Dynamic Information Acquisition and Portfolio Bias

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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

1 Introduction

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

In addition, the dynamic nature of the asset markets in this economy generate the well known\beauty contest" motive, where agents would like to forecast future market beliefs, since they determine the resell price of the assets. However, the best way to do so is to try and learn about the same things that the average market participant learns about { as a result information is no longer a pure strategic substitute, as is the case in the standard static model. In the static framework, 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 di erent 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 identi ed by an investor's private information, then the future price would not adjust appropriately and hence the investor would not pro t 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 rst place. his 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 pro le that is declining over time (as information capacity increases), 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

Thus, due to its dual use, domestic information has a relatively higher value, and as a result agents tilt their information acquisition towards it, leading to information asymmetry and home biased portfolios.

In this model, information is not a pure strategic substitute, but rather could be either a 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 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 Pastor (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 international diversification over time.

Unlearnable uncertainty, and its effects on the agents' incentives for full vs partial specialization is discussed in passing in van Nieuwerburgh and Veldkamp (2010). However, there the unlearnable uncertainty is exogenous, while in this model the relative size of the learnable vs unlearnable uncertainty is endogenous, and depends on the information choices of the agents, through their effects on the equilibrium asset prices. On the other hand, the "beauty contest" nature of dynamic asset pricing markets and their natural pull towards strategic coordination in the action of agents is well known in the asset pricing literature (e.g. Allen, Morris and Shin (2006)). The contribution of this paper is to show that giving agents a choice over their information, generates endogenously both unlearnable uncertainty and coordination incentives in learning. In turn, this allows the information model to better match the data on international portfolio biases.

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

Figure 1: The Evolution of the Equity Home Bias

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 their domestic markets go up from 15% 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 is the direction of the international capital flows that underly this decline in the home bias. Are investors generally increasing their holdings of all foreign assets in their portfolio, or is there systematic heterogeneity in the foreign portion of portfolios? The EHB index can only tell us something about the ratio of home assets relative to the sum total of all foreign holdings, 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

$$\text{Foreign Bias}_{ij} = 1 \quad \frac{\text{Non-country } j \text{ share of foreign holdings of Country } i}{}$$

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 speci cally, 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 e ect on the counter-factual EHB index.

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, 83% of the decline in the home bias between 2001 and 2013 is due to the 5% biggest movers in foreign holdings. In particular, if we adjust the

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 across countries, but the framework can easily be extended to accommodate it.

3.1 Information Structure

Agents do not observe the value of the persistent economic fundamental a

N countries), that occurs after observing the private signals of the agents and is given by

$$= H(\{a_t, \varepsilon_{t+1}, \ldots, \varepsilon_{t+T}\} | I_t^p) \quad H(\{a_t, \varepsilon_{t+1}, \ldots, \varepsilon_{t+T}\} | I_t^{(i)})$$

where $H(X)$ is the entropy of random variable X and $H(X|Y)$ is the entropy of X conditional on knowing Y.[8] The set I_t^p (de ned below) is the set of public information that we assume the agent acquires for free, and thus are not subject to the entropy cost, and $I_t^{(i)} = \{I_t^p \cup {}_t^{(i)}\}$ is the private information set of agent i, which combines the public information with her vector of private signals about the di erent countries ${}_t^{(i)} = [{}_{1t}, \ldots, {}_{Nt}]'$. Thus, measures the amount of information about the unknown country fundamentals that is contained in the private signals, over and above the free "public" information.

Given the prior assumption that all factors are uncorrelated across countries, we can express the total information acquired as the sum of the information acquired about each country individually

$$= {}_1 + \quad + {}_N$$

Where the the information of each individual signal is similarly de ned as the information about a given country's fundamentals over and above the costless public information:

$${}_k = H(a_t \ldots$$

fb ft8 / h) 83 4 . 0 Td [(t)]TJ / F5 7.8 Td [(p)]TJ -0.883 -8.365 fj jPf0J / F58 7. 971 Tf 36.661 5. 8 Td [(p)]TJ -0. 883 -8. 36 5 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.[10]

the agents follow a Normal distribution, which leads to the familiar mean-variance optimal portfolio holdings:

$$x^{(i)}_{jjt} = \frac{E(p_{j;t+1} + (1 \quad)d_{j;t+1} j I^{(i)}_j) \quad p_{jt}R}{\mathrm{Var}(p_{j;t+1} + (1 \quad)d_{j;t+1} j I^{(i)}_j)} \quad \frac{Cov(\; d_{j;t+1}; p_{j;t+1} + (1 \quad)d_{j;t+1} j I^{(i)}_j)}{\mathrm{Var}(p_{j;t+1} + (1 \quad)d_{j;t+1} j I^{(i)}_j)}$$

$$x^{(i)}_{jkt} = \frac{E(p_{k;t+1} + (1 \quad)d_{k;t+1} j I^{(i)}_j) \quad p_{kt}R}{\mathrm{Var}(p_{k;t+1} + (1 \quad)d_{k;t+1} j I^{(i)}_j)}$$

where $x^{(i)}_{jkt}$ is the amount of the risky asset of country 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 o er 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 covariance (second) term in the rst equation. Two forces could potentially a ect 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, $\mathrm{Var}(p_{j;t+1} + (1 \quad)d_{j;t+1} j I^{(i)}_j) \neq \mathrm{Var}(p_{k;t+1} + (1 \quad)d_{k;t+1} j I^{(i)}_j)$ for $j \neq k$

$p_{k;t+1}$ has a loading of

$$E(a_{k;t}|I_t^{(i)}) = \hat{a}_{kt} = \hat{\ }^2_{kt} \quad {}_a \frac{1}{{}^2_a}{}^2_a + \frac{1}{{}^2_d} d_{kt} + \frac{1}{{}^2_k} {}^{(i)}_{kt} + (\frac{{}_{ak}}{{}_{zk}})^2 \frac{1}{{}^2_z}(p_t + \frac{{}_{zk}}{{}_{ak}} z_{kt})$$

and the posterior variance is

$$\mathrm{Var}(a_{k;t}|I_t^{(i)}) = \hat{\ }^2_{kt} = \left(\frac{1}{{}^2_a}{}^2_a + \frac{1}{{}^2_d} + \frac{1}{{}^2_k} + (\frac{{}_{ak}}{{}_{zk}})^2 \frac{1}{{}^2_z} \right)^{1}$$

Plugging everything back in the market clearing condition (2) gives us the solution for the coe cients of the equilibrium prices. I will focus on a symmetric equilibrium where all agents in each country make the same information choices, so we can dispense with the i subscripts and focus only on the country subscripts j. The details of the derivations are given in the Appendix, and here I will just highlight the structure of the two most important coe cients { the ones on the unknown fundamental and noise term:

$$ {}_{ak} = \frac{{}^2_k q_k}{R}(1 + \frac{{}_k q_k}{{}^2\ {}^2_z}) \tag{4}$$

$$ {}_{zk} = \frac{{}^2_k}{R}(1 + \frac{{}_k q_k}{{}^2\ {}^2_z}) \tag{5}$$

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

$$ {}^2_k = \left(\frac{1}{N} \sum_j \frac{1}{\mathrm{Var}(p_{k;t+1} + (1 \quad)d_{k;t+1}|I_{jt}^{(i)})} \right)^{1}$$

where we sum over the countries j and q_k is a weighted average of the precision of the private signals of all market participants,

$$q_k = \sum_j \frac{1}{N}$$

$$
{}_{ak} = \frac{{}_{a}\ {}_{k}}{R}\left(1 - \frac{1}{N}\sum_j \frac{{}^{2}_{k}}{\mathrm{Var}(p_{k;t+1} + (1 - \ )d_{k;t+1} | I^{(i)}_{jt})}\frac{\hat{}^{2}_{jt}}{\frac{{}^{2}_{a}}{1 - {}^{2}_{a}}}\right)
$$

which shows that it is a decreasing function of the weighted average of the ratio of the posterior variance of a_{kt} (across agents in different countries) and its prior variance { $\frac{\hat{}^{2}_{jt}}{\frac{{}^{2}_{a}}{1-{}^{2}_{a}}}$. Thus, the more information the market as a whole has about a_{kt}, the higher is ${}_{ak}$. In the extreme of no information about a_{kt}, ${}_{ak} = 0$, and in the other extreme where everyone knows a_{kt} perfectly ${}_{ak} = \frac{{}_{a}\ {}_{k}}{R}$ which is the discounted value of the cash flows due to a_{kt}. Intuitively, as market participants acquire more information about some of the unknown fundamental terms, they trade more aggressively on that information and thus it gets reflected more strongly in the asset price. [12]

$$\max_{1,\dots,\ N} E(U_j(x_t(\ _t)))$$

s.t.

$$\sum_k \ _k \quad K$$

$$_k \quad 0$$

thus choosing the informativeness of his signals to maximizes his expected utility integrating over the unknown realizations of his private signals, taking as given the optimal portfolio choice x_t as a function of his information choice. The rst constraint says that the agent can use up to no more than K bits of total information (this is the information capacity constraint), and 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.

First, I con rm 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.* $_{kt} = \ _k$ *for all k and t.*

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

This tells us that at any time period t, the currently young generation (of any country { note that country subscripts are suppressed to reduce clutter) allocates its nite 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 coe cients given above, we see that this guarantees that they do not change over time either, and hence we have a stationary equilibrium.

To gain intuition about the result, it's useful to derive the ex-ante expected utility that enters the information choice.

$E(U(x_t E$

returns are

$$ex_{k;t+1} = {}^{2}_{k}\ {}_{k}\left(\frac{1}{{}^{2}_{a}}{}^{2} + \frac{1}{{}^{2}_{d}}\right)a_t + {}_{k}\,''^{a}_{k;t+1} + : : : \qquad (7)$$

Clearly, when the future innovation of the fundamentals is high, the realized excess return is also high since the future innovation is pure news to the market and is not incorporated in the current equilibrium price. The return is also increasing in a_{kt} since today's fundamental do not vary over time either. The details of the proof amount 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

$$\mathrm{Var}(E(ex_{k;t+1} | I_t)) = \mathrm{Var}(\;_k\; a_{kt} \quad Rp_{kt}) \quad {}^2_k \; {}^2\hat{}^2_k$$

which shows again that if information choice does not vary over time, then this variance term does not vary either. And we can again show that there is no incentive to change information choice, and thus there is an equilibrium where information acquisition is time-invariant.

Lastly, note that if we combine all of these results, we arrive at the conclusion that in

The key to understanding the increasing returns is 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 useful information leads to bigger trading profits when applied to a bigger portfolio holding. This generates a feedback effect between information and portfolio choice. In particular, as ${}_k$ 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 the only effect in the benchmark static model, and results in global increasing returns to information.

In the dynamic model, however, there is also an additional effect — increasing asset holdings exposes the agent to progressively larger amounts of unlearnable valuation risk. Recall that the return of asset k does not depend only on learnable uncertainty about the value of a_{kt}, but also on the future innovations to fundamentals, dividends and noise trading, which all affect the asset return through their effect on the future price p_{kt}. This moderates the incentive to increase portfolio holdings in response to an increase in ${}_k$, and weakens the feedback loop described above. When agents have not acquired much information about asset k, the posterior variance of the current fundamental is relatively high, and as a result *learnable* uncertainty is the majority of total uncertainty, and hence the first effect dominates and information displays increasing returns. However, when information is abundant, the majority of remaining uncertainty is unlearnable, and in this case the second effect dominates and 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.:*

$$\frac{\partial MB_k}{\partial \ {}_k} \propto \underbrace{{}_k^2 \ {}^2 \hat{}_k^2}_{\text{Learnable Uncertainty}} \quad \underbrace{{}_k^2 \ {}_a^2 + (\ {}_{dk} + (1 \quad))^2 \ {}_d^2 + \ {}_{zk}^2 \ {}_z^2}_{\text{Unlearnable Uncertainty}} > 0$$

In particular, this means those are assets that:

1. *The agent has not learned much about — high* $\hat{}_k^2$
2. *Feature less unlearnable uncertainty — low* ${}_k^2 \ {}_a^2 + (\ {}_{dk} + (1 \quad))^2 \ {}_d^2 + \ {}_{zk}^2 \ {}_z^2$

The proposition has two main implications. 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 acquired 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. Hence, as the amount of information that has already been acquired increases, the next unit of information reduces an ever smaller portion of the remaining uncertainty, which weakens the feedback between portfolio and information choice. Thus, agents face increasing returns to information when information is relatively scarce, and decreasing returns otherwise.

The second interesting result is that whether information features increasing or decreasing returns also depends on the structure of the equilibrium price p_{kt}, which determines the size of the unlearnable uncertainty. In particular, assets for which the price is more responsive to innovations to fundamentals and dividends or noise trader shocks, are more likely to feature decreasing returns to information. This will have important implications as relatively scarce, i.e. $K \leq K_0$, the agent finds it optimal to fully specialize in learning only about the home fundamental. This is the best use of the scarce information.

As information capacity increases, however, 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 $K \in (K_0, K_1]$, the agent only acquires information about one foreign asset, then as information capacity increases further, he adds a second foreign asset to his learning portfolio and so on. Eventually, when information is sufficiently abundant, he would be learning about all assets. Thus, as information capacity increases, it percolates in a step-wise fashion through the whole menu of available assets.

The particular structure of the problem implies that the information asymmetry of home vs foreign information is non-monotonic in information capacity. When information is relatively scarce, the agent fully specializes in home information and does not acquire any foreign information. In that part of the state space, as information capacity rises, 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 the ability of the agent to acquire information increases sufficiently, so that $K > K_0$, the agent starts acquiring foreign information as well. As a result, as the information capacity increases, 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, in the symmetric equilibrium case we are currently analyzing, 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 asset when information capacity is sufficiently abundant 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 $_{k'} = {}_k$ for any two foreign assets k' and k that the agent decides to learn about.

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.

4.5 Strategic Substitutability and Complementarity in Information Choice

In the previous section we considered what happens to information choice as the information capacity of a single agent changes. Here we turn to the question of how the aggregate information capacity affects an individual's information choice. The bottom line result is that the model features forces of both strategic substitutability and strategic complementarity, and which one dominates depends on parameters.

In the standard static model information is a pure strategic substitute, and many of the same forces are active in the dynamic model as well. Primarily, when the precision of private which is *increasing* in $_k$. Hence, holding a given agent's information xed, if everyone else becomes better informed then $_k$ increases, ^^2_k stays constant, and thus the posterior variance of the excess return increases. Essentially, since now the rest of the market is better informed and thus is acting more aggressively on their private information, this makes expected excess returns more responsive to fundamental news and thus more volatile. Increased information increases the role of the asset pricing factor that is due to today's information about a_{kt}.

On the one hand, this force exerts an upwards pressure on ^2_k and thus on ex-ante excess returns and variances. On the other, the increase in $_k$ also has an additional, direct e ect pushing up both of these ex-ante moments. In terms of the expected excess return, an increase in $_k$ increases the hedging-driven component of the ex-ante expected return. In terms of the ex-ante variance, an increase in $_k$ unsurprisingly increases the ex-ante variance of realized excess returns term { Var($_k$ a_{kt} Rp_{kt}). Both of this tend to push higher the marginal bene t of information and thus serve as incentives for strategic coordination in information choice.

In addition, an increase in the aggregate market information can also increase learnable uncertainty. As $_k$ goes up, this increases the share of the total asset return variance that is attributable to uctuations in today's fundamental, which the agents can learn about. Essentially, this increases the scope of learning for today's agents. When there are better informed traders the future asset price p_{kt} is more highly dependent on the value of fundamentals. Today's agents cannot learn directly about the future fundamental innovation, but since a_{kt} is persistent information about today's value is still useful in forecasting the future price.

This channel is due to the \beauty contest" nature of dynamic these issues in more detail in a later section focused on numerical exercises.

4.6 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. 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, z_j, 2) a fund that is perfectly diversi ed over the foreign assets the agent does learn about and holds nothing else, $z_{j;learn}$, and 3) a fund that is perfectly diversi ed over the foreign assets he does not learn about $z_{j;no\ learn}$. The aggregate portfolio of country j can be expressed as,

$$x_j = \quad z_j + \quad {}_1 z_{j;learn} + \quad {}_2 z_{j;no\ learn}$$

This follows directly from previous results. The agent always nds it optimal to learn the most about the home asset, hence there is asymmetry in home vs foreign information which a ects 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 capacity increases. The rst and most obvious e ect is the \home bias", which measures the relative holding of home versus all foreign assets. In a model with no learning and no non-tradable income in equilibrium all agents hold the market portfolio (also known as the CAPM portfolio):

$$x^{MKT} = z.$$

To illustrate what happens when we introduce non-tradable income > 0 and learning, I will use an example with just two symmetric countries, a home and a foreign one. The equilibrium portfolios become

$$x_h^{NoInfo} = z_h \quad \frac{}{2} \frac{{}_h(\ \hat{}_h^2 + \ {}_a^2)}{{}_h^2 \ 2\hat{}_h^2 + (\ {}_{dh} + (1 \quad))^2 \ {}_d^2 + \ {}_h^2 \ {}_a^2 + \ {}_{zh}^2 \ {}_z^2}$$

$$x_f^{NoInfo} = z_f + \qquad {}_f(\ \hat{}_f^2 \qquad =$$

$$))^2 \ {}_d^2 + ; \ {}_h^2{}^2 + \ {}_z^2{}^2$$

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. So the hedging channel by itself is not helping in generating home bias, but is in fact doing the opposite.

The information channel that works in the opposite direction by generating information asymmetry, where agents are better informed about the home asset. Letting $\,^{2}_{ek} = \,^{2}_{k}\,^{2}_{a} + (\,_{dk} + (1 \quad))^{2}\,^{2}_{d} + \,^{2}_{zk}\,^{2}_{z}$ denote the amount of unlearnable uncertainty agents face, then when agents can acquire information, the resulting optimal portfolio of the home agent is:

$$x_h = E(\quad (x_h^{(i)}) = \frac{\,^{2}_{h}}{\,^{2}_{h}\,^{2}\hat{\,}_{h} + \,^{2}_{eh}} \quad \int^{+}$$

Figure 4: Portfolio Bias and Information Capacity

Figure 5: Concentration of Foreign Holdings and Information Capacity

bias is falling, the concentration in the foreign portion of portfolios is non-monotonic. This is illustrated by 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 K 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 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 K. Figure 6 illustrates this by comparing the resulting home bias with a model where there is no non-tradable income (= 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.

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

Figure 6: Effect of Non-Tradable Income

5 General Equilibrium and Numerical Exercises

In this section, I consider the full version of the model where agents can also learn about future innovations to the fundamentals ($T > 0$). Moreover, while previously we focused on analyzing an individual agent's optimal actions keeping the rest of the market fixed, here we will also solve for the general equilibrium distribution of information and portfolios.

Allowing agents to learn news about the future serves two purposes. First, it not only increases the scope of learning by expanding the learnable portion of uncertainty, but there is also a complementarity between learning about the current fundamentals and about future innovations to the fundamentals. As a result, the marginal benefit of information about a_{kt} is increasing in the information acquired about $\varepsilon_{k;t+l}$. Both of these forces serve to amplify the amount of information asymmetry, and thus portfolio home bias that can be achieved in equilibrium. Second, it also increases the forces for *strategic* complementarity in information acquisition across agents.

These two effects are best understood by examining the structure of the equilibrium asset prices and asset returns. The equilibrium price for asset k is now given by

$$p_{kt} = \lambda_k + \lambda^0_{ak} a_{kt} + \sum_{l=1}^{T} \lambda^l_{ak} \varepsilon^a_{k;t+l} + \lambda_{dk} d_{kt} + \lambda_{zk} z_{kt};$$

It is a straightforward extension of the special case with $T = 0$ analyzed earlier. The price is a function not only of the current fundamental, but also of the future innovations $\varepsilon^a_{k;t+l}$. Importantly, the coefficient on any future innovation, $^l_{ak}$ depends on the average precision of private signals about it, and thus on how much information agents choose to devote to learning about that particular innovation. If no one is learning about one of these terms then $^l_{ak} = 0$, but is positive when some market participants are informed about it.

In turn, the excess return on asset k is given by

$$p_{k;t+1} + (1 \quad)d_{k;t+1} = {}_k + {}_k \, {}_a a_{kt} + {}_k \varepsilon^a_{k;t+1} + \underbrace{\sum_{l=1}^{T-1} {}^l_{ak} \varepsilon^a_{k;t+1+l}}_{\text{Additional terms due to learning}} + \underbrace{{}^T_{ak} \varepsilon^a_{k;t+T+1} + {}_{zk} z_{t+1} + {}_{dk} \varepsilon^d_{k;t+1}}_{\text{Unlearnable uncertainty}} : \quad (9)$$

The expression showcases how allowing for $T > 0$ increases the scope of learning and thus the share of learnable uncertainty in asset returns. On the one hand, there is the direct effect of simply allowing agents to learn about $\varepsilon^a_{k;t+1}$ which drives next periods dividends. Moreover, learning about the more distant future introduces new factors driving asset returns { captured by the summation term in the above expression. The only reason that the asset return realizing at time $t+1$ is driven by shocks that are yet to realize at time $t+2$ and later, is because agents collect information on them, and through their trading actions incorporate them into prices. Thus, the capital gains portion of the asset returns is now also driven by news about the further future.

This increases the amount of asset return variation that is due to learnable factors, and hence increases the scope of learning. As a result, information acquisition has a bigger

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($= 0{:}9$), with a volatility of innovations roughly in line with US TFP data ($_a = 0{:}1$), and the model implies a labor share of two-thirds $= 0{:}67$. The variance of the noise in the dividends was chosen to be large enough so that the uncertainty left in a_{kt}, after seeing d_{kt}, is about 2 ^2_a. Lastly, the risk-aversion and the size of noise traders were chosen by targeting an average equilibrium excess return of 6% with a Sharpe ratios of 0.3. Using these parameters, we look for an equilibrium both in asset markets and information choice { meaning that we look for the xed point between information choice and the resulting asset prices, such that agents do not want to change their information choices.

Figure 7: Equity Home Bias. The gure shows the resulting equilibrium Home Bias, in the model under the following parameters:

which the market has chosen to learn about them. The more the market learns about them, the greater are their price coe cients, and as a result the bigger role they play in the capital gains component of asset returns.[14] Essentially, with $T > 0$, there are multiple (learnable) factors driving asset returns that are a function of the average market information, and it is precisely through these factors that the complementarity works. The more we have of them holdings are in fact becoming more concentrated in just one country { the one with more informed markets. Eventually, of course, at a high enough value for K investors start learning about the other foreign country as well. Still, their preference for the more informed country is quite persistent.

Figure 8: Foreign Holdings, asymmetric model

This is reminiscent of the empirical finding that the home bias decline in the data has come about as a result of increased capital flows into a handful of developed OECD countries. Thanks to the strategic complementarity in learning that arises in the dynamic model, we can explain both the fall in the home bias, and the concentrated nature of the underlying international capital flows with i) an increase in information capacity across the world and ii) heterogeneity in information capacity across countries.

6 Home Bias and Information Capacity in the Data

The model implies a strong link between information capacity and the level of the home bias, and in particular implies that the decline of the home bias is linked to an increase in information capacity. To examine these hypothesis empirically, I analyze the relationship between the growth in country-wide access to information technology and the decline of the home bias in my dataset of fifty-three countries from 1995 to 2015.

Before we begin it is worth nothing that the role of information costs in portfolio determination, and speci cally the *negative* relationship between information and portfolio under-diversi cation 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) nd 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 nancial sophistication (Campbell et al. (2007), Goetzmann and Kumar (2008), Guiso and Jappelli (2008),

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

strong, negative relationship with the home bias. Remarkably, the relationship remains even after including both country and time xed e ects. In terms of economic signi cance, the estimated coe cient 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)
Internet users	-0.18	-0.18	-0.10	-0.11
	(0.08)	(0.08)	(0.04)	(0.04)
Financial openness	0.011	0.006	0.006	0.005
	(0.010)	(0.012)	(0.003)	(0.003)
Trade openness	-0.03	0.01	-0.05	-0.08
	(0.08)	(0.09)	(0.03)	(0.05)
Mkt Cap / GDP	0.04	0.04	0.05	0.05
	(0.02)	(0.02)	(0.009)	(0.01)
GDP p.c.	0.29	0.34	0.05	-0.004
	(0.19)	(0.19)	(0.04)	(0.06)
Country xed e ects	Yes	Yes	Yes	Yes
Time xed e ects	No	Yes	No	Yes

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

$$\overline{EHB}_{it}^{5yr} = {}_{0i} + {}_{t} + {}_{1}\overline{InternetUsers}_{it}^{5yr} + {}_{2}\overline{FO}_{it}^{5yr} + {}_{3}\overline{Trade}_{it}^{5yr} + {}_{4}\overline{MktCap/GDP}_{it}^{5yr} + {}_{5}\overline{GDPpc}_{it}^{5yr} + \varepsilon_{it}$$

, and denote signi cance 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