does remarkably well in matching the cross-country variations in capital-output ratios across countries, it is silent on the fundamental drivers of these loadings. The literature typically interpret them as a reduced form way of capturing heterogeneity in country characteristics that make some currencies safer than others. This interpretation, however, is subject to problem of endogeneity. In particular, there could be some channels through which capital-output ratio may affect a country's loading on the global shock. If such channels indeed exist, the currency risk mechanism discussed in this paper becomes an amplification mechanism, which may still generate interesting dynamics. However, since my sample consists of 10 developed countries that are relatively homogeneous to each other, the scope of the endogeneity problem should be limited. The main message from this paper is that taken the estimated loadings as given, currency risk can have quantitatively important implications for capital-output ratios. I leave the micro-foundation of these loadings for future research[34].

5. Conclution

Heterogenous loadings on a global shock has been a standard modeling device in international asset pricing literature to capture the idea that some currencies are safer than others. It is widely used to understand violations of UIP, exchange rate dynamics and currency premia. Intuitively, currency of high loading countries appreciate in global bad times, making them a good hedge against global risk and investors require a lower return for assets in such countries. In this paper, I have argued that heterogenous loadings and currency risk should also have quantitatively important real implications: high loading countries should feature lower expected return to capital and accumulate more capital. Using a model with external habit, my quantitative exercise shows that if we set the loadings on the global shock to match cross-country GDP correlations, we can explain around 50% of the cross-country variations in capital-output ratios among countries issuing the G10 currencies. External habit is essential for the quantitative success of the model in terms of matching currency premia and capital-output ratios. Compared to existing international long-run risk frameworks, it has the advantage of generating large currency premia with 0 expected change in exchange rates thus better match the data.

My paper is silent on the economic sources of the heterogeneity in loadings on the global shock. One interesting extension is thus to apply external habit to existing frameworks that are trying to micro-found the loadings and evaluate the relative importance of potential channels. I have also consciously abstracted away from other sources of heterogeneities that could have important implications for capital output ratios, for example capital share, but the

[34]In Appendix H, I show that the estimated loadings line up nicely with country size (Hassan (2013)) and trade centrality Richmond (2019), which are arguably exogenous to capital-output ratios. Sweden and Australia appears to be outliers, suggesting there may be other important drivers.

modeling tools developed in this paper can easily be extended to a more complicated set-up and potentially be used to evaluate the relative importance of different drivers of capital-output ratios. In addition, it is an empirical fact that risk-free rates differ persistently across countries, which should have implications beyond capital-output ratios. Because my model can induce long-lasting differences in risk-free rates across countries as in the data, it can potentially be used to study cross-country patterns of other important economic variables that are tightly linked to risk-free rates.

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A. Controlling for Country Characteristics

Table A1: Regression of Capital-output ratios on Currency Premia with Controls, G10

	Dependent variable:							
	Capital-output Ratios Relative to the US							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{E}(rx)$	-7.952^{*}	-8.748^{**}	-7.001	-7.720^{*}	-7.552^{*}	-10.651	-7.217	-8.191
	(3.409)	(3.321)	(4.343)	(3.611)	(3.302)	(5.624)	(4.074)	(4.403)
FDI	0.142							
	(0.397)							
FOI		-0.140						
		(0.196)						
CC			-0.078					
			(0.182)					
GE				-0.086				
				(0.245)				
PS					-0.151			
					(0.187)			
RQ						0.193		
						(0.360)		
RL							-0.108	
							(0.257)	
VA								-0.002
								(0.350)
Constant	0.228	0.637	0.478	0.479	0.493^{*}	0.033	0.517	0.336
	(0.300)	(0.426)	(0.340)	(0.420)	(0.204)	(0.562)	(0.441)	(0.491)
Observations	9	9	9	9	9	9	9	9
R^2	0.508	0.537	0.512	0.507	0.546	0.520	0.511	0.497
Adjusted R^2	0.343	0.382	0.350	0.343	0.395	0.360	0.349	0.330
Residual Std. Error (df = 6)	0.150	0.146	0.150	0.151	0.144	0.149	0.150	0.152
F Statistic (df = 2; 6)	3.093	3.477^{*}	3.150	3.088	3.609^{*}	3.252	3.141	2.966
Note:						*p<0.1; **p<0.05; ***p<0.01		

This table summarizes regressions of log capital-output ratio relative to the US on currency premia and different controls for countries issuing the G10 currencies:

$$ky^i = \alpha\, \mathbb{E}(rx^i) + \beta \text{control}^i + \epsilon^i$$

FDI stands for Financial Development Index, FOI stands for Chinn-Ito financial openness index (Chinn and Ito (2006)). CC stands for control of corruption, GE stands for government effectiveness, PS stands for political stability and absence of violence/terrorism, RQ stands for regulatory quality, RL stands for rule of law, and VA stands for voice and accountability.
Data Source: Capital-output ratios are from PWT 10.0. Currency premia are from Verdelhan's website. FDI is from the IMF Financial Development Indicator dataset. FOI is from the Chinn-Ito Index website. All the other variables are from the World Governance Indicators by the World Bank. Data range from 1994 to 2019.

As is shown in Table A1 , the strong negative relationship between capital-output ratios and currency premia is robust to including a series of controls representing financial development, governance and financial openness within the G10 countries. Because of limitation on the sample size, I can only control for each variable separately.

Table A2: Regression of Capital-output ratios on Currency Premia with Controls, All Countries

	Capital-output Ratios Relative to the US	
	(1)	(2)
$\mathbb{E}(rx)$	-3.279	-9.285^{**}
	(3.768)	(3.435)
FDI	0.139	0.050
	(0.393)	(0.436)
FOI	0.184^{***}	
	(0.066)	
CC	-0.816^{***}	-0.696^{***}
	(0.220)	(0.240)
GE	0.734^{**}	0.452
	(0.276)	(0.286)
PS	0.051	0.139
	(0.132)	(0.142)
RQ	0.059	0.346
	(0.257)	(0.262)
RL	0.033	0.012
	(0.268)	(0.299)
VA	0.071	0.063
	(0.071)	(0.079)
Constant	-0.177	0.043
	(0.191)	(0.194)
Observations	37	37
R^2	0.601	0.487
Adjusted R^2	0.468	0.341
Residual Std. Error	0.219 (df = 27)	0.243 (df = 28)
F Statistic	4.520^{***} (df = 9; 27)	3.324^{***} (df = 8; 28)

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

This table summarizes regressions of log capital-output ratio relative to the US on currency premia and different controls for a sample of 37 countries (See Appendix C for the list of countries).

$$ky^i = \alpha\,\mathbb{E}(rx^i) + \beta\text{control}^i + \epsilon^i$$

FDI stands for Financial Development Index, FOI stands for Chinn-Ito financial openness index (Chinn and Ito (2006)). CC stands for control of corruption, GE stands for government effectiveness, PS stands for political stability and absence of violence/terrorism, RQ stands for regulatory quality, RL stands for rule of law, and VA stands for voice and accountability.
Data Source: Capital-output ratios are from PWT 10.0. Currency premia are from Verdelhan's website. FDI is from the IMF Financial Development Indicator dataset. FOI is from the Chinn-Ito Index website. All the other variables are from the World Governance Indicators by the World Bank. Data range from 1994 to 2019.

As is shown in Table A2 , for a broader range of 37 countries, the strong negative relationship between capital-output ratios and currency premia is robust to including a series of controls representing financial development and governance (Panel (2)) but is weakened when financial openness is included (Panel (1)). This is to be expected because in the broader sample with developing countries, financial openness is crucial how each economy covaries with the world, and thus the loadings on the global shock and currency premia. But within the countries issuing the G10 currencies, all countries have very high openness and thus financial openness is less relevant.

B. Risk-free Rate Volatility

Table A3: Volatility of Risk-free Rates, Model v.s. Data

Country	Data(%)	Model(%)
AUS	2.04	1.19
CAN	2.05	1.27
CHE	0.59	0.93
EUR	2.76	0.89
GBR	1.28	0.89
JPN	3.46	1.18
NOR	2.23	1.00
NZL	1.88	1.28
SWE	2.01	0.78

This table summarizes volatility of real interst rates in the data and in model simulations. Model moments are obtained by simulating the model for 10000 periods.
Data Source: Real interest rates are from the World Development Indicators of the World Bank.

This table confirms the findings in Chen (2017) that risk-free rates are stable in the model when the sensitivity is set to a constant in (2). Note that the real interest rate volatilities in this table are rough estimates and are presented here purely to give a broad idea of the risk-free rate volatilities in the data. The main takeaway is that the model generated risk-free rates are stable.

C. The List of Countries in the Broader Sample

The broader sample in Figure 1 include: United Arab Emirats, Australia, Austria, Belgium, Canada, Switzerland, Czech Republic, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Hong Kong SAR China, Hungary, Indonesia, India, Ireland, Italy, Japan, South Korea, Kuwait, Mexico, Malaysia, Netherlands, Norway, New Zealand, Philippines, Poland, Portugal, Saudi Arabia, Singapore, Sweden, Thailand, United States, South Africa.

Currency premia for countries in the Euro Zone are replaced by the Euro currency premia after Euro is introduced.

D. Solving the Simplified Model with Log-linearization

Under the simplified model, the system of equations in period 1 can be log-linearized as:

$$\begin{aligned}
\hat{c}^i &= \frac{1}{2}(1+\nu)\hat{x}^i_i + \frac{1}{2}(1-\nu)\hat{x}^i_j \\
\hat{\lambda}^i_C &= -\gamma\hat{s}^i - \gamma\hat{c}^i \\
\hat{\lambda}^i_X &= \hat{\lambda}^i_C + \hat{c}^i - \hat{x}^i_i \\
\hat{\lambda}^i_X &= \hat{\lambda}^j_C + \hat{c}^j - \hat{x}^j_i \\
\hat{y}^i &= \hat{z}^i + \alpha\hat{k}^i_0 \\
Y^{i\star}\hat{y}^i &= X^{i\star}_i\hat{x}^i_i + X^{j\star}_i\hat{x}^j_i \\
\hat{s}^i &= \rho_s\hat{s}^i_0 + \lambda_s\Delta c^i
\end{aligned}$$

The Mathematica file that derives this system is available upon request.

We want to solve for

$$\hat{k}^i_0 = \log(\nu\eta) + \log\left[\mathbb{E}_0\left(e^{\hat{\lambda}^i_X + \hat{y}^i - \hat{\lambda}^i_{C0}}\right)\right] \tag{A1}$$

Now, note that we have $\frac{X^{i\star}_i}{Y^{i\star}} = \frac{1}{2}(1+\alpha)$, $\frac{X^{j\star}_i}{Y^{i\star}} = \frac{1}{2}(1-\alpha)$, we solve for $\hat{\lambda}^i_X + \hat{y}^i$ as a function of the exogenous shocks.

We start from the resource constraints,

$$\hat{y}^i = \frac{1}{2}(1+\nu)\hat{x}^i_i + \frac{1}{2}(1-\nu)\hat{x}^j_i$$

which gives us

$$\hat{x}_i^j = \frac{1}{\frac{1}{2}(1-\nu)}\hat{y}^i - \frac{1+\nu}{1-\nu}\hat{x}_i^i \tag{A2}$$

Now we have

$$\hat{c}^i = \frac{1}{2}(1+\nu)\hat{x}_i^i + \hat{y}^j - \frac{1}{2}(1+\nu)\hat{x}_j^j \tag{A3}$$

Then marginal utility of consumption is given by

$$\begin{aligned}
\hat{\lambda}_C^i &= -\gamma\hat{s}^i - \gamma\hat{c}^i \\
&= -\gamma\lambda_s(\hat{c}^i - \hat{c}_0^i) - \gamma\hat{c}^i \\
&= -\gamma(1+\lambda_s)\hat{c}^i - \gamma\lambda_s\hat{c}_0^i \\
&= -\gamma(1+\lambda_s)\left(\frac{1}{2}(1+\nu)\hat{x}_i^i + \hat{y}^j - \frac{1}{2}(1+\nu)\hat{x}_j^j\right) + \gamma\lambda_s\hat{c}_0^i \qquad \text{(A4)}
\end{aligned}$$

Now note that

$$\begin{aligned}
\hat{\lambda}_C^i + \hat{c}^i - \hat{x}_i^i &= \hat{\lambda}_C^j + \hat{c}^j - \hat{x}_i^j \\
\hat{\lambda}_C^i + \hat{c}^i - \hat{x}_j^i &= \hat{\lambda}_C^j + \hat{c}^j - \hat{x}_j^j
\end{aligned}$$

which implies

$$-\hat{x}_i^i + \hat{x}_j^i = -\hat{x}_i^j + \hat{x}_j^j$$

And we have

$$\hat{x}_i^i + \hat{x}_j^j = \hat{y}^i + \hat{y}^j \tag{A5}$$

To get another equation, we examine

$$\lambda_C^i + \hat{c}^i - \hat{x}_i^i = \lambda_C^j + \hat{c}^j - \hat{x}_i^j$$

Plugging in (A2), (A3) and (A4), we have

$$\begin{aligned}
&-\gamma(1+\lambda_s)\left(\frac{1}{2}(1+\nu)\hat{x}_i^i + \hat{y}^j - \frac{1}{2}(1+\nu)\hat{x}_j^j\right) + \gamma\lambda_s\hat{c}_0^i - \frac{1}{2}(1-\nu)\hat{x}_i^i + \hat{y}^j - \frac{1}{2}(1+\nu)\hat{x}_j^j \\
&= -\gamma(1+\lambda_s)\left(\frac{1}{2}(1+\nu)\hat{x}_j^j + \hat{y}^i - \frac{1}{2}(1+\nu)\hat{x}_i^i\right) + \gamma\lambda_s\hat{c}_0^j + \frac{1}{2}(1+\nu)x_j^j - \frac{1+\nu}{1-\nu}\hat{y}^i + \frac{1}{2}\frac{(1+\nu)^2}{1-\nu}\hat{x}_i^i
\end{aligned}$$

Combined with (A5), we can then easily solve for $\hat{x}_i^i$

$$\hat{x}_i^i = \frac{1}{2}\frac{(\gamma(1+\lambda_s)-1)(1-\nu)\nu}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}(\hat{y}^i+\hat{y}^j) + \frac{\gamma(1+\lambda_s)(1-\nu)+\nu}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^i$$

Substituting back to (A4), we can easily obtain

$$\begin{aligned}
\hat{\lambda}_C^i &= -\frac{1}{2}\gamma(1+\lambda_s)\frac{(1+\nu)\gamma(1+\lambda_s)(1-\nu)+\nu(1+\nu)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^i \\
&\quad - \frac{1}{2}\gamma(1+\lambda_s)\frac{(1-\nu)\gamma(1+\lambda_s)(1+\nu)-\nu(1-\nu)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^j \\
&= -\frac{1}{2}\gamma(1+\lambda_s)\frac{(1-\nu)\gamma(1+\lambda_s)(1+\nu)-\nu(1-\nu)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}(\hat{y}^i+\hat{y}^j) \\
&\quad - \gamma(1+\lambda_s)\frac{\nu}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^i
\end{aligned} \tag{A6}$$

and we have

$$\begin{aligned}
\hat{\lambda}_X^i &= \hat{\lambda}_C^i + \hat{c}^i - \hat{x}_i^i \\
&= \frac{1}{2}(1-\gamma(1+\lambda_s))\frac{(1-\nu)\gamma(1+\lambda_s)(1+\nu)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}(\hat{y}^i+\hat{y}^j) - \frac{\gamma(1+\lambda_s)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^i
\end{aligned} \tag{A7}$$

Then we have

$$\hat{\lambda}_X^i + \hat{y}^i = \frac{1}{2}(1-\gamma(1+\lambda_s))\frac{(1-\nu)\gamma(1+\lambda_s)(1+\nu)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}(\hat{y}^i+\hat{y}^j) + \frac{\nu^2(1-\gamma(1+\lambda_s))}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\hat{y}^i$$

Substituting back to (A1), we can then solve for capital stock as

$$\hat{k}_0^i = \frac{1}{2}\nu\left(1-\frac{1}{(1+\lambda_s)\gamma}\right)^2 \operatorname{var}(\hat{\lambda}_C^i) + const \tag{A8}$$

where *const* is a constant that is commom across countries. The Mathematica file that solves the full expression for it is available upon request.

D.1. Proof of Proposition 1

Proof. Obvious from (A8). □

D.2. Proof of Proposition 3

Proof. Recall that the two countries are at the deterministic steady state at period one so $\hat{\lambda}^i_{C,0} = \hat{\lambda}^j_{C,0}$. Change in exchange rate is given by

$$\begin{aligned}\Delta ex &= \hat{m}^i - \hat{m}^j \\ &= \hat{\lambda}^i_C - \hat{\lambda}^j_C \\ &= \frac{\nu\gamma(1+\lambda_s)}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}[(\beta^\star_z - \beta_z)\sigma_g\varepsilon_g + \sigma(\varepsilon^\star - \varepsilon)]\end{aligned}$$

The last equality is obvious from (A6).

□

D.3. Proof of Proposition 4

Proof. Taking cross-country differences using A8 and substitute in A6, we have

$$\begin{aligned}\hat{k}^j_0 - \hat{k}^i_0 &= \log\left[\mathbb{E}_0\left(e^{\hat{\lambda}^j_X + \hat{y}^j - \hat{\lambda}^j_{C0}}\right)\right] - \log\left[\mathbb{E}_0\left(e^{\hat{\lambda}^i_X + \hat{y}^i - \hat{\lambda}^i_{C0}}\right)\right] \\ &= \frac{1}{2}\frac{\nu^2(1-\gamma(1+\lambda_s))^2}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\left[(\beta^j_z)^2 - (\beta^i_z)^2\right]\sigma^2_g\end{aligned}$$

Recall that risk-free rate is given by

$$R^f_{i,0} = \frac{1}{\mathbb{E}_0\left(\beta\frac{\Lambda^i_{C,1}}{\Lambda^i_{C,0}}\right)}$$

And the expected return to capital is given by

$$\mathbb{E}(R^I_{i,1}) = \mathbb{E}(\frac{\Lambda^i_{X,1}}{\Lambda^i_{C,1}}\alpha\frac{Y^i_1}{K^i_0})$$

Write them in log-deviation terms, we have

$$\begin{aligned}\hat{r}^f_{i,0} &= -\log(\eta) - \log\left(\mathbb{E}_0(e^{\hat{\lambda}^i_C - \hat{\lambda}^i_{C0}})\right) \\ \hat{r}^I_{i,1} &= \log(\nu) + \hat{\lambda}^i_X - \hat{\lambda}^i_C + \hat{y}^i - \hat{k}^i_0\end{aligned}$$

Substitute in our solution (A6), (A7) and (A8),, we have

$$\hat{r}^f_{j,0} - \hat{r}^f_{i,0} = -\frac{1}{2}\frac{\nu\gamma^2(1+\lambda_s)^2}{\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2}\left[(\beta^j_z)^2 - (\beta^i_z)^2\right]\sigma^2_g$$
$$\hat{r}^I_{j,1} - \hat{r}^I_{i,1} = -\frac{1}{2}\frac{\nu^2(1-\gamma(1+\lambda_s))^2[\gamma(1+\lambda_s)(1+\nu(1-\alpha))(1-\nu)+\nu^2(1-\alpha)]}{(\gamma(1+\lambda_s)(1+\nu)(1-\nu)+\nu^2)^2}\left[(\beta^j_z)^2 - (\beta^i_z)^2\right]\sigma^2_g$$

□

E. Currency Premium Under Verdelhan (2010)

Verdelhan (2010) extends the standard habit model of Campbell and Cochrane (1999) to an international setup. Under his specification, consumption growth is exogenously given and $\lambda(\cdot)$ is a function. In particular,

$$(1+\lambda(s_0))^2 = \frac{1}{\mathrm{var}(\Delta c)}\frac{1-\rho_s}{\gamma}(1-2(s_0-\bar{s}))$$

Note that consumption growth, which is constant under the setup in Verdelhan (2010), is built into the sensitivity function $\lambda(\cdot)$. Verdelhan (2010) also assumes symmetric countries so $\mathrm{var}(\Delta c) = \mathrm{var}(\Delta c^\star)$, but even if we allow the two countries to have different variance of consumption growth so that $\mathrm{var}(\Delta c) \neq \mathrm{var}(\Delta c^\star)$, we still end up with

$$\begin{aligned}
\mathbb{E}(rx) &= \mathbb{E}\left(-\frac{1}{2}(\mathrm{var}(m^\star) - \mathrm{var}(m))\right) \\
&= -\frac{1}{2}\,\mathbb{E}[\gamma^2(1+\lambda^\star(s^\star))\,\mathrm{var}(\Delta c^\star) - \gamma^2(1+\lambda(s))\,\mathrm{var}(\Delta c)] \\
&= \mathbb{E}(s_0 - s^\star_0) \\
&= 0
\end{aligned}$$

So setting the sensitivity function to a constant and to be the same across countries, while being a simple tweak, is essential for external habit to generate large currency premia.

F. Expected Change in Exchange Rates under Epstein and Zin (1989) Preference

Under Epstein and Zin (1989) preference, there is a hard-wired relationship between first and second moment of the log SDF.

$$\begin{aligned}\mathbb{E}(m_{t+1}) &= \log(\delta) - \frac{1}{\psi}\mu - \frac{1}{2}(1-\gamma)\left(\frac{1}{\psi} - \gamma\right)\mathbb{E}(\text{var}_t(u_{t+1})) \\ \frac{1}{2}\,\mathbb{E}(\text{var}_t(m_{t+1})) &= \frac{1}{2}\left(\frac{1}{\psi} - \gamma\right)^2 \mathbb{E}(\text{var}_t(u_{t+1}))\end{aligned}$$

The first moment of the log SDF is tightly linked to the second moments, and is not independent of heterogenous loadings. So if there is large heterogenous-loading induced unconditional currency premia (large differences in $\mathbb{E}(\text{var}_t(m_{t+1}))$), there is large unconditional movements in change in exchange rates $\mathbb{E}(\Delta ex) = \mathbb{E}(m - m^{\star})$. In fact, $\mathbb{E}(\Delta ex_{t+1}) = -\frac{\gamma-1}{\gamma-\frac{1}{\psi}}\,\mathbb{E}(rx_{t+1})$, under standard calibrations, expected change in exchange rates account for a large portion of the currency premia.

G. Target Moments

Table A4: Moment Matching

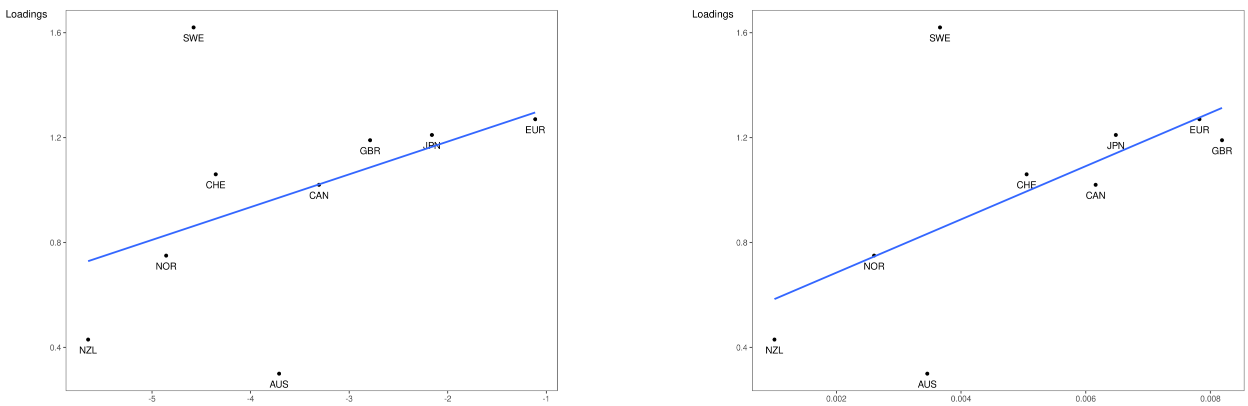
Country	s.d. of GDP (%)		correlation	
	Data	Model	Data	Model
AUS	0.58	0.58	0.43	0.43
CAN	1.06	1.06	0.78	0.78
CHE	1.12	1.12	0.78	0.78
EUR	1.12	1.12	0.87	0.87
GBR	1.05	1.05	0.88	0.88
JPN	1.41	1.41	0.74	0.74
NOR	1.11	1.11	0.60	0.60
NZL	0.99	0.99	0.42	0.42
SWE	1.48	1.48	0.87	0.87

This table shows target moments used in Section 4. "s.d. of GDP" stands for standard deviation of HP-filtered GDP, and "correlation" stands for the correlation between each country's HP-filtered GDP with the average across countries in the sample. All moments are quarterly.

Data source: OECD National Account Statistics.

H. Economic Drivers of the Loadings

Figure A1: Estimated Loadings, Country Size and Trade Centrality



(a) Country Size (b) Trade Centrality

This figure plots log GDP share(Panel(a)) and a measure of trade centrality (Panel(b)) against estimated loadings on the global shock. The line of best fit has a slope of 0.13 (s.e. 0.10) for log GDP share and a slope of 101.54 (s.e. 52.82) for trade centrality Source: PWT 10.0, OECD National Account Statistics and Richmond's website[a].

[a] Richmond (2019): `https://robertjrichmond.com/data/Richmond_Centrality.xlsx`

Figure A1 shows that the estimated loadings lines up nicely with country size and trade centrality, except for Sweden and Australia, which suggests other important drivers.