# Dynamic Information Acquisition and Home Bias in Portfolios

(Preliminary and Incomplete)

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**Abstract**

While international portfolios are still heavily biased towards home assets, the home bias has exhibited a clear downward trend in the last few decades. Interestingly, the underlying rise in foreign investment has been primarily directed to just a handful of OECD countries, and has not given rise to an across the board increase in all foreign investments. To understand the evolution of the home bias, this paper develops a dynamic model of information acquisition and portfolio choice. The dynamic framework introduces two new endogenous forces due to the fact that asset payoffs depend on the future asset prices and hence on the future information sets. First, there is a measure of endogenous unlearnable uncertainty in asset payoffs which generates decreasing returns to information when agents are sufficiently well informed about an asset, and hence gives a reason to diversify information and portfolios. In addition, the dynamic framework introduces a strategic complementarity in learning, due to the "beauty contest" of dynamic asset markets, which is absent in the benchmark static model where learning is purely a strategic substitute. As a result of both of these new endogenous forces, the model can explain the high overall level of the home bias, its decline over time and the fact that the rise in foreign investment has been coordinated on just a handful of destination countries. Moreover, the model predicts that the home bias decline is linked to the fall in information costs, and I find direct evidence of this in the data.

**JEL Codes:** F3, G11, G15, D8, D83

**Keywords:** Home Bias, Information Choice, Portfolio Choice, Dynamics

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# 1 Introduction

Empirical evidence indicates that investors fail to take sufficient advantage of international diversification opportunities, and heavily overweight domestic equities in their portfolios.[1] This phenomenon is commonly referred to as the "home equity bias", and is a long standing issue in international finance that is especially puzzling since it has persisted decades after the liberalization of international capital flows in the 80s. It has given rise to a large and active literature, and a number of potential explanations have been proposed, such as endogenous information asymmetry (Van Nieuwerburgh and Veldkamp (2009)), hedging of non-tradable labor income (Coeurdacier and Gourinchas (2011), Heathcote and Perri (2007)), behavioral models (e.g. Huberman (2001)) and others.

However, the primary focus of the existing literature has been on rationalizing the overall level of the home bias, while its more recent trend downward has received considerably less attention. And although the home bias is still a significant puzzle, it has declined markedly over the last two decades – the average level of foreign asset holdings around the world have increased from being just 10% of the benchmark CAPM prediction in 1995 up to 35% of CAPM in 2015. However, this rise in foreign investment has not been equally distributed across the world, but has rather been primarily directed to just a handful of OECD countries. Thus, while investors are holding more foreign equity than before, their foreign holdings themselves tend to be highly concentrated. This evolution of the home bias over the last few decades is a salient feature of the data and understanding it could shed new light on the puzzle as a whole. Nevertheless, existing models are static and do not speak directly to its movements over time.

This paper develops a dynamic model of endogenous information acquisition that can address both the high overall level of the home bias, and its decline over time. It extends the benchmark, static model of Van Nieuwerburgh and Veldkamp (2009) by introducing overlapping generation of agents and infinitely lived assets. Similar to that model, there is a feedback between information and portfolio choice that generates increasing returns to information, and agents find it optimal to specialize their information acquisition in domestic assets, which leads to strong information asymmetry and home bias in equilibrium. However, in my model, asset markets are open every period, and thus asset payoffs depend not only on dividends but also on the future equilibrium market price. These prices are determined by the information available to future market participants, which introduces a measure of endogenous unlearnable uncertainty. This weakens the feedback effect between information and portfolio choice, and helps generate decreasing returns to information when agents are

[1] See for example French and Poterba (1991), Tesar and Werner (1998), Ahearne et al. (2004)

relatively well informed about a given asset.[2]

In addition, the dynamic nature of the asset markets in this economy introduces a "beauty contest" motive, where agents would like to forecast future market beliefs, as those determine the future price at which they can resell the asset. As a result, information is no longer a pure strategic substitute. In a static model, agents want to learn about things that the market does not know because this allows them to exploit any mis-pricing – intuitively, they are trying to identify "under-valued" assets. However, in the dynamic model agents have somewhat different incentives – they want to identify assets that are i) mis-priced by the market and ii) are *likely* to be properly priced in the future. If the market does not eventually correct the mis-pricing identified by an investor's private information, then the future price would not adjust appropriately and hence the investor would not profit from identifying this mis-pricing. Intuitively, in the dynamic model it makes sense to invest in under-valued assets only to the extent to which you expect future market beliefs to agree with you that the asset was undervalued in the first place. As a result, this gives rise to a strategic complementarity in learning that is absent from the static model, where learning is purely a strategic substitute. Combined with the endogenous unlearnable uncertainty, these two mechanisms allow the dynamic model to obtain a high level of home bias, a profile that is declining over time (as information costs fall), and the observation that the increase in foreign investment is concentrated in just a handful of advanced markets (where the average investor is well informed).

In the model, there are $N$ countries, each of which is populated by a continuum of overlapping generations that live for two periods.[3] In each country there is a Lucas tree with a stochastic dividend, a portion of which is traded internationally, and the rest is a non-tradable endowment of the domestic agents. The payoff of the Lucas tree is driven by a persistent process that is specific to each country. The Young agents of each generation are born with some initial wealth that they invest in the $N$ risky assets and a riskless international bond. The Old agents sell all of their assets to the new generation of Young agents, consume the proceeds plus their non-tradable endowment, and exit.

When making their portfolio choice, agents see the whole history of state variables and can purchase noisy signals about the realization of future economic fundamentals. Information is valuable because it reduces the uncertainty about future consumption, which depends on portfolio returns and the non-tradable endowment. Moreover, information is non-rival, and hence a unit of information about the home fundamental factor can be used equally well

[2] In a different framework, Veldkamp (2011), shows that exogenously introducing unlearnable risk can lead to interior solutions in the static model. In the dynamic model studied here, however, unlearnable uncertainty is not imposed exogenously but arises as a consequence of equilibrium forces.

[3] Similar to the setup in Bacchetta and van Wincoop (2006).

to learn about the future dividend of the home tradable asset and the future non-tradable income. Thus, due to its dual use, domestic information has a relatively higher value, and as a result agents tilt their costly information acquisition towards it, leading to information asymmetry and home biased portfolios.[4]

In addition, there is a feedback loop between information acquisition and portfolio choice. Information decreases the uncertainty of an asset's return, and as a result investors increase their portfolio holdings of that asset. As the holdings of the asset increase, however, the next unit of information about this asset is now more valuable to the agent, since information is non-rival and hence more valuable when applied to a bigger trade. Thus, an initial tilt towards home information leads to portfolio re-balancing that increases the relative value of home information further, which in turn leads to another shift toward home information and so on. This feedback loop is at the heart of the increasing returns to information that obtain globally in the standard static framework, however in the dynamic model there is also a countervailing equilibrium force.

Since returns depend on future market prices, and thus on future market beliefs, to the extent to which information available today cannot fully span future market beliefs, investors are exposed to some unlearnable uncertainty encoded in asset prices. This changes the incentives to specialize. Rebalancing the portfolio towards home assets makes investors increasingly exposed to the unlearnable valuation risk in future home asset prices, and thus increases the non-diversifiable risk of the portfolio. This moderates the feedback between information and portfolio choice, and as a result, increases in home information lead to smaller adjustments in portfolios. This effect grows stronger as investors have learned more about a specific asset, and unlearnable uncertainty becomes a larger share of its residual uncertainty. In essence, information acquisition helps reduce an ever smaller proportion of the remaining uncertainty, and the effect of the unlearnable valuation risk eventually comes to dominate, and the increasing returns to information disappear. Thus, investors face increasing returns to information about an asset when they have acquired relatively little information about that asset, and face decreasing returns otherwise.

Consequently, information asymmetry and home bias have a non-monotonic relationship with the ability to acquire information. When information is scarce, it is optimal to specialize fully, and learn only about the domestic fundamental, while when information is abundant, agents spread out learning across a variety of different factors. So as information costs fall, the home bias is at first increasing, when information is still relatively scarce, and then decreases

[4]Non-diversifiable labor income plays a similar role in swaying information choice in Nieuwerburgh and Veldkamp (2006), who study the own company stock bias in a static framework. I extend the analysis to a dynamic setting, and focus on the interaction between the resulting decreasing returns to information and non-tradable income and its implications about the secular decline of the home bias.

as information becomes more abundant. As a result, the dynamic model can generate both a high overall level of home bias, due to the incentives to specialize in domestic information initially, and a gradual decline as information costs fall.

Note that in the model, information is generally a strategic substitute, as is also true in the benchmark static model. Agents have incentives to try and learn information that the rest of the market does not know, because they profit from exploiting the pricing mistakes of the average market participant. Hence, in equilibrium agents try to hold information sets that are different from those of the average market participant. Similarly, the incentive to specialize is also a strategic substitute – agents are more likely to face increasing returns to information about an asset if the market knows relatively little about it. Still, those forces are not enough to generate increasing returns to information by themselves. While agents want to be different, they realize that in making themselves so they incur increasing exposure to unlearnable valuation risk. Thus, the recursive nature of the dynamic model introduces an effect leading towards decreasing returns to information, even in frameworks where information would otherwise have increasing returns. Lastly, in the dynamic model information is not *always* a strategic substitute but becomes a strategic complement at higher levels of information. As a result, once investors decide to diversify learning in foreign assets, they tend to coordinate on markets where the average participant is better informed. This is also true in the data, as most of the foreign investment underpinning the fall in the home bias has been concentrated in just a few OECD markets.

Importantly, the share of unlearnable uncertainty in the dynamic model is an endogenous quantity. As such, it changes as other market participants change their information acquisition choices. This has a number of interesting implications, two of which I explore in more detail in the paper. First, an increase in aggregate information increases the unlearnable uncertainty faced by any given agent, because it makes future market beliefs more sensitive to future news. As a result, the incentives to specialize in information acquisition, and thus home bias itself, decrease for all agents. This is a general equilibrium effect that is distinct from the fact that home bias tends to decrease as *individual* information increases. For example, it implies that when informed foreign investors enter a new market, the home bias of the domestic agents will decrease, as the share of unlearnable uncertainty increases, and thus, the incentives to specialize in domestic information decrease. Second, because agents face increasing returns to information when learning about a new asset, foreign assets are added to the learning portfolio in a discrete fashion. As a result, the capital flows in the model can exhibit fickleness and retrenchment.

The model makes a clear prediction that the home bias decline is linked with falling information costs. This is intuitively appealing, because the sharp decline in the home bias over the last two decades has coincided with the information technology (IT) boom. To test this hypothesis rigorously, I examine the relationship between the growth of IT and the rate of decline in the home bias for a broad sample of fifty-three countries. Consistent with the model, I find a clear negative relationship, signifying that countries which have experienced a larger expansion in IT exhibit stronger decline in the home bias. The relationship persists after controlling for other potential covariates and country and time fixed effects, suggesting that falling information costs indeed play an important role in the decline of the home bias.[5]

Lastly, while the model predicts that falling information costs are generally associated with a fall in the home bias, this is not true for the concentration of the *foreign* portion of the portfolio. This happens because the return to information is increasing at first, but decreasing after a critical threshold of total information about an asset is reached. As a result, once investors start diversifying learning into foreign assets, they do not do so equally across all assets. Instead, they first specialize in just one foreign asset and start learning about others, one by one, only as information costs fall even further. Thus, the concentration of the foreign portion of portfolios has interesting dynamics as well, and the catchall home bias measure does not necessarily tell the whole story. Moreover, the strategic complementarity in learning ensures that investors around the world will choose to invest in the same handful of advanced countries, where the markets are well informed. I show this is true in the data as well, where for the average country, the great majority of the home bias decline has come about as the result of changes in the holdings of equity in just a few OECD countries.

A closely related paper is Mondria and Wu (2010), who also study the decline in the home bias using a modified version of the Van Nieuwerburgh and Veldkamp (2009) model. However, their model is not fully dynamic, but is rather a repeated static game, which makes the information acquisition problem quite similar to the standard static framework, and inherits its global increasing returns to information and does not feature any complementarity in learning across periods. The main innovation in their paper is to generalize the structure of the private information signals, allowing the agents to learn about linear combinations of the fundamentals. In that framework, they show that a transition from financial autarky to frictionless international financial markets could lead to a fall in the home bias, however, their model still implies that lower information costs lead to higher home bias. In contrast, my model focuses on how multi-period assets and the resulting dynamic considerations introduce both a desire to coordinate learning and decreasing returns to information when investors are relatively well informed, which helps the model generate a high home bias, and also the

[5]The negative relationship between information and portfolio under-diversification more generally is borne out in the micro-level data as well – see for example Campbell et al. (2007), Goetzmann and Kumar (2008), Guiso and Jappelli (2008), Kimball and Shumway (2010), Gaudecker (2015).

negative relationship between home bias and information technology in the data.

More generally, the paper is related to the literature modeling the home bias puzzle with the help of information frictions. There is a long history of models assuming information asymmetry exogenously and studying the resulting portfolio choice (e.g. Merton (1987), Gehrig (1993), Brennan and Cao (1997), Coval and Moskowitz (2001), Brennan et al. (2005), Hatchondo (2008). The major drawback of this approach is summarized by Pástor (2000), who shows that for sufficient home bias to exist, the home agents must possess very strong prior information advantages, and hypothesizes that such large information asymmetry is unlikely to be be sustainable in equilibrium, as agents would seemingly have a strong incentive to learn about the uncertain foreign assets. Van Nieuwerburgh and Veldkamp (2009) provide an elegant and powerful answer to this criticism, by showing that there is a strong feedback effect between portfolio and information choice that generates increasing returns to information, and hence in fact optimal learning enhances any prior information asymmetries. Mondria (2010) and Mondria and Wu (2011) extend the framework by considering more general information acquisition technologies and the interaction with foreign transaction costs. This paper extends the literature to a dynamic setting with multi-period assets, and studies the model's implications about the evolution of the home bias over time.

The paper is also related to the open-macroeconomics literature on the home bias, and specifically the strand that considers the importance of labor income in the determination of international portfolios. Coeurdacier and Gourinchas (2011) and Heathcote and Perri (2007) develop two distinct frameworks where the joint determination of the equilibrium real exchange rate, labor income, and asset returns generates a positive labor income-hedging demand for the home equity asset. This paper shares the key insight that non-tradable income, of which labor income is an example, plays an important role in the formation of home biased portfolios, but the mechanisms are fundamentally different. In my model, non-tradable income does not provide a positive hedging demand, but rather is the reason that the agents decide to bias their information acquisition strategy towards the home asset.

# 2 Motivating Empirical Evidence

It is well established that aggregate equity portfolios are heavily biased towards domestic assets. For example, at the end of 2008 the average share of foreign assets in portfolios across the world was just one third of what it should be under the CAPM (Coeurdacier and Rey (2013)). This high overall level of home bias has been a long-standing puzzle in international finance ever since it was first documented by French and Poterba (1991), and has sparked a large and active literature. In this section, I emphasize that in addition to having a high overall level, the home bias also exhibits a clear downward trend, and has decreased by about a third since 1995. While much less attention has been paid to this trend, it is a salient feature of the data as well, and a comprehensive explanation of the home bias phenomenon should account for both its level and secular decline.

I work with an annual data set of 52 countries for the time period from 1976 to 2015, that I have compiled with data from the IMF and the World Bank.[6] I have included all countries for which there is an extensive amount of portfolio data available, with the exception of small countries that are also major international financial centers like Luxembourg and Singapore. The data set is fairly comprehensive, and covers both developing and developed countries – thirty-one of the countries, about 60% of the total, are members of the OECD. The complete list of countries and other details about the data set are in the Appendix.

To quantify the home bias, I follow the literature and measure it as the deviation from the market portfolio, and define the Equity Home Bias (EHB) index:

$$EHB_i = 1 - \frac{\text{Share of Foreign Assets in Country } i\text{'s Portfolio}}{\text{Share of Foreign Assests in World Portfolio}}$$

This index is zero when the share of foreign assets in country $i$'s portfolio is equal to their corresponding share in the market portfolio, and is positive when the portfolio over-weights domestic assets, and thus exhibits home bias. In the extreme case where the portfolio is composed exclusively of domestic assets, it is equal to 1.

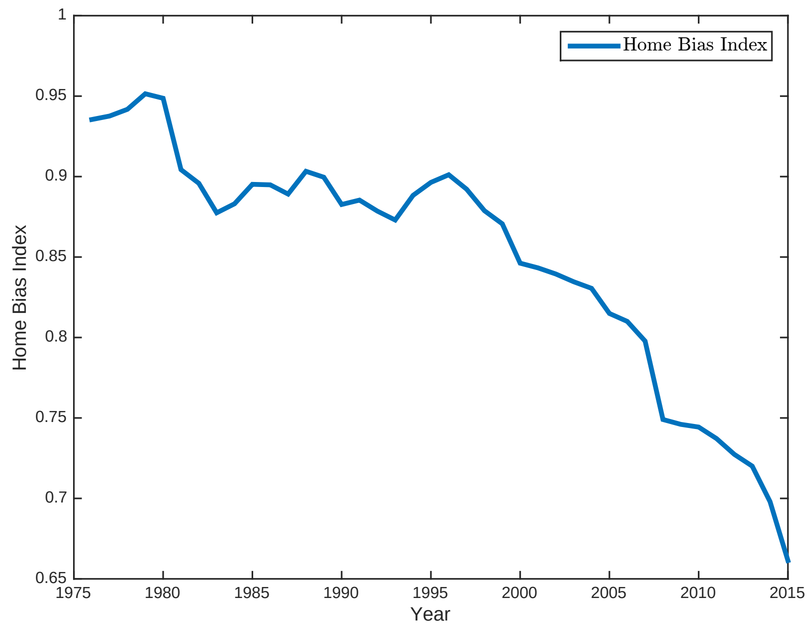
The home bias is clearly a pervasive feature of the data both across time and across countries. All country-year pairs exhibit a positive EHB index, and the average value across time and countries is 0.8, which signifies that the average share of foreign assets over that time period was just 20% of the CAPM benchmark. Moreover, the standard deviation of the average EHB across countries is just 0.07.

Such statistics speak to the remarkably high overall level of the home bias, but mask the fact that it has also exhibited a very interesting evolution over time. To illustrate this, Figure 1 plots the average EHB for the fifty-three countries across time. The downward trend is very clear. The average home bias was roughly 0.93 in 1976, but has fallen all the way down to 0.65 by 2015. In other words, the share of foreign assets has went from being ten times smaller than the CAPM benchmark, to three times smaller. Thus, even though the home bias is still very much a puzzle today, it has also experienced a remarkable downward trend and has declined by about a third (as measured by the EHB index).

The decline is a very robust feature of the data, with virtually every single country experiencing a fall in the EHB index in the last two decades. It is not simply a EU effect

[6] For a smaller subset of countries, the data can be extended back to 1976 and the results on the general downward trend of the home bias remain the same.

Figure 1: The Evolution of the Equity Home Bias




– the EU countries saw a fall of 0.35 points in their EHB index, while the non-EU OECD countries saw an almost identical fall of 0.3 points. Moreover, the trend cannot be explained away with the opening of emerging markets alone. A significant part of the increase in foreign investment has been directed to OECD countries, who saw the foreign ownership of their domestic markets go up from 5% to 38%, while emerging markets' foreign ownership went up from 10% to 18%. There is, however, cross-sectional heterogeneity in the speed of the decline for different countries. Most obviously, emerging markets have experienced significantly slower rate of decline than developed markets, with non-OECD countries seeing a decline of 0.07 while OECD countries experienced a decline of 0.37 on average.

It is also interesting to consider what drives this decline in the home bias. Are investors generally increasing their holdings of all foreign assets in their portfolio, or is there heterogeneity in the foreign portion of portfolios? The EHB index can only tell us something about the ratio of home assets to an aggregate of all foreign assets, but not about different foreign assets separately. To look at potential heterogeneity in foreign holdings, I use the Consolidated Portfolio Investment Survey (CPIS) database of the IMF to obtain data on the specific foreign holdings of each country. This database allows me to construct detailed portfolios for each country and thus see not just an aggregate figure for their foreign investments, but also how these investments are distributed across the world. However, this detailed dataset is available only for 2001 to 2013, and not for the whole 1976-2015 sample.

When looking at individual foreign holdings, I again standardize them by their respective

CAPM weights, and define the bias in each individual foreign holding as

$$\text{Foreign Bias}_{ij} = \frac{\text{Country } j\text{'s share in foreign holdings of Country } i}{\text{Contry } j\text{'s share in foreign portion of world portf.}} - 1 \tag{1}$$

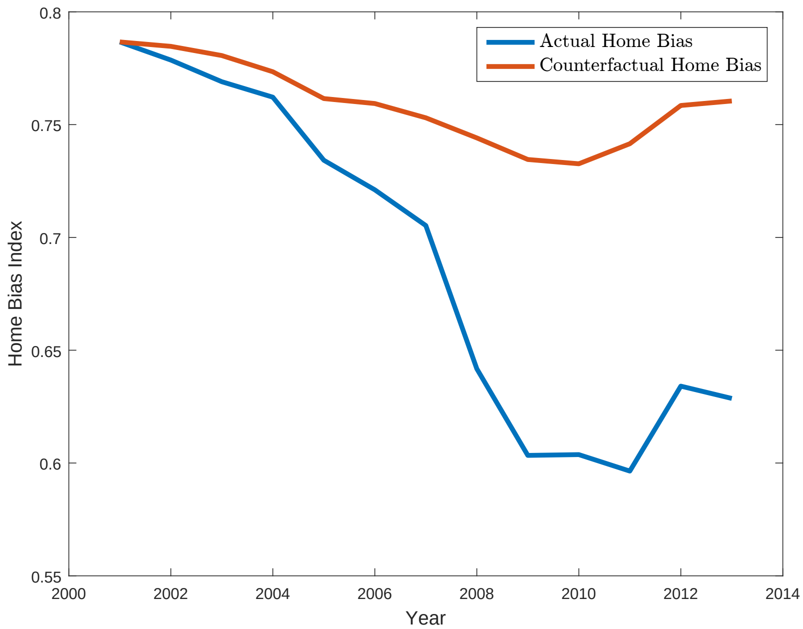
The index Foreign Bias$_{ij}$ measures how over- or under-weighted are country $j$ assets in the foreign portfolio of country $i$. If the index is positive, this means that country $i$ is over-weighing its investments into country $j$, as compared to the CAPM, and vice versa. Note that the index is specifically defined on the *foreign* portfolio of each country, and not on its portfolio as a whole. This is because as we know the overall portfolio is heavily biased towards home assets, and thus all foreign assets are under-weighted against CAPM. But it is still interesting to ask what foreign assets are more or less over-weighted relative to each other, and hence the index in (1).

A few interesting results emerge. First, the distribution of foreign holdings of countries exhibits large fat right tails. The great majority of foreign holdings are held in roughly the same proportions, but a few are heavily over-weighted, and represent large positive outliers. The average kurtosis of the distributions of all fifty-three countries in my data set is 23.4 and the average skewness is 4.

In terms of the evolution of foreign holdings over time, most barely change at all, but a few experience large shifts. The large movers are roughly equally distributed among negative and positive shifts, thus foreign portfolios have seen both some assets increase a lot in weight, and other decrease a lot, while most remain virtually unchanged. More specifically, the distribution of changes in Foreign Bias$_{it}$ again exhibits fat tails with an average kurtosis of 26, and generally 92% of the changes in Foreign Bias$_{it}$ are less than 0.1. Lastly, those few big movers in each portfolio, are not all the same across the portfolios of all countries.

Most interestingly, the majority of the overall increase in foreign assets since 2001 has come due to the few investments that have experienced large shifts in their individual bias. Thus, for the average country, the increase in foreign assets has come about not due to a broad increase in foreign holdings, but primarily due to shifts in the holdings of a few of its foreign assets. To quantify this point, I compute a counter-factual home bias (EHB) index, where for each country's portfolio I adjust the weights of the 5% of the biggest movers (both positive and negative) so that their Foreign Bias$_{it}$ remains at its initial 2001 level. So for large positive moves in ForeignBias$_{it}$ this amounts to reducing the eventual increase in the country $j$ holdings of country $i$, but for large negative moves in ForeignBias$_{it}$ it amounts to *increasing* the holdings of that foreign asset. Since this counter-factual includes adjustments that go both in the direction of increasing and decreasing the home bias, it is unclear what would be the overall effect on the counter-factual EHB index.

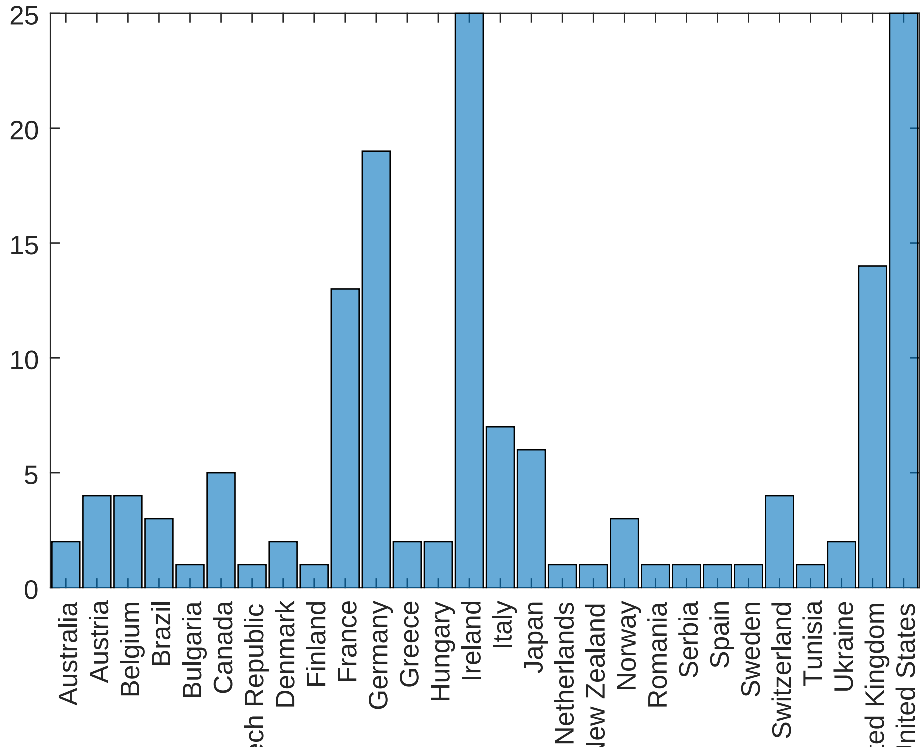
Figure 2: Counter-Factual Home Bias




The resulting counter-factual EHB index (again averaged over all countries) is plotted in Figure 2. The figure shows that the bulk of the reduction in the home bias has come about as the result of just a handful of big movers in foreign holdings, and not as a broad-based increase in foreign assets. In particular, 84% of the decline in the home bias between 2001 and 2013 is due to the 10% biggest movers in foreign holdings (again both positive and negative moves have been included). In particular, if we adjust the holdings of the 10% of biggest movers, so that they do not change their $\text{ForeignBias}_{it}$ index, then the home bias would have decreased by just 0.03 points on average between 2001-2013, but in fact it has decreased by 0.16 points. Thus, we see that relying on the EHB index by itself is hiding some interesting heterogeneity in the trends of specific foreign investments. The fall in the home bias has happened due to the rapid increase in holdings of a few foreign assets in each portfolio, and not because of a general increase in all foreign assets.

Even more curiously, there is strong cross-sectional correlation on the identity of these top 5 assets across different countries. Simply put, investors across the world seem to increase their holdings of the same handful of OECD countries. To show this, I collect the identity of the the 5 foreign assets that have seen the biggest increase in their portfolio weights for each OECD country, and then construct a histogram. The result is plotted in Figure 3 below, and show that the increase in investment underlying the drop in the home bias has been disproportionately directed to just a few OECD countries, with the US, UK, France and Germany being one of the most popular destinations.

Figure 3: Distribution of the TOP 5 foreign holdings




Overall, the trend downward is clearly an important, robust feature of the data, that goes beyond the opening up of emerging markets and lifting of capital restrictions. However, the underlying increase in foreign investment has not been spread around the world, but has been heavily concentrated in OECD markets. Understanding these facts can help discipline models of the home bias, and help us better understand the puzzle as a whole.

# 3 The Model

In this section I turn towards a model that can explain not only the high overall level of the home bias, but also its decline and the fact that underlying = increase in foreign investment has been directed to just a handful of developed markets. I will in particular consider working with a model of information frictions, where the home bias arises due to agents finding it optimal to be better informed about home as opposed to foreign information. I am motivated to work with information models due to abundant evidence that information frictions are important empirical determinants of the home bias (see Ahearne et al. (2004), Amadi (2004), Massa and Simonov (2006)) and the fact that the downward trend in the home bias really started only in the mid-1990s, at the same time as the IT boom which is believed to have greatly driven down the cost of information.

The existing, information-based models of the home bias do not speak directly to its trend because they are static, and aim to understand the average level of the home bias, not its evolution over time. Nevertheless, at first look it seems like the basic mechanism goes against the observed negative relationship between the home bias and information. A key insight of the previous literature is that information exhibits increasing returns, which leads to full specialization in learning (e.g. Van Nieuwerburgh and Veldkamp (2009)). Thus, agents optimally choose to focus all of their costly information acquisition on domestic information. This is very helpful in generating a high overall level of home bias, because optimal learning endogenously leads to information asymmetry and portfolio concentration. However, at the same time, a lower marginal cost of information will tend to increase information asymmetry and thus home bias, and not decrease it.

In this section, I extend the model of Van Nieuwerburgh and Veldkamp (2009) to a dynamic setting and show that information acquisition does not display increasing returns globally. It rather exhibits increasing returns when information costs are high, but once information costs fall below a threshold, information has decreasing returns. As a result, a dynamic model of endogenous information acquisition can rationalize both the high level of the home bias, and its trend downwards. The model can also be viewed as a dynamic Noisy Rational Expectations model (NRE), in the spirit of Bacchetta and van Wincoop (2006) and Watanabe (2008), but one where the private signal precisions and information sets are endogenous.

There are $N$ countries, each of which is populated with a continuum of overlapping generations of agents that live for two periods each. In the first period, agents make information and portfolio choice decisions, and in the second they consume their resulting wealth and exit. In each country, there is a Lucas tree with a stochastic dividend. A portion $1-\delta$ of each tree is traded on international financial markets, and the other $\delta$ portion is a non-tradable endowment of the domestic agents. Agents can also trade a riskless bond internationally at a fixed interest rate $R$, and thus their portfolios are formed by shares in the $N$ different Lucas trees (i.e. risky assets) and holdings of the riskless bond. Each new generation of Young agents is born with some initial wealth $W_0$, hence a Young agent in country $j$ at time $t$ faces the budget constraint

$$W_0 = \sum_k p_{kt} x_{jkt} + b_{jt},$$

where $x_{jkt}$ is the amount of the risky security of the $k$-th country he buys, $p_{kt}$ is the equilibrium price of that asset and $b_{jt}$ is the amount invested in the riskless bond.

Next period, the agents are in the Old phase of their lives and sell all their assets at the prevailing market prices to the new crop of Young agents, and face the budget constraint

$$c_{j,t+1} = \delta a_{j,t+1} + \sum_k x_{jkt}(p_{k,t+1} + (1-\delta)a_{k,t+1}) + b_{kt}R$$

where $a_{j,t+1}$ is the stochastic fruit of the Lucas tree in country $j$, at time $t+1$. Thus, $\delta a_{j,t+1}$ is the non-tradable endowment of the agents, $d_{j,t+1} \equiv (1-\delta)a_{j,t+1}$ is the dividend of a share of the risky asset of country $j$, and $\sum_k x_{jkt}(p_{k,t+1} + (1-\delta)a_{k,t+1}) + b_{kt}R$ is the portfolio return. I will alternatively refer to $a_{jt}$ as the economic fundamental or factor of country $j$ as well. It is assumed that these factors follow symmetric AR(1) processes:

$$a_{j,t+1} = \mu_j(1-\rho_j) + \rho_j a_{j,t} + \varepsilon_{j,t+1}$$

where all innovations are iid Normal $\varepsilon_{j,t+1} \sim N(0, \sigma_j^2)$. For simplicity, I abstract from comovement across countries, but the framework can easily be extended to accommodate it.

Each period agents observe the full history of realized states and prices, and can purchase noisy signals about next period's fundamentals of the form

$$\eta_{jkt}^{(i)} = a_{k,t+1} + \varepsilon_{\eta_j kt}^{(i)},$$

where $\varepsilon_{\eta_j kt}^{(i)}$ is iid, mean-zero Gaussian variable. Thus, the noisy signals have idiosyncratic error, hence the beliefs of the agents within the same country are not perfectly correlated.

The informativeness of those signals is not fixed exogenously, but is chosen optimally by the agents, subject to a cost $C(\kappa)$ of the total amount of information, $\kappa$, encoded in the chosen signals, that is increasing and convex. Information, $\kappa$, is measured in terms of entropy units (Shanon (1948)). This is the standard measure of information flow in information theory and is also widely used by the economics and finance literature on optimal information acquisition (e.g. Sims (2003), Van Nieuwerburgh and Veldkamp (2010)). It is defined as the reduction in uncertainty, measured by the entropy of the unknown variable, that occurs after observing the vector of noisy signals $\boldsymbol{\eta}_{jt}^{(i)} = [\eta_{j1t}, \ldots, \eta_{jNt}]'$:

$$\kappa = H(\mathbf{a}_{t+1}|\mathcal{I}_t^p) - H(\mathbf{a}_{t+1}|\mathcal{I}_t^{(i)})$$

where $H(X)$ is the entropy of random variable $X$ and $H(X|Y)$ is the entropy of $X$ conditional on knowing $Y$.[7] Moreover, $\mathcal{I}_t^p = \{\mathbf{a}^t, \mathbf{p}^t\}$ is the information set consisting of all public information, the history of states and prices, and $\mathcal{I}_t^{(i)}\{\mathbf{a}^t, \mathbf{p}^t, \boldsymbol{\eta}_{jt}^{(i)}\}$ is the private information set of agent $i$, which combines the public signals with her two private signals. Thus, $\kappa$ measures the amount of information about the vector of future fundamentals $\mathbf{a}_{t+1}$ contained in the private signals $\eta_{jt}^{(i)}$, over and above the publicly available information. Given the prior assumption that all factors are uncorrelated across countries, we can express the total information $\kappa$ as the sum of the informational contents of the individual signals $\eta_{j1t}^{(i)}, \ldots, \eta_{jNt}^{(i)}$:

$$\kappa = \kappa_1 + \cdots + \kappa_N$$

Where the the information of each individual signal is similarly defined as the information about the underlying fundamental over and above the publicly available information:

$$\kappa_k = H(a_{k,t+1}|\mathcal{I}_t^p) - H(a_{k,t+1}|\{\mathcal{I}_t^p, \eta_{jkt}^{(i)}\})$$

After observing the signals, the agents use Bayesian updating with the correct priors to form their posterior beliefs. Contrary to the standard approach in the literature, I assume the agents have identical priors over both the home and foreign factors, and hence there is no exogenously imposed information advantage. The goal is to study the properties and extent of information asymmetry that can arise purely as a result of endogenous forces, but introducing some prior informational advantages would not change the analysis qualitatively.

The overall information framework is meant to capture the idea that these are sophisticated agents that have full access to all information on today's state of the world, and can produce information about the future states as well. However, obtaining and processing that information is costly, in terms of time, money and mental effort, which is here captured by the cost function $C(\kappa)$. For simplicity, I assume that this is a utility cost, but the framework can accommodate an explicit split into monetary and utility costs.

Lastly, I assume that the agents' have mean-variance utility over their end-of-life consumption,

$$U_j = E(c_{j,t+1}^{(i)}|\mathcal{I}_{jt}^{(i)}) - \frac{\gamma}{2}\operatorname{Var}(c_{j,t+1}^{(i)}|\mathcal{I}_{jt}^{(i)})$$

where $\gamma$ is the absolute risk aversion coefficient (common across all agents). This is the standard utility function used in the literature on endogenous information choice and portfolio choice, due to its analytical tractability (Van Nieuwerburgh and Veldkamp (2009, 2010), Mondria (2010)). In essence, this is an en exponential (CARA) utility function with an added desire for early resolution of uncertainty.[8] The results also hold under CRRA, but the

[7] Entropy is defined as $H(X) = -E(\ln(f(x)))$, where $f(x)$ is the probability density function of X.

[8] See Van Nieuwerburgh and Veldkamp (2010) for more details.

mean-variance function is more convenient for showing the results cleanly.

### 3.1 Portfolio Choice and Asset Market Equilibrium

After observing their private signals and updating beliefs, agents form their optimal portfolios. In doing so, they need to forecast the risky asset payoffs, $p_{k,t+1} + d_{k,t+1}$. Dividends, $d_{k,t+1} = (1-\delta)a_{k,t+1}$, are Gaussian by assumption, and I conjecture and later verify that the equilibrium prices $p_{kt}$ are linear in the state variables, and hence are Gaussian as well. Thus, the posterior beliefs of the agents follow a Normal distribution, which leads to the familiar mean-variance optimal portfolio holdings:

$$x^{(i)}_{jjt} = \frac{E(p_{j,t+1} + d_{j,t+1}|\mathcal{I}^{(i)}_j) - p_{jt}R}{\gamma\,\mathrm{Var}(p_{j,t+1} + d_{j,t+1}|\mathcal{I}^{(i)}_j)} - \frac{Cov(\delta a_{j,t+1}, p_{j,t+1} + d_{j,t+1}|\mathcal{I}^{(i)}_j)}{\mathrm{Var}(p_{j,t+1} + d_{j,t+1}|\mathcal{I}^{(i)}_j)}$$

$$x^{(i)}_{jkt} = \frac{E(p_{k,t+1} + d_{k,t+1}|\mathcal{I}^{(i)}_j) - p_{kt}R}{\gamma\,\mathrm{Var}(p_{k,t+1} + d_{k,t+1}|\mathcal{I}^{(i)}_j)}$$

where $x^{(i)}_{jkt}$ is the amount of the risky asset $k$, that the $i$-th agent in the $j$-th country buys. There are two motives for buying the risky assets – a speculative one and a hedging one. For speculative purposes, agents like to buy assets that offer high expected excess returns and not too much variance. In addition, the home asset ($x_{jjt}$) is also useful for hedging the risk coming from non-tradable income – this is captured by the term $-\frac{Cov(\delta a_{j,t+1}, p_{j,t+1}+d_{j,t+1}|\mathcal{I}^{(i)}_j)}{\mathrm{Var}(p_{j,t+1}+d_{j,t+1}|\mathcal{I}^{(i)}_j)}$. Two forces could potentially affect the agent's desire to alter her portfolio holdings from being split equally between all available assets. One is the additional hedging motive to trade the home asset, and the other is any potential information asymmetry, $\mathrm{Var}(p_{j,t+1} + d_{j,t+1}|\mathcal{I}^{(i)}_j) \neq \mathrm{Var}(p_{k,t+1} + d_{k,t+1}|\mathcal{I}^{(i)}_j)$ for $j \neq k$, which would alter the speculative portion of the portfolios.

In addition to the informed traders, each risky asset is also traded by a measure of "noise" traders, which trade for reasons exogenous to the model. The net noise trader demand for asset $k$ is $z_{kt} \sim iidN(0, \sigma^2_z)$. Market clearing requires that the sum of the informed agents trades and the noise traders equals the asset supply, $\bar{z}_k$, and thus for each asset we have the market clearing condition

$$\bar{z}_k + z_{kt} = \frac{1}{N}\sum_j \int x^{(i)}_{jkt}di \tag{2}$$

I look for a linear stationary equilibrium where equilibrium prices are time-invariant, linear functions of the state variables. Because of the linear-Gaussian information structure, conditional expectation, and hence also portfolio holdings, are linear in the information sets of the agents. Furthermore, given that the market clearing condition (2) sums over these asset demands, it is perhaps unsurprising that equilibrium prices turn out to be linear in the *aggregate* information set:

$$\mathcal{I}_t^{Agg} = \{\mathbf{a}^t, \mathbf{p}^t, \mathbf{a}_{t+1}, \mathbf{z}_t\}$$

This is the information set of a hypothetical social planner that is able to aggregate the information sets of all individual agents. It includes the actual realizations of the future fundamentals $a_{k,t+1}$ because the noise in the private signals of the agents is iid, and hence aggregating over them perfectly reveals the future fundamentals. Moreover, notice that if an agent knew the value of $a_{k,t+1}$, then he would be able to also invert the equilibrium prices, and uncover the measure of noise traders $z_{kt}$. Thus, the aggregate information set contains both the future fundamentals, and the current measure of noise traders, both of which are unknown to any single investor.

Furthermore, given that the fundamental processes and the noise traders are assumed to be independent across countries, it turns out that each equilibrium price is a function of only domestic variables and takes the form,

$$p_{kt} = \bar{\lambda}_k + \bar{\lambda}_{ak} a_{kt} + \lambda_{ak} a_{k,t+1} + \lambda_{zk} z_{kt},$$

where the coefficients $\bar{\lambda}_k, \bar{\lambda}_{ak}, \lambda_{ak}, \lambda_{zk}$ are determined by the market clearing conditions. Given this, we can explicitly compute the expected payoffs,

$$\hat{\mu}_{jkt}^{(i)} = E(p_{k,t+1} + d_{k,t+1} | \mathcal{I}_{jt}^{(i)}) = \bar{\lambda} + \underbrace{(1 - \delta + \bar{\lambda}_{ak} + \lambda_{ak}\rho_a)}_{\equiv \Lambda_k} E(a_{k,t+1} | \mathcal{I}_{jt}^{(i)})$$

where I define the variable $\Lambda_k$ as the loading of the asset payoff onto the unknown future fundamental $a_{k,t+1}$. Similarly, the conditional variance is

$$\mathrm{Var}(p_{k,t+1} + d_{k,t+1} | \mathcal{I}_{jt}^{(i)}) = \Lambda_k^2 \,\mathrm{Var}(a_{k,t+1} | \mathcal{I}_{jt}^{(i)}) + \lambda_{ak}\sigma_a^2 + \lambda_{zk}\sigma_z^2 \tag{3}$$

The conditional expectation and variance of the future fundamental $a_{k,t+1}$ follows the standard formulas for updating Gaussian variables with Gaussian signals. The agents have two sources of signals, the idiosyncratic signal $\eta_{jkt}^{(i)}$, and the equilibrium price itself contains the signal $\tilde{p}_{kt} = a_{k,t+1} + \frac{\lambda_{ak}}{\lambda zk} z_{kt}$, which they combine with their prior knowledge of $a_{kt}$ to compute,

$$E(a_{k,t+1} | \mathcal{I}_{jt}^{(i)}) = \hat{\sigma}_{kt}^2 \left( \frac{\rho_a a_{k,t}}{\sigma_a^2} + \frac{\lambda_{ak}^2}{\lambda_{zk}^2 \sigma_z^2} \left( a_{k,t+1} + \frac{\lambda_{ak}}{\lambda zk} z_{kt} \right) + \frac{1}{\sigma_{\eta_{jk}}^2} \eta_{jkt} \right)$$

and the posterior variance:

$$\hat{\sigma}_{kt}^2 = \mathrm{Var}(a_{k,t+1}|\mathcal{I}_{jt}^{(i)}) = \left(\frac{1}{\sigma_a^2} + \frac{\lambda_{ak}^2}{\lambda_{zk}^2\sigma_z^2} + \frac{1}{\sigma_{\eta_{jk}}^2}\right)^{-1}$$

Plugging everything back in (2) gives us the solution for the coefficients of the equilibrium prices. The details are given in the Appendix, and here I will just focus on the coefficients $\lambda_{ak}$ and $\lambda_{zk}$ which determine the relative informativeness of the price as a signal about future fundamentals. The solutions for those two coefficients are:

$$\lambda_{ak} = \frac{1}{R}\bar{\sigma}_k^2\bar{q}_k\left(1 + \frac{\bar{\phi}_k\bar{q}_k}{\gamma^2\sigma_z^2}\right)$$
$$\lambda_{zk} = -\frac{1}{R}\gamma\bar{\sigma}_k^2\left(1 + \frac{\bar{\phi}_k\bar{q}_k}{\gamma^2\sigma_z^2}\right)$$

where I define $\bar{\sigma}_k^2$ as the average market participant's posterior variance of the return of the $k$-th asset, which is given by

$$\bar{\sigma}_k^2 = \left(\frac{1}{N}\sum_j \frac{1}{\mathrm{Var}_{jk}(p_{k,t+1} + d_{k,t+1})}\right)^{-1}$$

and $\bar{q}_k$ is the following weighted average of the precisions of all market participants,

$$\bar{q}_k = \sum_j \frac{1}{N}\frac{\Lambda_k\hat{\sigma}_{jkt}^2}{\Lambda_k^2\hat{\sigma}_{jk}^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2}\frac{1}{\sigma_{\eta_{jk}}^2}$$

and $\bar{\phi}_k$ is given by

$$\bar{\phi}_k = \frac{1}{N}\sum_j \frac{\Lambda_k\hat{\sigma}_{jk}^2}{\mathrm{Var}_{jk}(p_{k,t+1} + d_{k,t+1})} = \frac{1}{N}\sum_j \frac{\Lambda_k\hat{\sigma}_{jk}^2}{\Lambda_k^2\hat{\sigma}_{jk}^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2}$$

To gain more intuition, note that we can re-write $\lambda_{ak}$ as

$$\lambda_{ak} = \frac{1}{R}\Lambda_k(1 - \frac{\bar{\phi}_k\bar{\sigma}_k^2}{\Lambda_k\sigma_a^2})$$

and that $\frac{\bar{\phi}_k\bar{\sigma}_k^2}{\Lambda_k}$ represents the average market participants posterior variance over the unknown fundamental $a_{k,t+1}$. Thus, in the limit of no private information, when everyone's beliefs equal their priors ($\sigma_a^2$), we have $\lambda_{ak} = 0$. Since no one has any information about the future $a_{k,t+1}$, its value is not compounded into the equilibrium price today. In the other extreme, when everyone has perfect foresight and the fundamental is fully revealed, $\lambda_{ak} = \frac{1}{R}\Lambda_k$, which implies that movements in $a_{k,t+1}$ are priced perfectly, and trading on it offers just the risk-free return $R$.[9]

Lastly, note that even though agents can receive signals about all future fundamental shocks, there is a measure of "unlearnable" uncertainty that arises endogenously in the model. That is, the posterior variance of the asset payoffs, equation (6), is not a exclusively a function of the posterior variance of $a_{k,t+1}$, which the agents can decrease through costly information acquisition. In particular, the posterior variance of the payoffs also includes the terms $\lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2$, which represent shocks that the agents cannot learn about. These are news that realize in the future, and are outside of the scope of today's information – they represent "unlearnable uncertainty" to today's agents.

It is important to note that this unlearnable uncertainty arises endogenously, as a result of the recursive nature of the dynamic model. The key is that that future information sets are naturally always one step ahead of today's information sets. Agent's private signals contain news about the one step-ahead fundamental, meaning that today's agents receive information about $a_{k,t+1}$, and that next period's agents receive information about $a_{k,t+2}$. This extra information is incorporated in tomorrow's prices, since it affects the $t+1$ asset demands, and thus next period's equilibrium price $p_{k,t+1}$ depends on the innovations at time $t+2$:

$$p_{k,t+1} = \bar{\lambda}_k + (\bar{\lambda}_{ak} + \lambda_{ak}\rho_a)a_{k,t+1} + \underbrace{\lambda_{ak}\varepsilon_{a_k,t+2} + \lambda_{zk}z_{k,t+1}}_{\text{Unlearnable Uncertainty}}$$

Hence, today's agents face some unlearnable uncertainty in the future valuation of the asset, $p_{k,t+1}$, and that's because the information available to them today does not fully span the market beliefs tomorrow. The two-step ahead innovations are news that are realized in the future, and are thus outside of the scope of learning of today's agents. This is a reflection of the fact that information sets are recursive, and grow over time:

$$\mathcal{I}_t^{Agg} \subset \mathcal{I}_{t+1}^{Agg} \text{ and } \mathcal{I}_{t+1}^{Agg} \backslash \mathcal{I}_t^{Agg} \neq \emptyset$$

Since, $\mathcal{I}_t^{Agg}$ is coarser than $\mathcal{I}_{t+1}^{Agg}$, the future aggregate information set $\mathcal{I}_{t+1}^{Agg}$ contains uncertainty that is unlearnable for agents at time $t$. Note that this is not a result of assuming that agents can only learn about fundamentals one period ahead. If they could learn about both $a_{k,t+1}$ and $a_{k,t+2}$, for example, then next periods information sets would still contain the

[9] As is known, the equilibrium in the dynamic NRE models is not necessarily unique. In fact, there can be up to $2^k$ different equilibria – see Watanabe (2008). For most of the analytical result, the equilibrium selection does not matter. For numerical results, as is standard I will focus on the "low volatility" equilibrium, which is the unique stable one.

unlearnable $\varepsilon^a_{k,t+3}$. More generally, even if agents had access to information about any future period, up to some arbitrary $T < \infty$, then the next period's price would contain unlearnable information about $a_{k,t+T+1}$, which would again be outside of today's scope of learning. In other words, in any *recursive* dynamic model, next period's agents are always one step-ahead of today's agents, and hence the information available today does not span the information tomorrow, and hence does not fully span future market beliefs. As a result, agents always face some measure of unlearnable valuation risk.

## 3.2 Information Choice

Agents choose the precision of their signals ex-ante, at the beginning of the period, after they observe the value of the fundamentals today $\mathbf{a}_t$, but before receiving the private signals and asset markets open. Recall that the information carries a cost $C(\kappa)$, where $\kappa$ is the total amount of information encoded in the agent's private signals (suppressing subscripts to reduce clutter)

$$\kappa = H(\mathbf{a}_{t+1}|\mathcal{I}^p_t) - H(\mathbf{a}_{t+1}|\mathcal{I}^{(i)}_t)$$

First, note that I am implicitly assuming that the information encoded in the prices (and any other public signals) is free, and agents need to pay only for information over and above that. This is the typical Grossman assumption, but could be easily relaxed. Moreover, since all elements of the vector $\mathbf{a}_{t+1}$ are independent, we can write the above constraint as

$$\kappa_= \sum_k H(a_{k,t+1}|\mathcal{I}^p_t) - H(a_{k,t+1}|\mathcal{I}^{(i)}_t) = \sum_k \kappa_k$$

where I have defined $\kappa_k \equiv H(a_{k,t+1}|\mathcal{I}^p_t) - H(a_{k,t+1}|\mathcal{I}^{(i)}_t)$ as the amount of information purchased for each individual fundamental $a_{k,t+1}$. Given the Gaussian structure of the problem, the entropy has a convenient closed form expression, which is simply the reduction in log variance from observing the private signal:

$$\kappa_{jkt} = \ln(\mathrm{Var}(a_{k,t+1}|\mathcal{I}^p_t)) - \ln(\hat{\sigma}^2_{jk})$$

Then, the agent chooses a combination of $\kappa_k$ to maximize ex-ante expected utility

$$\max_{\kappa_1,\ldots,\kappa_N} E(U_j(\mathbf{x}^*_t)|\mathbf{a}^t) - C(\sum_k \kappa_k)$$

s.t.

$$\kappa_k \geq 0$$

The goal of the agent is to maximize his expected utility, knowing that after his signals realize, he will update his beliefs accordingly, and will optimally choose the portfolio $\mathbf{x}_t^*$. Finally, the non-negativity constraint is a "no forgetting constraint", meaning that the agent cannot choose to obtain "negative" information about one of the assets, which will be equivalent to "loosing" information from one of its priors.

The first main result is to confirm that the information choice is indeed time-invariant, which would validate our earlier assumption that the equilibrium prices are time-invariant functions of the state variables. The result is formalized in the proposition below.

**Proposition 1.** *The optimal allocation of information is time-invariant, i.e.* $\kappa_{jkt} = \kappa_{jk}$ *for all* $j, k$ *and* $t$.

*Proof.* Intuition is sketched out in the text, and details are in the Appendix. □

This result tells us that at any time period $t$, the currently young generation (of country $j$) allocates its finite information capacity in the same way that next period's generation would do, and last period's did as well. Thus, the posterior variance of the average market participant is time-invariant. Going back to the formulas for the equilibrium price coefficients given above, we see that this guarantees that they do not change over time either.

To gain intuition about the result, it's useful to derive the ex-ante expected utility that enters the information choice. I do so for the agent living in country $j$, and will suppress all resulting $j$ subscripts to reduce clutter.

$$E(U(\mathbf{x}_t^*)|\mathbf{a}^t) = W_0R + \delta\rho_a a_{jt} + \frac{1}{2\gamma}\sum_k \frac{\mathrm{Var}(ex_{k,t+1}|\mathbf{a}^t) + (E(ex_{k,t+1}|\mathbf{a}^t))^2}{\Lambda_k^2\hat{\sigma}_k^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2} - \frac{(\delta E(ex_{j,t+1}|\mathbf{a}^t) + \frac{\gamma\delta^2(\lambda_{aj}^2\sigma_a^2 + \lambda_{zj}^2\sigma_z^2)}{2\Lambda_k})\Lambda_j\hat{\sigma}_j^2}{\Lambda_j^2\hat{\sigma}_j^2 + \lambda_{aj}^2\sigma_a^2 + \lambda_{zj}^2\sigma_z^2}$$

where $ex_{k,t+1} = p_{k,t+1} + d_{k,t+1} - Rp_{kt}$ is the excess return of the $k$-th asset. Information enters the agent's expected utility in two ways. First, it alters his optimal speculative portfolio, which is given by the summation in the third term, and it alters his optimal hedging portfolio, which operates through the last term. From a return maximization perspective, information about all $k$ assets is symmetric, but only home information helps in forming the hedging portfolio, and hence the last term is not a summation.

We can then derivate in respect to $\kappa_k$ to see what is the marginal benefit of an extra unit of information about the $k$-th asset.[10] To make the notation less burdensome let

[10]This is the marginal *benefit* and not utility, because the marginal utility would also take into account the cost function. We turn to that in a second.

$B = \delta E(ex_{j,t+1}|\mathbf{a}^t) + \frac{\gamma\delta^2(\lambda_{aj}^2\sigma_a^2+\lambda_{zj}^2\sigma_z^2)}{2\Lambda_k}$, and then

$$\frac{\partial U}{\partial \kappa_{kt}} = \frac{\mathrm{Var}(ex_{k,t+1}) + E(ex_{k,t+1})^2}{2\gamma}\frac{\Lambda_k^2\hat{\sigma}_k}{(\Lambda_k^2\hat{\sigma}_k^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2)^2} + \mathbf{1}_{k=j}B\frac{\Lambda_j\hat{\sigma}_j^2}{(\Lambda_j^2\hat{\sigma}_j^2 + \lambda_{aj}^2\sigma_a^2 + \lambda_{zj}^2\sigma_z^2)^2}$$

where I have slightly abused notation and written the ex-ante expectation and variance without the explicit conditioning on the known history $\mathbf{a}^t$.

The expression shows three main things – agents like to learn about assets that 1) have high ex-ante expected excess returns, 2) have ex-ante volatile excess returns, and 3) prefer learning about the home asset ($B > 0$). Understanding these effects starts with the fact that information is non-rival, in the sense that a unit of information can be equally applied to optimizing one's returns and to forming a better hedging portfolio. The third effect is perhaps the easiest one to understand – the home asset does not offer only potentially high excess returns, but also the benefit of hedging the non-tradable labor income of the agents. As a result, ceteris paribus, home information is the most valuable, because it can help in both forming a better speculative portfolio, and a better hedging portfolio.

The fact that agents like to learn about assets with high ex-ante expected excess returns is also quite straightforward. Those are the assets that are likely to present the most profitable trading opportunities once markets open and hence are likely to represent a bigger portion of the total portfolio of the agents. Since information is non-rival, it is better to apply a unit of information to a big portfolio holding, rather than to a small one, and hence agents want to maximize learning about assets they expect to be a big part of their portfolios.

On the other hand, agents also like to learn about assets with high ex-ante volatility. Part of this is again because such assets are more likely to present profitable trading opportunities. The other reason is that volatile excess returns indicate that the market does not posses good information about the underlying fundamentals and hence mis-prices it. As a result, when the fundamentals become revealed next period, the price adjusts to account for it, which drives volatility in the excess returns. To see this more clearly, note that the realized excess returns are given by

$$ex_{k,t+1} = \bar{\sigma}_k^2\gamma(\tilde{z} + z_{kt}) + \bar{\sigma}_k\bar{\phi}_k(\frac{\varepsilon_{k,t+1}^a}{\sigma_a^2} + \frac{\bar{q}_k}{\gamma\sigma_z^2}z_{kt}) + \lambda_{ak}\varepsilon_{k,t+2}^a + \lambda_z z_{k,t+1} \tag{4}$$

In general, the returns are high when the innovation to $a_{k,t+1}$, or noise trader supply $z_{kt}$, is above mean and low otherwise, but the sensitivity of the returns to those shocks depend on the posterior variance as perceived by the average market participant. If the market has perfect information $\bar{\sigma}_k^2 \to 0$, then the excess returns do not respond to movements in the second term in the equation above. This is because those shocks are known, and properly priced at the rate $\frac{1}{R}$ today.[11] Hence, high volatility indicates that the market leaves some of the variation in future fundamentals and noise trader shocks mis-priced, and this is the type of variation private information can help agents exploit.

In particular, the expected excess return is

$$E_t(ex_{k,t+1}) = \gamma\bar{\sigma}_k^2(\tilde{z} + z_{kt}) + (\bar{\sigma}_k^2\bar{\phi}_k - \Lambda_k\hat{\sigma}_{jk}^2)(\frac{\varepsilon_{k,t+1}^a}{\sigma_a^2} + \frac{\bar{q}_k}{\gamma\sigma_z^2}z_{kt}) + \frac{\Lambda_k\hat{\sigma}_{jk}^2}{\sigma_\eta^2}\varepsilon_{kt}^\eta$$

This shows that when the agents are better informed than the market, $\bar{\sigma}_k^2\bar{\phi}_k - \Lambda_k\hat{\sigma}_{jk}^2 > 0$, the agent's expectations correctly time the market. They go up (and the portfolio shares as well) when the actual excess return is indeed likely to be high and vice versa. Thus, superior information helps the agent engage in profitably exploiting the pricing mistakes of the average market participant. But for this to be worthwhile, there must be sufficient amount of mis-pricing, i.e. you want to learn about volatile assets, where the market price has not incorporated all of the learnable uncertainty.

Lastly, to show that the information acquisition strategy does not vary over time, we need to show that the ex-ante expected excess returns and variances are not time-varying. The ex-ante excess return is given by

$$E(ex_{k,t+1}) = \gamma\bar{\sigma}_k^2\left[\bar{z}_j + \frac{\delta}{N}\frac{\Lambda_k\hat{\sigma}_{kk}^2}{\Lambda_k^2\hat{\sigma}_{kk}^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2}\right]$$

Basically, the average excess return on risky assets reflects the compensation agents require for holding the full supply of the risky asset. When the supply is high, in order for the markets to clear the expected excess return must be high, so as to incentive the risk-averse agents to increase their holdings. The net supply of the asset is given by the term

$$\bar{z}_j + \frac{\delta}{N}\frac{\Lambda_k\hat{\sigma}_{kk}^2}{\Lambda_k^2\hat{\sigma}_{kk}^2 + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2}$$

which has two components. The first one is just the exogenous supply and the second, is any extra net supply coming from the hedging demands of the agents in country $k$. Since the domestic assets and the non-tradable income are positively correlated, the hedging portfolios of agents would generally short the domestic assets, and this is demand that needs to be picked up by the rest of the market. In effect, this increases the total supply of the asset that needs to be soaked up by the speculative portfolios. Since supply is exogenously fixed over time, if the information strategy itself does not vary (i.e. $\hat{\sigma}_{jj}^2$ is time invariant) then ex-ante expected excess returns do not vary over time either. The details of the proof amount

[11] Also as shown before $\lambda_{ak} \to 0$ as average information increases to perfect foresight.

to showing that since the ex-ante excess return is given by the same function each period, agents have no incentives to vary information acquisition.

On the other hand, the ex-ante variance can be expressed as

$$\mathrm{Var}(ex_{k,t+1}) = \bar{\sigma}_k^2 \left(\Lambda_k \bar{\phi}_k + \bar{\sigma}_k^2(\gamma^2\sigma_z^2 + \gamma\bar{q}_k\phi_k)\right) + \lambda_{ak}^2\sigma_a^2 + \lambda_{zk}^2\sigma_z^2$$

which shows again that if information choice does not vary over time, then the ex-ante variance of excess returns do not vary either. And we can again show that there is no incentive to change information choice.

Also note that information acquisition is a strategic substitute. This can be seen from the expressions for ex-ante expectations and variances. When the market is well informed about a particular asset (i.e. $\bar{\sigma}_k^2$ low), then the ex-ante expected excess return and ex-ante volatility is low, making that asset unappealing to learn about. Thus, agents like to learn about things that the other agents are generally not well informed about. This is the same result as in Van Nieuwerburgh and Veldkamp (2009) and others.

Lastly, note that if we combine all of these results, we arrive at the conclusion that in the symmetric equilibrium (where all asset returns and variances are ex-ante symmetric) we have home bias in information acquisition. This is essentially due to the dual nature of the home asset, as both an investment and a hedging vehicle. The result is summarized by the proposition below.

**Proposition 2.** *If $\delta > 0$ agents in country $j$ optimally chooses $\kappa_j > \kappa_k$ for all $k \neq j$, i.e. they choose to acquire more information about the home fundamentals.*

*Proof.* Follows from symmetry, the fact that information is non-rival, and the positive correlation between the domestic risky asset and non-tradable domestic income. Details are in the Appendix. □

## 3.3 Information Specialization

The principal feature of the standard, static models of information and portfolio choice is increasing returns to information. It incentivizes agents to fully specialize in learning, and thus only acquire domestic information, which is at the heart of the models' ability to generate home bias. In this section, I show that the desire to specialize in the dynamic model is more nuanced, explain the differences and why they arise.

To understand when and why increasing returns to information obtain, it is useful to compute the derivative of the marginal benefit of extra information. Full details are given in the appendix, but it can be shown that it is proportional to

$$\frac{\partial MB_k}{\partial \kappa_k} \propto \underbrace{\Lambda_k^2 \hat{\sigma}_k^2}_{\text{Learnable Uncertainty}} - \underbrace{(\lambda_{ak}^2 \sigma_a^2 + \lambda_{zk}^2 \sigma_z^2)}_{\text{Unlearnable Uncertainty}} \tag{5}$$

Thus, the marginal benefit of information is increasing whenever the amount of learnable uncertainty of the asset ($\Lambda_k^2 \hat{\sigma}_k^2$) is bigger than the amount of unlearnable uncertainty $\lambda_{ak}^2 \sigma_a^2 + \lambda_{zk}^2 \sigma_z^2$. The key is again that information is non-rival, and hence one unit of information could be as easily applied to a \$1 bet as to a \$100 bet. However, a unit of information is more useful when asset holdings are bigger, since the same information could be applied to making a bigger portfolio more profitable. This generates a feedback effect between information and portfolio choice. In particular, as $\kappa_k$ increases, the posterior variance of asset $k$ decreases, and hence the agent expects to hold more of that asset ($x_k$ goes up). As expected holdings increase, however, the expected benefit of an extra units of information about the $k$-th asset increases as well – the more informed you are about an asset, the more of that asset you tend to hold, and thus the more useful the next unit of information. This feedback loop is at the heart of the increasing returns to information in the benchmark static model.

In the dynamic model analyzed here, however, there is also an additional effect – increasing asset holdings (i.e. $x_k$ going up) exposes the agent to progressively larger amounts of unlearnable valuation risk. This is best seen from equation (4) above – the realized return of asset $k$ does not depend only on learnable uncertainty in the form of $a_{k,t+1}$ and $z_{kt}$, but also on the unlearnable shocks $\varepsilon_{k,t+2}^a$ and $z_{k,t+1}$. Those shocks represent valuation risk, because they affect excess returns only through the future equilibrium price $p_{k,t+1}$, and are unlearnable from the view point of today's agents because are essentially news that realize in the future. This moderates the incentive to increase portfolio holdings in response to an increase in $\kappa_k$, and weakens the feedback loop described above. When agents have not acquired much information about asset $k$, the posterior variance is relatively high, and as a result *learnable* uncertainty is the majority of total uncertainty, $\Lambda_k^2 \hat{\sigma}_k^2 > \Lambda_k^2 \hat{\sigma}_k^2$, and hence the first effect dominates and information displays increasing returns. However, when information is abundant, the majority of remaining uncertainty is unlearnable, $\Lambda_k^2 \hat{\sigma}_k^2 < \Lambda_k^2 \hat{\sigma}_k^2$, and in this case the second effect dominates and hence information displays decreasing returns. This is formalized in the proposition below.

**Proposition 3.** *Increasing returns to information exist when the asset in question has more learnable uncertainty remaining, than unlearnable uncertainty, i.e.:*

$$\underbrace{\Lambda_k^2 \hat{\sigma}_k^2}_{\textit{Learnable Uncertainty}} - \underbrace{(\lambda_{ak}^2 \sigma_a^2 + \lambda_{zk}^2 \sigma_z^2)}_{\textit{Unlearnable Uncertainty}} > 0$$

*In particular, this means those are assets that:*

1. *The agent has not learned much about – high* $\hat{\sigma}_k^2$
2. *The market is less informed about –* $\lambda_{ak}^2$ *is low*
3. *The market agrees on, and hence prices are less sensitive to noise shocks –* $\lambda_{zk}^2$ *is low*

The proposition has three main results. First, as an agent learns more and more about a particular asset, the returns to information generally decrease. Even if an asset exhibits increasing returns when the agent has purchased no information, eventually, as the agent acquires more information that asset will start to exhibit decreasing returns. This is because only a portion of the total uncertainty about an asset's payoffs is learnable, since the information available today does not perfectly span future market beliefs. Hence, as the amount of information that has already been acquired increases, the next unit of information can only reduce an ever smaller portion of the remaining uncertainty of the asset's return, which weakens the feedback between portfolio and information choice. Thus, as we will see in more detail in the next section, agents face increasing returns to information when information costs are high and information is scarce, and decreasing returns otherwise.

The second interesting result is that just as information is a strategic substitute, *specialization* is itself also a strategic substitute. Agents do not like to specialize in assets that the market is generally well informed about. This is because when the average market participant is better informed about $a_{k,t+1}$, future movements in the fundamental are better priced by the market, and hence the market price is more responsive to it – i.e. $\lambda_{ak}$ is high. But when this is the case, investors face more unlearnable valuation risk since the future price is more sensitive to future market beliefs, and hence to future news about $\varepsilon^a_{k,t+2}$.

The other component of the valuation risk is the loading on the noise shocks, $\lambda_{zk}$, which however is *non-monotonic* in the precision of the market's information. In particular, it can be shown that $\lambda_{zk}$ is smallest when either the market has no information, or if the market is perfectly informed about the future fundamental $a_{k,t+1}$. This is because when the market participants agree with each other, either when they all agree they do not possess useful future information, or when they all have it fully, then there is not much useful information in the market price. As a result, agents do not use the price as a signal and rely primarily on their own private information.

On the other hand, when information is dispersed and agents' beliefs differ, then it is useful to try and learn the information that the other market participants have. In that case, the price is a very informative signals and agents pay attention to it. However, that opens up the possibility for "rational confusion", since some of the movements in the market price are caused by noise shocks, $z_{kt}$, but they get incorrectly interpreted as useful information about the future fundamentals. It can be shown that this rational confusion amplifies the effects of the noise shocks on the equilibrium price, and hence increases the value of $\lambda_{zk}^2$. Thus, market prices become more sensitive to noise shocks, which increases the valuation risk faced by agents. The rational confusion effect is strongest for intermediate values of information dispersion, when the market participants disagree the most.

### 3.4 Information Costs and Optimal Information Acquisition

In this section I turn to analyzing what happens with information choice and home bias when the cost of information falls. To start, note that I will say that function $C_1(.)$ exhibits higher information costs than $C_2(.)$ if $C_1(\kappa) \geq C_2(\kappa)$ for all $\kappa > 0$. Next, note that the full information problem can be solved in two steps. First given a fixed amount of total information $\kappa$, the agent chooses the optimal allocation of this information among the different $\kappa_k$. Second, given that optimal allocation, the agent optimizes over the total amount of information to purchase $\kappa$. The main results of this section are formalized in the two theorems below.

**Proposition 4.** *Every cost function $C(\kappa)$ implies a unique optimal total information $\kappa^*$. Moreover, if $C_1'(\kappa) \geq C_2'(\kappa)$ for all $\kappa > 0$, then $\kappa_1^* < \kappa_2^*$.*

*Proof.* Sketched in the text, details in the Appendix. □

The first result is straightforward. Given a convex cost function, there exists a unique total amount of information that the agent likes to purchase, since at some point the marginal cost of additional information becomes too high. The second result is also very intuitive, if we decrease the marginal cost of information, then the optimal quantity of information purchased will increase (remember that information always displays decreasing returns *eventually*).

**Proposition 5.** *There exist positive constants $\{K_0 < K_1 < \cdots < K_{N-1}\}$ such that if*

- $\kappa^* \leq K_0$ – *agents specialize fully in learning about the domestic asset: $\kappa_j > 0$, $\kappa_k = 0$ for all other $k$*
- $\kappa^* \in (K_{L-1}, K_L]$ – *agents learn about home and $L > 0$ foreign assets: $\kappa_j > 0, \kappa_{k'} > 0$ for $L$ different $k' \neq j$, and $\kappa_k = 0$ for all other $k$*
- $\kappa^* > K_{N-1}$ – *agents learn about all assets: $\kappa_k > 0$ for all $k$.*

*Moreover, all foreign assets that the agent chooses to learn about receive the same amount of information acquisition. Thus, for any two $k, k'$ where $\kappa_k > 0, \kappa_{k'} > 0$ we have $\kappa_k = \kappa_{k'}$*

*Proof.* Sketched in the text, details in the Appendix. □

The general intuition for the result follows from the conditions under which information displays increasing returns. As we saw in Proposition 2, increasing returns obtain when the agent has not learned much about a particular asset. Moreover, from Proposition 1 we know that the most preferred asset is the home asset. As a result, when information costs are relatively high and it is not profitable to acquire much information in total, i.e. $\kappa^* \leq K_0$, the agent finds it optimal to fully specialize in the home asset. This is the most valuable asset, and is the one that the scarce information is best used on.

As information costs fall and $\kappa^*$ increases, the agent moves into the part of the parameter space where home information starts exhibiting decreasing returns, and thus eventually finds it optimal to start acquiring information about foreign assets as well. However, this information diversification does not happen smoothly across all assets. Rather, at first when $\kappa^* \in (K_0, K_1]$, the agent only acquires information about one foreign asset, then as information costs drop further he adds a second foreign asset to his learning portfolio and so on. Eventually, when information costs are low enough, he would be learning about all assets.

Information percolates through the different available assets in this step-wise manner because this is the best way of economizing on information acquisition costs. Since information has increasing returns when it is scarce, the agent finds it optimal to specialize whenever he first starts learning about a particular asset. Thus, when new assets are added to the learning portfolio the agent fully specializes in them. And as information costs fall further, at some point he finds it optimal to add a second foreign asset to the learning portfolio, in which case he specializes in acquiring information in two foreign assets, but none of the other ones and so on.

The particular structure of the problem implies that the information asymmetry of home vs foreign information is non-monotonic in information costs. When information costs are high, the agent fully specializes in home information and does not acquire any foreign information. In that part of the state space, as information costs fall, the asymmetry is in fact rising, because the agent invests more and more resources into home information, but does not acquire any foreign information. But once information costs fall to the point where $\kappa^* > K_0$, the agent starts acquiring foreign information as well, and in fact he starts acquiring more foreign than home information. As a result, as the information costs fall, the agent is gradually diversifying his learning into foreign information, and his overall information asymmetry decreases as well.

Lastly, it is interesting to note that the agent splits the foreign assets into two groups – those he chooses to learn about and those he chooses not to. If at any point the agent chooses to learn about more than one foreign asset, then those assets will all receive the same amount of information acquisition. The intuition is that it is only beneficial to learn about more than one foreign assets when the information costs are low enough so that the agent has fully exhausted the increasing returns of the first foreign asset. But once he decides to add a second foreign asset to his learning portfolio, it is again best to fully exhaust the gains to specialization in that asset immediately as well. And thus, whenever the agent is learning about two foreign assets he is in fact on an interior solution for information allocation, and since all foreign assets are symmetric, this results in $\kappa_{k'} = \kappa_k$ for any two foreign assets $k'$ and $k$ that the agent decides to learn about.

So then even though home vs foreign information asymmetry is falling monotonically with information costs, the foreign assets are not treated as a homogeneous group that rises all together. In fact, the agent specializes in a subset of the foreign assets, and completely ignores the others. As a result, the concentration of the foreign holdings of the agent are in fact also at first increasing, and then decreasing as information costs fall. That is because initially the agent specializes learning in just one or two foreign assets, and only eventually gets around to learning about all foreign assets.

The analysis of this section considered changing the information cost of one agent in a way that does not affect the information costs faced by the market as a whole. When the information costs fall in the aggregate (same for everyone), then the sequence of cutoffs $\{K_l\}$ decrease because the incentives to specialize decrease. This is because when the market as a whole is better informed, $\lambda_{ak}^2$ is high, the valuation risks are higher and individual agents find it less desirable to specialize. This is a general equilibrium effect – as the counter-parties to your trades become more informed, it is less profitable for you to specialize in information acquisition.

**Proposition 6.** *If the information costs fall for all market participants, then the positive constants* $\{K_0 < K_1 < \cdots < K_{N-1}\}$ *decrease.*

## 3.5 Optimal Portfolios

As a result of the step-wise nature of optimal information acquisition, the optimal portfolio is formed by three types of assets – the home asset, the foreign assets that the agent does learn about, and the foreign assets he does not. In fact, this gives rise to a three-fund separation theorem. In particular, the optimal risky asset portfolio is a convex combination of 1) a fund holding 100% domestic assets, $\bar{\mathbf{z}}_j$, 2) a fund that is perfectly diversified over the foreign assets the agent does learn about and holds nothing else, $\bar{\mathbf{z}}_{learn}$, and 3) a fund that is perfectly diversified over the foreign assets he does not learn about $\bar{\mathbf{z}}_{no\ learn}$. The aggregate portfolio of country $j$ can be expressed as,

$$\bar{\mathbf{x}} = \alpha\bar{\mathbf{z}}_j + \beta_1\bar{\mathbf{z}}_{learn} + \beta_2\bar{\mathbf{z}}_{no\ learn}$$

This result follows directly from the previous section. The agent always finds it optimal to learn the most about the home asset, hence there is asymmetry in home vs foreign information which affects home vs foreign holdings. However, the agent does not treat all foreign assets symmetrically. There is a subset of assets (possibly empty) that the agent allocates positive information acquisition to, and the rest of the assets do not receive any information. The agent treats all foreign assets within each subclass equally, which generates the three-fund theorem above.

It is interesting to consider how the portfolio holdings are adjusted when information costs fall. The first and most obvious effect is the "home bias", which measures the relative holding of home versus all foreign assets. To quantify the home bias, I will use the same Equity Home Bias index as in the empirical section, which was defined as:

$$EHB = 1 - \frac{\text{Foreign Equity as a Share of the National Portfolio}}{\text{Foreign Equity as a Share of the World Market Portfolio}}$$

The market portfolio is simply the exogenous vector of asset supply

$$\bar{\mathbf{x}}^{MKT} = \bar{\mathbf{z}}.$$

This is the CAPM portfolio, and will be the equilibrium portfolio in this model when there is no learning $C(\kappa) = \infty$ for all $\kappa > 0$, and there is no non-tradable income $\delta = 0$. In that case, agents are identical across both countries and in equilibrium all hold the market portfolio, given by the per-capita supply of assets. To illustrate what happens when we introduce non-tradable income $\delta > 0$ and learning, I will use an example with just two symmetric countries, a home and a foreign one. When agents have non-tradable income, $\delta > 0$, but still face infinite information costs, then the equilibrium portfolios become

$$\bar{x}_h^{NoInfo} = \bar{z}_h - \frac{\delta}{2}\frac{\sigma_a^2}{(1+\lambda_a^2)\sigma_a^2 + \lambda_z^2\sigma_z^2}$$

$$\bar{x}_f^{NoInfo} = \bar{z}_f + \frac{\delta}{2}\frac{\sigma_a^2}{(1+\lambda_a^2)\sigma_a^2 + \lambda_z^2\sigma_z^2}$$

where a subscript $h$ denotes the home country and $f$ denotes the foreign country. Compared to the CAPM portfolio, this one is tilted towards foreign assets due to the hedging motive introduced by non-tradable income. The portfolios exhibit *foreign* bias, because of the negative hedging demand for the home asset. Given symmetry, $\bar{z}_h = \bar{z}_f = \bar{z}$, the resulting

EHB index value is

$$EHB^{NoInfo} = 1 - \frac{\bar{x}_f^{NoInfo}}{\bar{x}_h^{NoInfo} + x_f^{NoInfo}} = -\frac{\delta}{2\bar{z}} \frac{\sigma_a^2}{(1+\lambda_a^2)\sigma_a^2 + \lambda_z^2 \sigma_z^2}$$

It is negative, since the portfolio is biased towards foreign assets. So the hedging channel by itself is not helping us in generating home bias. It is the information channel that works in the opposite direction by generating information asymmetry, where agents are better informed about the home asset. Letting $\sigma_e^2 = \lambda_a^2 \sigma_a^2 + \lambda_z^2 \sigma_z^2$ denote the amount of unlearnable uncertainty agents face, then when agents can acquire information, the resulting optimal portfolio of the home agent is:

$$\bar{x}_h = E(\int (x_h^{(i)}) = \frac{\bar{\sigma}_h^2}{\hat{\sigma}_h + \sigma_e^2} \left[ \bar{z} + \frac{\delta}{2} \frac{\hat{\sigma}_h^2}{\hat{\sigma}_h^2 + \sigma_e^2} \right] - \delta \frac{\hat{\sigma}_h^2}{\hat{\sigma}_h^2 + \sigma_e^2}$$

$$\bar{x}_f = E(\int (x_f^{(i)}) = \frac{\bar{\sigma}_f^2}{\hat{\sigma}_f + \sigma_e^2} \left[ \bar{z} + \frac{\delta}{2} \frac{\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + \sigma_e^2} \right]$$

The resulting EHB is

$$EHB^{OptInfo} = 1 - \frac{\bar{\sigma}_h^2}{\hat{\sigma}_f^2 + \sigma_e^2} - \frac{\delta}{2\bar{z}} \frac{\bar{\sigma}_h^2}{\hat{\sigma}_f^2 + \sigma_e^2} \frac{\hat{\sigma}_f^{*2}}{\hat{\sigma}_f^{*2} + \sigma_e^2}$$

The third component is the hedging channel that was already discussed (starred variables represent the choice variable of the foreign agent), and the second component works through the informational channel. Since optimal information acquisition is skewed towards the domestic asset (Proposition 5), then $1 - \frac{\bar{\sigma}_h^2}{\hat{\sigma}_f^2 + \sigma_e^2} > 0$ and thus the second component generates positive home bias. Moreover, the optimal information acquisition also lowers the negative effect of the hedging channel, since $\hat{\sigma}_f^{*2} < \sigma_a^2$.

Thus, the overall level of the home bias depends on the equilibrium information asymmetry. It depends on how different is the home agent's precision over foreign assets, $\hat{\sigma}_f^2$, compared to the precision on home assets, $\bar{\sigma}_h^2$.[12] average market participant's precision over domestic assets, $\bar{\sigma}_h^2$. In turn, Proposition 5 shows that this information asymmetry is non-monotonic in information costs. As information costs decrease, information asymmetry is at first increasing, as people further specialize into domestic assets, and then steadily falls as costs go to zero. The home bias in portfolios, measured by EHB, exhibits the same non-monotonicity, as illustrated in Figure 4, which is drawn for an economy with five total

[12] Note that in the formula above the comparison is actually between the precision of the home agent on foreign assets and the precision of the average market participant over home assets. That's because the formula is for the equilibrium EHB – as home agents acquire more information about home assets, then the overall market precision over home assets increases, and thus $\bar{\sigma}_h^2$ goes down.

countries ($N = 5$).

Figure 4: Portfolio Bias and Information Capacity

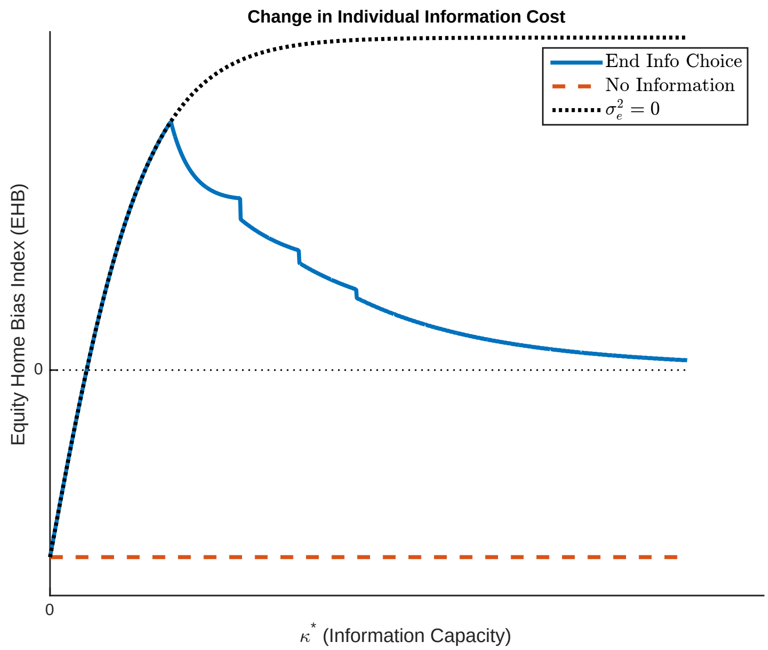
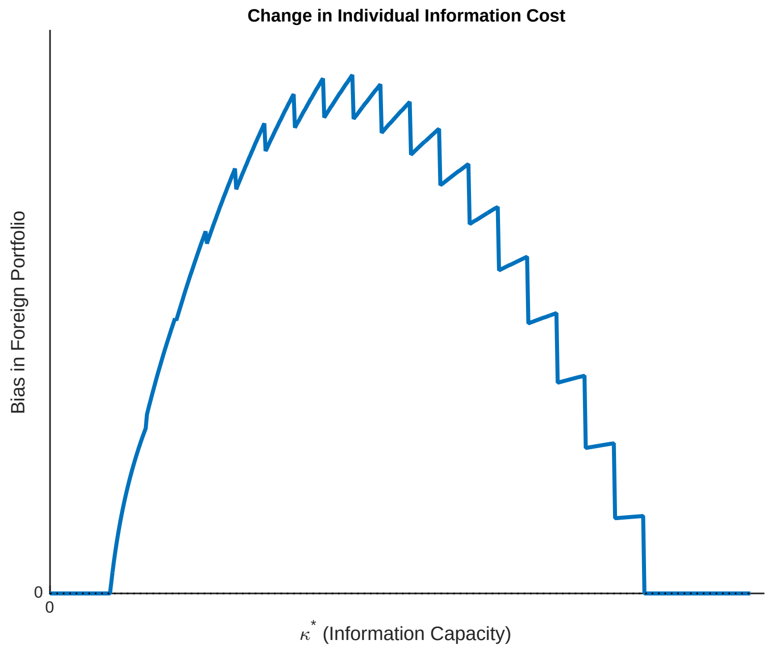



Figure 4 also hints at another important effect – the increased investment in foreign assets is not spread out equally across all foreign assets. As we know from Proposition 5, the agent learns only about a subset of the available foreign assets, and moreover any assets that he learns about are treated equally. Thus, as information costs fall enough to incentivize the agent to start acquiring foreign information, at first he only focuses on one of the foreign assets. As information costs fall sufficiently, he finds it optimal to learn about an additional foreign asset and so on and so forth.

This can be seen from the discrete drops in the EHB (blue line) as information costs fall. At first the home bias is falling smoothly, and that's the region in which the agent is learning only about the home asset and 1 foreign asset. Then as information costs fall further, there's a discrete drop in the home bias, which happens at the point where there agent starts acquiring information about a second foreign asset. As information at first enjoys increasing returns, it is never optimal for the agent to learn just a little bit about the new foreign asset, while still learning a lot about the initial foreign asset he started learning about. Instead, there's a discrete jump in the amount of information acquired about this second asset, that goes from 0 straight to the amount learned about the other foreign asset. Then the agent keeps investing in acquiring more information about those two foreign assets as information costs fall further, until a point at which he finds it optimal to learn about 3 foreign assets and etc.

Figure 5: Concentration of Foreign Holdings and Information Capacity



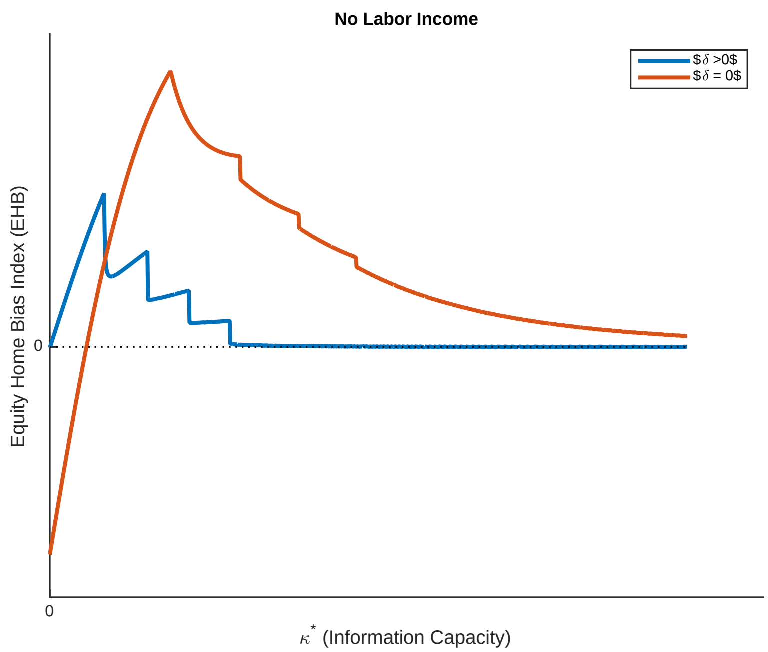

Therefore, as information costs and the home bias fall, the foreign portion of the portfolio is undergoing its own non-monotonic adjustment in concentration, where its own concentration is at first rising and then falling. When information costs are so high that the agent only acquires home information, then he holds a under-weighted position in a perfectly diversified foreign fund. However, as information costs fall and he diversifies learning, the concentration of the agent's foreign holdings increases. At first he specializes in one foreign asset, then in two, three and so on. In the limit, he goes back to a perfectly diversified foreign fund. Thus, in the parameter space where the home bias (EHB) exhibits a monotonic fall, the concentration in the foreign portion of portfolios is non-monotonic. This is illustrated in Figure 5, which plots a concentration index for the foreign holdings of the agents. As we can see, at first concentration among foreign holdings is increasing, and then it decreases.[13]

It is also interesting to consider the effect on the non-tradable income. On the one hand, it generates a negative hedging demand, which is best seen in the fact that the EHB index for low values of information, $\kappa^*$ is negative in Figure 4. On the other, the fact that the non-tradable income is correlated with the domestic dividends gives the agents an incentive

[13]It plots the bias index defined as $\sum_k \frac{1}{N-1}|\text{Foreign Bias}_{ik}|$, where Foreign Bias$_{ik} = \frac{x_{ik}}{\sum_{k\neq i} x_{ik}} / \frac{\bar{z}_k}{\sum_{k\neq i} \bar{z}_k} - 1$

to value home information more than foreign information, and is the reason that agents focus their learning on home information. Thus, it is a big part of the reason that the EHB index is initially strongly increasing with $\kappa^*$. Figure 6 illustrates this by comparing the resulting home bias with a model where there is no non-tradable income ($\delta = 0$), but instead agents have a small information advantage over home information. As we can see, in that case we can still generate some home bias, due to the initial desire to specialize, but the incentive to specialize wears off much quicker. As a result, the overall level of the home bias that can be achieved is much smaller, and comes at a lower level of total information acquired.

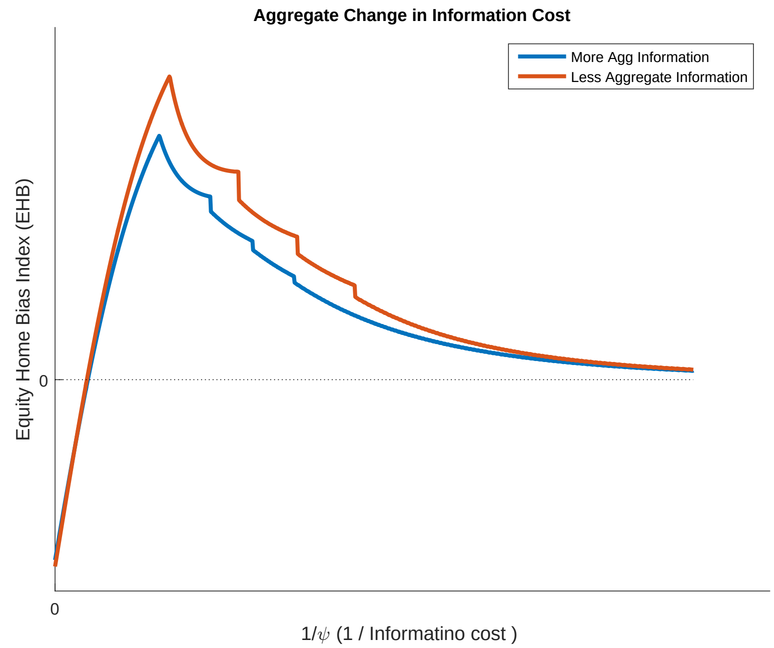
Figure 6: Effect of Non-Tradable Income




Lastly, the comparative static exercises up to this point considered changing the information costs of just one agent, and keeping the equilibrium unchanged. What happens if the whole market experiences a fall in information costs? The individual agent effect described above is still active – at first you increase home bias in information acquisition, and then you gradually decrease it. However, there is also an additional general equilibrium effect – as the overall informativeness of the market increases, the gains to specialization decrease. As a result, it is less profitable to specialize, and investors find it optimal to start diversifying learning, and hence portfolio holdings, earlier. This is illustrated in Figure 7 below.

It shows the resulting EHB of a single investor for different values of information costs, at different levels of aggregate market information. The red line displays the case where

Figure 7: Portfolio Bias and Information Capacity




the market has less information, and the blue line when it has more information. As the average market participant becomes more informed, the agent faces increased valuation risk (through larger $\lambda_{ak}^2$) and this decreases the desire to specialize through equation (5). Notice that the overall EHB level is lower at all levels of information acquired by the agent $\kappa^*$. This is because he is facing an increased amount of unlearnable valuation risk, and hence the gains to specialization are lower, and wear off quicker. As a result, the critical values of information $\{K_l\}$ at which the agent starts to diversify into learning about more assets are now all lower. Hence the diversification in foreign assets comes sooner, and progresses faster as information costs fall.

# 4 Learning about the More Distant Future and Strategic Complementarity in Learning

Up to this point, we had assumed that agents can only acquire information about variables one period ahead, and that all of this information becomes common knowledge tomorrow. This not only limits the scope of learning, but also eliminates any potential coordination motives across time. In this section, I generalize the learning problem to allow agents to learn about any future innovations up to $T < \infty$ periods ahead. This creates an overlap of the learning scope for agents across two periods, and generates a force of strategic complementarity of learning that is absent in both the static model and the dynamic model with $T = 1$, where learning is clearly a strategic substitute.

To keep things tractable, for now I will assume that agents do not update their beliefs using the market price, but rely exclusively on their private signals $\boldsymbol{\eta}_{jkt}^{(i)}$ which are now a $T$x1 vector of unbiased signals defined as:

$$\boldsymbol{\eta}_{jkt}^{(i)} = \begin{bmatrix} \varepsilon_{k,t+T}^{a} \\ \vdots \\ \varepsilon_{k,t+1}^{a} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\eta_j t,T} \\ \vdots \\ \varepsilon_{\eta_j t,1} \end{bmatrix}$$

where the vector of signal errors are iid Gaussian variables with mean 0 and variance $\sigma_{\eta_j kl}^2$, with $l = 1, \ldots, T$ indexing the error of the signal for the $l-$th horizon. Thus, now for each asset we have a vector of $T$ signals, each one of which is an unbiased signal about the innovation to the fundamental $l$ periods ahead ($\varepsilon_{k,t+l}^a$) with iid, idiosyncratic error. As before, the signals are subject to an entropy cost. Given that all fundamentals and signals are independent across countries, we can again express the total acquired information as the sum of entropy allocated to each country's fundamentals:

$$\kappa = \kappa_1 + \cdots + \kappa_N$$

and the total information acquired about a given country's fundamentals is given by:

$$\kappa_k = H(\begin{bmatrix} \varepsilon_{k,t+T}^{a} \\ \vdots \\ \varepsilon_{k,t+1}^{a} \end{bmatrix}) - H(\begin{bmatrix} \varepsilon_{k,t+T}^{a} \\ \vdots \\ \varepsilon_{k,t+1}^{a} \end{bmatrix} | \boldsymbol{\eta}_{jkt}^{(i)}) = \frac{1}{2}\sum_{l=1}^{T} \ln(\frac{\sigma_a^2}{\hat{\sigma}_{jkl}^2})$$

where $\hat{\sigma}_{jkl}^2 = \mathrm{Var}(\varepsilon_{k,t+l}^a | \boldsymbol{\eta}_{jkt}^{(i)})$ is the posterior variance of future fundamental innovations. The assumption of no learning from prices buys us the nice, linearly separable expression for the total information allocated to country $k$. Since all signals available to the agents are orthogonal to each other, the posterior variance matrix is also diagonal and hence the entropy reduces to the sum of the log diagonal elements. If we had also allowed the agents to learn from the price, this will induce a non-diagonal correlation structure in the posterior variance matrix and we would not have the analytical expression above. We will maintain this "no learning from prices" assumption for now to derive some analytical results and intuition, and will later relax it in a numerical exercise.[14]

Everything else in the model remains the same. As a result, the structure of optimal portfolios is again the usual mean-variance expression. However, since now agents potentially have information about fundamentals up to $t+T$ periods ahead, the equilibrium price is given by

$$p_{kt} = \bar{\lambda}_k + \bar{\lambda}_{ak} a_{kt} + \sum_{l=1}^{T} \lambda_{akl} \varepsilon^a_{k,t+l} + \lambda_{zk} z_t$$

The price now responds to more than one period ahead fundamentals ($l > 1$), even though they do not affect tomorrow's dividends, because they matter for the re-sale value of the asset. This captures the "beauty contest" nature of financial markets. An important part of the payoff to any risky asset is the price at which it can be sold tomorrow, which in turn depends on the market beliefs tomorrow. As such, agents today try to forecast the future market beliefs (i.e. information sets) and trade accordingly. Since future fundamental innovations affect dividends further into the future, those will matter to future agents, and hence they will be priced in the future price $p_{t+1}$. As a result, today's expected returns depend on those future fundamentals, and thus agents have incentive to acquire information about $\varepsilon^a_{k,t+l}$ and trade on it. Thus any such information will end up being priced in today's equilibrium market price $p_{kt}$.

This already hints at the fact that this extension of the model features a force that generates strategic complementarity in learning. In particular, today's agents will only choose to spend any costly information on fundamentals $l > 1$ periods head if this is information they expect tomorrow's agents to learn about as well. To see this more clearly, notice that we can re-write the future $(t+1)$ asset payoff as as:

$$p_{k,t+1} + (1-\delta) a_{k,t+1} = \bar{\lambda}_k + \underbrace{(\bar{\lambda}_{ak} + (1-\delta))}_{=\Lambda_k} a_{k,t+1} + \underbrace{\sum_{l=1}^{T-1} \lambda_{akl} \varepsilon^a_{k,t+1+l}}_{\text{Term due to learning of future agents}} + \underbrace{\lambda_{akT} \varepsilon^a_{k,t+T+1} + \lambda_{zk} z_{t+1}}_{\text{Unlearnable Uncertainty}}$$

Abstracting from the constant, the first and the last term on the right hand side are exactly the same as we had before. The first term represents the effect of the $t+1$ innovation becoming known to the agents at $t+1$ – it gets fully priced in equilibrium price $p_{k,t+1}$ and

[14] The assumption can also be justified with a Rational Inattention argument. If all information (including the one coming from prices) was costly, the agents would optimally choose to pay no attention to the prices but only to their private signals, because they have a more efficient information structure. Essentially, the prices include additional noise (due to the noise traders $z_t$) that is costly to filter.

also affects that period's dividend. The last term is the endogenous unlearnable uncertainty about the future asset payoff, it is due to the fact that a part of the future price responds to information that is outside of the scope of the learning of today's agents ( $\varepsilon^a_{k,t+T+1}$ and $z_{k,t+1}$).

The middle term, however, is new. In some ways it acts similarly to the first term, since today's agents can acquire information about all terms of that sum. So this is learnable uncertainty, and something that the agents can act upon. However, the extent to which those terms affect future asset payoffs, depends entirely on the weight they receive in the future asset price, as governed by the price coefficients $\lambda_{akl}$. The more information the future agents acquire about those future innovations, the higher the values of $\lambda_{akl}$. In case future agents have no information about the innovations at horizons $l > 2$, then $\lambda_{jkl} = 0$ for all such $l$. If that is the case, then $\varepsilon^a_{jkl}$ has no effect on the expected payoffs at time $t$, and hence time $t$ agents spend no information resources on it. However, if future agents acquire information about one of those innovations, then the equilibrium price will reflect it and we will have $\lambda_{jkl} > 0$. In turn, this gives incentives to time $t$ agents to also acquire information about that future innovation. This captures a new inter-temporal force which could make learning a strategic complement. Some information is valuable purely because future agents might decide to learn about – thus in this fully dynamic model, agents make information decisions based on the future learning of others.

This is very different from the standard static and $T = 1$ models, where learning is purely a strategic substitute. In those models, agents want to learn about things that the market does not know and spread information around all the available assets relatively equally. In a model like this, agents will not learn about S&P500 assets, but would rather focus their information resources on obscure, small stocks that are unknown to the majority of the market participants.

This behavior is at once intuitive, but also a little bit at odds with our common understanding of asset markets as "beauty contests", where agents have incentives to coordinate on their beliefs and valuations of assets. After all, why would you invest the time and resources in finding an under-valued asset if the market never wakes up to its under-valuation? In a dynamic model where the re-sale value of the asset matters, investors like to identify assets that are both i) mispriced by the market and ii) the market is likely to corrects this mispricing quickly. Only then can the agent profit from its superior information. The static model only captures the force behind i), but the dynamic model with $T > 1$ allows for both.

The posterior variance of the returns is then given by

$$\mathrm{Var}(p_{k,t+1}+d_{k,t+1}|\mathcal{I}^{(i)}_{jt}) = \Lambda_k^2\hat{\sigma}^2_{jkl} + \sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda_{ak,T}\sigma^2_a + \lambda_{zk}\sigma^2_z \tag{6}$$

Similarly to before, shrinking the posterior variance is beneficial to agents because it allows them to build more profitable trades. In this case, however, agents can learn about more than just the one step ahead innovation and can affect any of the $T$ posterior variance terms above.

As before, the information choice happens before asset markets open and agents receive their private signals. The resulting objective function is very similar to the one we had before:

$$E(U(\mathbf{x}^*_t)|\mathbf{a}^t) = \frac{1}{2\gamma}\sum_k \frac{\mathrm{Var}(ex_{k,t+1}|\mathbf{a}^t) + (E(ex_{k,t+1}|\mathbf{a}^t))^2}{\Lambda_k^2\hat{\sigma}^2_{jkl} + \sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda_{ak,T}\sigma^2_a + \lambda_{zk}\sigma^2_z} - \frac{(\delta E(ex_{j,t+1}|\mathbf{a}^t) + \frac{\gamma\delta^2(\sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda_{ak,T}\sigma^2_a + \lambda_{zk}\sigma^2_z)}{2\Lambda_k})\Lambda_j\hat{\sigma}^2_j}{\Lambda_k^2\hat{\sigma}^2_{jkl} + \sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda_{ak,T}\sigma^2_a + \lambda_{zk}\sigma^2_z}$$

where to reduce clutter I have abstracted from constant terms that do not include any of the posterior variance terms.

Overall the expression looks very similar to before. The first term captures the benefits to information stemming from forming a better return seeking portfolio, and the second term captures the benefit from hedging non-tradable income. The main difference is in the posterior variance expressions, which we have already covered above.

The derivative in respect to one-step ahead information, $\hat{\sigma}^2_{t+1}$, is very similar to before and is mostly affected by all the same forces. Instead, I will focus on the derivative in respect to allocating information to the innovation at a horizon $l > 1$:

$$\frac{\partial U}{\partial \kappa_{kl}} = \frac{1}{2\gamma}\frac{(\mathrm{Var}(ex_{k,t+1}) + E(ex_{k,t+1})^2)\lambda^2_{akl}\hat{\sigma}^2_{k,t+l}}{(\Lambda_k^2\hat{\sigma}^2_{jkl} + \sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda_{ak,T}\sigma^2_a + \lambda_{zk}\sigma^2_z)^2} + \mathbf{1}_{k=j}B_l\frac{\lambda^2_{ajl}\hat{\sigma}^2_{j,t+l}}{(\Lambda_k^2\hat{\sigma}^2_{jkl} + \sum_{l=1}^{T}\lambda^2_{akl}\hat{\sigma}^2_{jkl} + \lambda^2_{ak,T}\sigma^2_a + \lambda^2_{zk}\sigma^2_z)^2}$$

This again has a very similar structure to the marginal benefit of $t+1$ information, however, note that the derivative is proportional to $\lambda^2_{akl}$ – the price coefficient on the $t+l$ innovation term. This price coefficient is larger when the market is better informed about that innovation, and hence captures the incentive for strategic coordination. This is a potentially important force that can help discipline *which* foreign assets the agents will choose to diversify in first, once they hit the decreasing returns to home information. In the $T = 1$ model, learning was a strategic substitute, so the most attractive foreign assets were the once about which the market is relatively less informed. All else equal, this means that agents would prefer to diversify into the foreign assets of countries with relatively low information. However, this would be at odds with the data, where we see the strongest growth in capital flows between developed OECD countries, which have also experienced much greater increases in the stock of information technology. In the $T > 1$ model, however, due to the incentive to coordinate on learning, investors are likely to diversify exactly in the assets of developed countries with well informed markets. Moreover, the model can also explain the flow of capital from emerging to developed countries – the returns to information are much bigger in the better informed markets, hence investors from emerging markets might focus their learning and investing there.[15]

Just as before, the second derivative of information (at any horizon) can be both positive and negative, and hence information about any given future fundamental innovation can display both increasing and decreasing returns. The intuition is again very similar. In terms of second derivatives, the most interesting innovation in the $T > 1$ model is in the cross-partial derivative. In particular, consider how increasing information about the innovation at some $t + l$ affects the marginal benefit of information about the $t + 1$ (next period) innovation:

$$\frac{\partial^2 U}{\partial \kappa_{k1} \partial \kappa_{kl}} = \frac{1}{2\gamma} \frac{(\mathrm{Var}(ex_{k,t+1}) + E(ex_{k,t+1})^2)\Lambda_k^2 \lambda_{akl}^2 \hat{\sigma}_{k,t+1}^2 \hat{\sigma}_{k,t+l}^2}{(\Lambda_k^2 \hat{\sigma}_{jkl}^2 + \sum_{l=1}^T \lambda_{akl}^2 \hat{\sigma}_{jkl}^2 + \lambda_{ak,T}\sigma_a^2 + \lambda_{zk}\sigma_z^2)^3} + \mathbf{1}_{k=j} B_1 \frac{\Lambda_k \lambda_{ajl}^2 \hat{\sigma}_{k,t+1}^2 \hat{\sigma}_{j,t+l}^2}{(\Lambda_k^2 \hat{\sigma}_{jkl}^2 + \sum_{l=1}^T \lambda_{akl}^2 \hat{\sigma}_{jkl}^2 + \lambda_{ak,T}^2 \sigma_a^2 + \lambda_{zk}^2 \sigma_z^2)^3} > 0$$

The cross-partial is positive, meaning that learning about the $t + l$-th innovation, increases the marginal benefit of information about the next period. This holds more generally – the more you learn about any of the innovations to a given country fundamental $k$, the greater is the marginal benefit of learning about innovations at other horizons for the same country. This reinforces the convexity of the objective function, and thus makes full specialization in learning about a single country (though possibly about innovations at different horizons) more appealing. This can help amplify the model's ability to generate concentrated portfolios.

# 5 Home Bias and Information Costs in the Data

The model implies a strong link between information costs and the level of the home bias, and in particular implies that the decline of the home bias is linked to falling information costs. This is an intuitive possibility, given that the decline of the home bias in the last two

[15]More generally, the $T > 1$ model can explain why analysts, and information more generally, are concentrated on following $S\&P500$ companies and not smaller, and more obscure companies. Those smaller companies are the ones that investors would like to learn about in the standard static model due to the strategic substitutability of learning. But here, most investors do indeed choose to learn about what everyone else is already learning, and thus information might get focused on a small subset of all assets.

decades has coincided with the IT boom. To examine this hypothesis rigorously, I analyze the relationship between the growth in IT and the decline of the home bias in my dataset of fifty-three countries from 1995 to 2015.

The role of information costs in portfolio determination, and the negative relationship between information costs and portfolio diversification in particular, is well established in both the micro and the macro data. Using a highly detailed dataset on a representative 3% sample of the Swedish population, Massa and Simonov (2006) find that portfolio concentration is driven by informational motives, and not hedging incentives or behavioral biases. Other recent work using micro-level data shows that portfolio concentration is decreasing in traditional proxies for information like education, income, wealth and direct measures of financial sophistication (Campbell et al. (2007), Goetzmann and Kumar (2008), Guiso and Jappelli (2008), Kimball and Shumway (2010), Gaudecker (2015)). On the other hand, a number of papers specifically study the home bias in equities, and find a strong relationship with information (see for example Kang et al. (1997), Ahearne et al. (2004), Bradshaw et al. (2004), Portes and Rey (2005), Aviat and Coeurdacier (2007), Lane and Milesi-Ferretti (2008)).

To measure the extent of IT penetration and adoption at the country level, I use data on the number of internet users per capita from the World Bank. This is my preferred measure for a number of reasons. First, the internet is the preeminent information technology and has had profound effects on the cost and availability of information around the world. Moreover, its wide-spread adoption had just started in the mid-1990s which corresponds with the timing of the trend break in the home bias. Second, this is also the measure with the best data availability, as measures such as computers per capita are less consistently available for all countries and years. Lastly, it implicitly also measures the availability of computers and, in the later years, other computing devices with connectivity features (e.g. laptops, smart phones and etc.).

I start by showing that there is a strong negative relationship between the levels of the equity home bias and information technology at the country level. This result corresponds with the similarly negative link previous literature has found between under-diversification and other measures of information. To do so, I average the EHB index and the number of internet users over time and look at the cross-sectional differences between countries. The results are presented in column (1) of Table 1, and show a significant negative relationship, meaning that countries with a higher level of internet use in general display lower levels of home bias. The remaining columns of Table 1 introduce additional controls that have traditionally been associated with the home bias – financial openness, as measured by the Chinn-Ito index (higher values mean more openness), trade openness defined as the ratio of trade (imports plus exports) to GDP, financial development as measured by market cap to

GDP, and real GDP per capita.

Table 1: Equity Home Bias and IT in Levels

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Internet users | -0.67*** | -0.48*** | -0.48*** | -0.49*** | -0.35** |
| | (0.09) | (0.10) | (0.09) | (0.11) | (0.15) |
| Financial openness | | -0.049*** | -0.049*** | -0.049*** | -0.037** |
| | | (0.013) | (0.013) | (0.013) | (0.015) |
| Trade openness | | | 0.01 | 0.01 | 0.01 |
| | | | (0.04) | (0.04) | (0.04) |
| Mkt Cap / GDP | | | | 0.001 | 0.008 |
| | | | | (0.04) | (0.35) |
| GDP p.c. | | | | | -0.05 |
| | | | | | (0.05) |
| N | 53 | 53 | 53 | 53 | 53 |

OLS estimates with heteroskedasticity robust standard errors in paranthesis of the regression

$$EHB_i = \alpha_0 + \beta_1 InternetUsers_i + \beta_2 FinancialOpenness_i + \beta_3 TradeOpenness_i + \beta_4 GDPpc_i + \varepsilon_i$$

***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Controlling for financial openness is self-explanatory and it is not surprising to see that it has a significant and negative relationship with the equity home bias. Countries that restrict capital flows also have more inward-looking portfolios. Trade openness is an important determinant of home bias in a large class of models that explain the home bias through a mechanism where home assets offer a hedge for real exchange rate risk. In those models, larger amounts of trade are associated with a lower home equity bias, because the consumption basket of the home agent is less dependent on home goods and hence he requires lower real exchange rate hedging. Lastly, it is also well known that richer countries exhibit lower values of home bias, hence I also include real GDP per capita, in order to ensure that the relationship with internet use is not simply picking up richer vs poorer countries. Importantly, in all specifications the coefficient on internet users remains negative and significant. In fact, in the full specification that includes all possible controls, only the internet users and financial openness are significant.

Having established a strong negative link between the level of the home bias and the level of IT, I turn to the relationship between their changes. To do so, I compute the average yearly change in each of the variables and estimate

$$\overline{\Delta EHB}_i = \alpha_0 + \beta_1 \overline{\Delta InternetUsers}_i + \beta_2 \overline{\Delta FO}_i + \beta_3 \overline{\Delta Trade}_i + \beta_4 \overline{\Delta MktCap/GDP}_i + \beta_5 \overline{\Delta GDPpc}_i + \varepsilon_i$$

This regression uses the cross-sectional variation in the rates of change of the regressors and $EHB_i$, to identify what best explains the observed decline in the home bias. The results are presented in Table 2 and display a negative and significant coefficient on the change of information technology in all specifications. This signifies that countries that have seen larger expansions of information technology, have also experienced a larger decline in their home bias. It is economically significant too, implying that a 64 percentage points increase in the number of users per capita (the average increase in the sample period) is associated with a 0.33 points decrease in the home bias index, which is roughly equal to the actual average decline in the home bias. The results suggest that falling information costs have indeed played an important role in the secular decline of the home bias. On the other hand, none of the other controls appears significant in the full regression specifications, and in fact financial openness and GDP have positive coefficients, implying that if anything, they would have acted to slow down the decline in the home bias. Trade Openness does have a negative coefficient, but is only significant when included in the regression by itself.

Table 2: Changes in Home Bias and IT

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\Delta$ Internet users | -0.56*** | -0.57*** | -0.53*** | -0.52*** | -0.52*** |
| | (0.10) | (0.12) | (0.11) | (0.11) | (0.11) |
| $\Delta$ Financial openness | | -0.011*** | -0.019 | -0.016 | -0.028 |
| | | (0.029) | (0.030) | (0.032) | (0.031) |
| $\Delta$ Trade openness | | | -0.12 | -0.12 | -0.13 |
| | | | (0.09) | (0.09) | (0.09) |
| $\Delta$ Mkt Cap / GDP | | | | 0.03 | 0.02 |
| | | | | (0.08) | (0.08) |
| $\Delta$ GDP p.c. | | | | | 0.04 |
| | | | | | (0.08) |
| N | 53 | 53 | 53 | 53 | 53 |

OLS estimates with heteroskedasticity robust standard errors in paranthesis of the regression

$$\overline{\Delta EHB}_i = \alpha_0 + \beta_1 \overline{\Delta InternetUsers}_i + \beta_2 \overline{\Delta FO}_i + \beta_3 \overline{\Delta Trade}_i + \beta_4 \overline{\Delta MktCap/GDP}_i + \beta_5 \overline{\Delta GDPpc}_i + \varepsilon_i$$

***, ** and * denote significance at the 1%, 5% and 10% level respectively.

I also consider a specification that exploits the panel dimension of the data. In particular, instead of looking at the average change of the variables over the whole 20 year period, I consider both 5 year averages and yearly changes of the variables for each country. The panel regression estimates, controlling for country and time fixed effects, are reported in Table 3, and they confirm the cross-sectional regression results – internet users per capita have a strong, negative relationship with the home bias. Remarkably, the relationship remains even after including all variable controls, and both country and time fixed effects. In terms of economic significance, the estimated coefficient is now smaller, but still, it implies that the observed increase in internet users per capita could account for about a third of the observed fall in the home bias.

Table 3: Changes in Home Bias and IT, Panel Regression

| | Five-year Changes | | Annual Changes | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Δ Internet users | -0.18** | -0.18** | -0.10** | -0.11** |
| | (0.08) | (0.08) | (0.04) | (0.04) |
| Δ Financial openness | 0.011 | 0.006 | 0.006** | 0.005* |
| | (0.010) | (0.012) | (0.003) | (0.003) |
| Δ Trade openness | -0.03 | 0.01 | -0.05* | -0.08* |
| | (0.08) | (0.09) | (0.03) | (0.05) |
| Δ Mkt Cap / GDP | 0.04** | 0.04** | 0.05*** | 0.05*** |
| | (0.02) | (0.02) | (0.009) | (0.01) |
| Δ GDP p.c. | 0.29 | 0.34* | 0.05 | -0.004 |
| | (0.19) | (0.19) | (0.04) | (0.06) |
| Country fixed effects | Yes | Yes | Yes | Yes |
| Time fixed effects | No | Yes | No | Yes |

OLS estimates with heteroskedasticity robust standard errors in paranthesis of the regression

$$\overline{\Delta EHB}_{it}^{5yr} = \alpha_{0i} + \gamma_t + \beta_1 \overline{\Delta InternetUsers}_{it}^{5yr} + \beta_2 \overline{\Delta FO}_{it}^{5yr} + \beta_3 \overline{\Delta Trade}_{it}^{5yr} + \beta_4 \overline{\Delta MktCap/GDP}_{it}^{5yr} + \beta_5 \overline{\Delta GDPpc}_{it}^{5yr} + \varepsilon_{it}$$

***, ** and * denote significance at the 1%, 5% and 10% level respectively.

The preponderance of the evidence supports the model's implications, and suggests that information has indeed played an important role in the secular decline of the home bias, and is likely an important determinant of the home bias puzzle as a whole.

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# A Appendix: Data

The list of countries in the database is: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Croatia, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Israel, Italy, Jamaica, Japan, Jordan, Korea, Latvia, Lithuania, Macedonia, Malaysia, Morocco, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Russian, Slovak, Slovenia, South Africa, Spain, Swaziland, Sweden, Switzerland, Turkey, United Kingdom, United States, Venezuela