

# Exchange Rate Disconnect Redux\*

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## Abstract

We find that variation in expected US productivity explains more than half of G6 exchange rate fluctuations vis-a-vis the USD. Both correctly-anticipated changes in productivity and expectational “noise”, which influences expected productivity but never its realization, play an important role in driving exchange rates. Together, these disturbances account for many unconditional exchange rate patterns, including predictable excess returns, low Backus-Smith correlations, and excess volatility. Our findings suggest these famous puzzles share a common empirical origin, one that is very much connected to (expected) fundamentals. All of these findings can be rationalized by a model in which excess currency returns are driven by endogenously-fluctuating bond convenience yields. This mechanism makes additional predictions about government debt dynamics that prove true in the data.

**JEL Codes:** D8, F3, G1

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The study of exchange rates is suffused with empirical “puzzles,” many of which suggest a disconnect between exchange rates and macroeconomic fundamentals that is hard to rationalize with standard models. In particular, there is a surprising lack of connection between a variety of macroeconomic aggregates (output, consumption, etc.) and exchange rates, both contemporaneously and in a forecasting sense – a set of results the literature broadly refers to as the “exchange rate determination” puzzle.<sup>1</sup> Another puzzling pattern is the lack of correlation between current interest rate differentials and subsequent exchange rate changes, which results in forecastable excess returns in violation of the Uncovered Interest Parity (UIP) condition.<sup>2</sup> A third puzzle emphasizes the low correlation between real exchange rates and consumption differentials across countries, which violates the so-called [Backus and Smith \(1993\)](#) risk-sharing condition that appears in a large class of models. While the field has explored many theories that could explain these phenomena, there is little model-free empirical evidence to suggest which mechanisms are most likely at play in generating these patterns.

In this paper, we seek to uncover the main drivers of exchange rate fluctuations, using as little theoretical structure as possible. We find that there are two disturbances, both related to expectations of productivity growth, which account for more than half of real exchange rate variation. These disturbances drive the majority of risk-sharing and UIP failures and explain a large portion of fluctuations in macroeconomic quantities such as consumption, while still implying that the exchange rate appears “disconnected” according to standard metrics. These two disturbances, which we separately identify, consist of (i) a fundamental disturbance to technology, which people partially anticipate; and (ii) an expectational “noise” disturbance, which drives changes in expected technology *that never materialize*. We stress that responses to noise that we recover are consistent with a rational agent who has access to noisy (but unbiased) information about future, unproven technologies. Overall, our empirical results suggest that the three major exchanges rate “puzzles” are, to a large extent, driven by a common mechanism – noisy information about future productivity.

Our analysis proceeds in two steps. First, we seek a purely “agnostic” description of the comovement patterns associated with changes in exchange rates. To do this, we follow the VAR procedure of [Uhlig \(2003\)](#), and recover a set of orthogonal shocks ordered by their respective importance in explaining exchange rate variation. We find that the “first” shock

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<sup>1</sup>See for example [Meese and Rogoff \(1983\)](#) and [Engel and West \(2005\)](#) among others.

<sup>2</sup>The UIP puzzle has been central to the exchange rate literature since the seminal work of [Fama \(1984\)](#), see [Engel \(2014\)](#) for an excellent survey.

(i.e. the one most important to exchange rate dynamics) explains a full three-quarters of exchange rate variation, and roughly half of the variation in macro aggregates. The shock also generates all three celebrated exchange rate puzzles described above. Our first key observation is that, while this shock immediately impacts the exchange rate, its effect on macroeconomic quantities, with the exception of interest rates, are delayed. Thus, it only generates a correlation between exchange rates and *future* macro aggregates, but leaves exchange rates effectively “disconnected” from contemporaneous macroeconomic quantities. Moreover, the shock also drives significant variation in expected currency returns, generating both the classic UIP puzzle and the UIP “reversal” at longer horizons that has been emphasized by [Engel \(2016\)](#) and [Valchev \(2020\)](#).

This first step of our analysis intuitively suggests that exchange rates, which are a forward-looking asset price, are reacting to the arrival of “news” about future fundamentals. However, this agnostic procedure cannot tell us what, specifically, those news are about. One obvious hypothesis, that is often emphasized in the broader macro literature, is the possibility of news about future TFP. To explore this question further, we regress quarterly exchange rate growth on current, lagged and *future* TFP growth and indeed find that while contemporaneous and past TFP growth shows no relationship with exchange rates, TFP growth four and five years *in the future* explains roughly one fifth of exchange rate variation.

While this is a remarkable result, given the classic findings of exchange rate “disconnect,” this exercise is quite limited in scope because it can only capture expectations about future TFP that indeed materialize subsequently. Realistically, however, it is unlikely that markets have perfect advance information – in other words, the world is likely to be characterized by *noisy* expectations of future TFP, where some expectations simply do not come true. Think, for example, about the uncertainty in forecasting the productivity impact of the internet that markets faced back in the 90s. Certain expectations, like those of *pets.com*, certainly did not come to pass, although they had a substantial effect on asset prices in the short-run. In order to examine the hypothesis of noisy TFP expectations, we turn to the structural identification approach of [Chahrour and Jurado \(2021\)](#), which is specifically designed to distinguish and separately identify true technological disturbances that eventually change TFP and disturbances that influence expectations of productivity, but are unrelated to any eventual change in productivity.

Implementing this approach in our baseline VAR, we find that both of these types of disturbances, actual TFP changes and “noise” in TFP expectations, play an important role in driving exchange rates and in generating the three puzzles summarized above. First, each

type of disturbance accounts for roughly a quarter of the variation in real exchange rates by itself. Second, the Impulse Response Functions (IRFs) to both disturbances generate significant fluctuations in expected currency returns, in line with both the classic UIP puzzle of high interest rates forecasting domestic currency profits and the newly documented “reversal” in this forecastability pattern at longer horizons. Both sets of disturbances also cause conditional movements in exchange rates and (delayed) movements in aggregates that generate the Backus-Smith puzzle, and the exchange rate determination puzzle more broadly.

Importantly, the expectational (“noise”) disturbances we identify are *unpredictable* expectational mistakes, and hence are not evidence of a behavioral bias. Moreover, this “noise” disturbance is conceptually different from exogenous disturbances in the demand for foreign currency bonds, which is the typical way the previous literature has modeled “noise” in exchange rate. Thus, our results show that exchange rates, and three of their major associated puzzles, are indeed tightly connected to fundamentals, and in particular to the noisy expectations of future productivity.

We next decompose the exchange rate into two components, the paths of future interest differentials and expected excess currency returns, and find that the expectation-related disturbances we identify operate primarily through the excess return channel. This indicates that many unconditional exchange rate patterns, including predictable excess returns, low Backus-Smith correlations, and excess volatility, arise because of endogenous UIP deviations driven by fluctuations in TFP expectations. It is not clear which models might explain these empirical properties of exchange rate dynamics, as expectational noise disturbances have not been previously considered in the literature of UIP deviations.

To offer one possible explanation, the last part of the paper presents a dynamic general equilibrium model where UIP deviations are driven by convenience yield fluctuations. Convenience yields have been explored as a potential channel for generating empirically relevant UIP deviations at both short and long horizons (Engel, 2016; Valchev, 2020), however that previous literature only considered mechanisms driven by either direct shocks to demand for liquidity or standard, unanticipated contemporaneous monetary shocks. We propose a modified version of an endogenous convenience yield mechanism, which is driven by TFP expectational disturbances, and show that the model can indeed replicate virtually all of our empirical findings. As a result, this is a model that can deliver not just UIP violations, but also generate the Backus-Smith and exchange rate determination puzzles. We also confirm, empirically, the key model implication that the currency excess returns are driven by a specific pattern in the dynamics of relative government debt supply.

**Related Literature** This paper is related to several different strands of the international and macro literatures. On the empirical side, we speak to the exchange rate determination puzzle which refers to the lack of correlation between exchange rates and macroeconomic fundamentals, both contemporaneously and in terms of forecasting future exchange rates with current macroeconomic fundamentals (Meese and Rogoff, 1983; Cheung et al., 2005; Engel and West, 2005). There is also the related observation that the exchange rate is “excessively” volatile and persistent, as compared to macroeconomic fundamentals – see for example Obstfeld and Rogoff (2000), Chari et al. (2002), Sarno (2005), Steinsson (2008).

Our finding that there is a connection between exchange rates and macroeconomic fundamentals, but one that runs between current exchange rates and future fundamentals, is the opposite of the forecasting relationship between current and past macro variables and exchange rates, for which past studies find only weak evidence (Meese and Rogoff, 1983; Rogoff and Stavrageva, 2008). However, it is consistent with previous studies that have documented that exchange rates Granger-cause some macroeconomic quantities (Engel and West, 2005; Sarno and Schmeling, 2014).<sup>3</sup> Our results contribute to this discussion, by showing that the link between current exchange rates and future fundamentals runs specifically through imperfect foresight regarding future productivity. Moreover, our results show that imperfect foresight about productivity can explain the three most famous exchange rate puzzles – consistent UIP violations, low Backus-Smith correlations, and excess volatility.

A recent related paper is Stavrageva and Tang (2020), who use survey of expectations to measure the surprises in macroeconomic announcements. They find that the new information about past macroeconomic fundamentals that the market obtains upon a new statistical release is an important driver of exchange rate fluctuations, and one that is especially important for the portion of the exchange rate driven by expected future currency returns. Our definition of “news” is different, as we specifically identify disturbances to beliefs about *future* US TFP *innovations* (as opposed to revision of beliefs about past endogenous variables such as output), hence we document the importance of the arrival of information about *future* productivity developments is a significant driver of exchange rates and currency returns.

Relative to the papers discussed above, our results also specifically show a link between the imperfect information about the future and two seminal exchange rate puzzles – the UIP (Fama, 1984; Engel, 2014) and the Backus-Smith puzzles (Backus and Smith, 1993). Both

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<sup>3</sup>Lilley et al. (2020) find a contemporaneous connection between US purchases of foreign bonds and the dollar, but only in the post-2009 period. Such contemporaneous relationships have proven elusive over a longer time span.

puzzles have received extensive theoretical attention, and numerous potential mechanisms have been proposed as resolution of one or the other.<sup>4</sup> Such models, however, have typically relied on the standard assumption that agents have full information on current and past innovations to the exogenous shocks driving the economy, but no information on their future innovations. As a result, while the models are consistent with the pricing puzzles, they often run counter to the exchange rate “disconnect,” since shocks drive contemporaneous changes in both exchange rates and other macroeconomic quantities.

To confront this challenge, a new strand of the literature has emerged that has analyzed mechanisms that can generate the exchange rate pricing puzzles based on exchange-rate-market specific “noise trader” shocks that have only a muted effect on the broader macroeconomy (Eichenbaum et al., 2020; Itskhoki and Mukhin, 2021). This is a new and more elaborate take on the older idea that, given the exchange rate disconnect fact, UIP-specific or FX-risk shocks are a convenient and powerful way of generating empirically realistic exchange rate dynamics (Devereux and Engel, 2002; Jeanne and Rose, 2002; Kollmann, 2005; Bacchetta and van Wincoop, 2006; Farhi and Werning, 2012).<sup>5</sup> In particular, Itskhoki and Mukhin (2021) show such FX-noise shocks can generate not only the UIP puzzle, but also the general disconnect and the Backus-Smith puzzle.

Relative to this recent literature emphasizing the role of shocks to noise-trader FX-demand, our empirical results suggest that another promising avenue is to examine models with imperfect information about future productivity. While both paradigms feature a notion of “noise”, the two are conceptually different. In the case of the existing literature, the “noise shock” is an exogenous shift in the demand for one currency relative to another, with no structural interpretation or connection to macroeconomic fundamentals. Our results, instead, provide evidence of a disturbance that creates noise in the expectations of future fundamentals. Hence, while our notion of noise is also orthogonal to fundamentals at all leads and lags, agents do not know this in real time and react to it as if it carries information about future productivity. In that sense, it is both a disturbance about fundamentals, and one that is perceived as such by the agents.

Overall, our results suggest a mechanism that provides a comprehensive explanation of

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<sup>4</sup>For example, time-varying risk (Alvarez et al., 2009; Verdelhan, 2010; Bansal and Shaliastovich, 2012; Farhi and Gabaix, 2015; Gabaix and Maggiori, 2015), non-rational expectations (Gourinchas and Tornell, 2004; Burnside et al., 2011; Ilut, 2012; Candian and De Leo, 2021) and liquidity premia (Valchev, 2020) have been proposed as explanations of the UIP Puzzle. On the other hand, Corsetti et al. (2010), Colacito and Croce (2013), and Karabarbounis (2014) develop models that explain the Backus-Smith puzzle.

<sup>5</sup>Relatedly, Huo et al. (2020) find that international comovement between macro aggregates is also likely explained by non-fundamental shocks, though they do not speak to correlation with exchange rates

empirical exchange rate dynamics should be able to generate all major exchange rate puzzles conditional on the *same* disturbances related to imperfect foresight of future productivity. Models that can generate multiple exchange rate puzzles out of TFP disturbances are rare – one such model (albeit without pure anticipation effects of future productivity) is [Colacito and Croce \(2013\)](#). Nevertheless, that model also cannot generate the reversal of UIP at longer horizons and the associated “excess volatility” of the exchange rate, as we discuss further below.

Instead, our paper provides a model based on endogenous convenience yield fluctuations that can explain the full complexity of our empirical evidence. The model shares the insight that convenience yields can generate empirically appealing deviations from UIP with earlier papers such as [Engel \(2016\)](#), [Valchev \(2020\)](#) and [Jiang et al. \(2021\)](#). In all of these previous papers, however, the convenience yield mechanisms are driven by surprise, unexpected shocks, while in our model, the convenience yield is driven by expectational disturbances, in line with our empirical evidence.

Lastly, there is a small but growing literature specifically documenting the effects of “news shocks” in the international data and developing international RBC models driven in part by news shocks. That literature, however, has typically focused on the question of comovement between macro aggregates across countries, and not on exchange rate dynamics and related puzzles. In that vein, [Siena \(2015\)](#) argues that news shocks only lead to a small amount of comovement between macro aggregates across countries, contrary to previous evidence by [Beaudry and Portier \(2014\)](#). Perhaps most closely related to us is the work of [Nam and Wang \(2015\)](#), who use a [Barsky and Sims \(2011\)](#) approach to identifying news-to-TFP shocks, and find that they are indeed an important driver of exchange rates in the data. In contrast to us, however, they do not consider the effect of the shocks on exchange rate puzzles and also do not separately identify the effects of fundamental disturbances from those driven by expectations disturbances that are orthogonal to fundamentals. [Gornemann et al. \(2020\)](#) develop an international model of endogenous TFP growth, and show that it can account very well for the low frequency movements in real exchange rates, which speaks, in another way, to the importance of predictable TFP growth to exchange rate volatility and persistence.

# 1 Initial Empirical Analysis

We start with an agnostic empirical exercise that is meant to uncover the basic statistical properties of the “main exchange rate shock,” in a manner similar to the identification of the “main business-cycle shock” in [Angeletos et al. \(2020\)](#). This approach is agnostic as to the structural interpretation of the estimated “shock,” and simply pulls out the linear combination of underlying structural shocks that has the highest explanatory power for a variable of interest, which will be the real exchange rate in our case.

While this “shock” does not have an immediate structural interpretation, the results are quite informative about the basic structure of dynamic comovements that are statistically associated with shocks that have a significant impact on the exchange rate. In particular, we find that a robust feature of the data is that unexpected exchange rate changes are strongly associated with *future* movements in macro aggregates such as consumption and investment. Driven by these findings, we dig deeper in this connection to future fundamentals, and evaluate the specific hypothesis that the exchange rate reacts to US TFP news. Our findings there indicate that indeed, noisy anticipation of future US TFP growth can explain up to half of the variation in the real exchange rate.

Let us start with the initial, agnostic empirical analysis. Following [Uhlig \(2003\)](#) and [Angeletos et al. \(2020\)](#), we structure the analysis around a VAR of the data, given by

$$Y_t = C(L)Y_{t-1} + u_t \quad (1)$$

where the vector  $Y_t$  contains data on the US and a trade-weighted aggregate for the other G6 countries.<sup>6</sup> Specifically, the vector  $Y_t$  contains (i) the nominal exchange rate  $S_t$  expressed in units USD per foreign currency, (ii) the Fernald series on US-TFP cleaned out of endogenous components like utilization, (iii) US real consumption and investment, (iv) foreign real consumption and investment, (v) the interest rate differential, (vi) and the CPI price level differential vis-a-vis the US:

$$Y_t' \equiv \left[ \ln(S_t), \ln(TFP_t^{US}), \ln(C_t^{US}), \ln(C_t^*), \ln(I_t^{US}), \ln(I_t^*), \ln\left(\frac{1+i_t^{US}}{1+i_t^*}\right), \ln\left(\frac{CPI_t^{US}}{CPI_t^*}\right) \right]$$

We use quarterly data for the time period 1976:Q1-2008:Q2 for the G7 countries. The sample stops at the end of 2007 to guard against a possible structural break in the aftermath

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<sup>6</sup>In the Appendix we also report separate estimation results for each G7 country, including them in  $Y_t$  one at a time; results are consistent across all exchange rate pairs.



of the financial crisis, as argued by [Baillie and Cho \(2014\)](#) and [Du et al. \(2018\)](#). The foreign variables in  $Y_t$  are trade-weighted G6 averages, e.g. the exchange rate is the trade-weighted exchange rate of the US vis-a-vis the other G6 countries,  $C_t^*$  is the trade-weighted consumption of the other G6 countries, etc. We include four lags, and estimate the VAR via Bayesian methods using Minnesota priors.

As in standard VAR analyses, any “shocks” estimated by our analysis are a linear combination of the VAR innovations  $u_t$ . But instead of picking a linear combination based on some “ordering” of the sequence in which shocks affect variables (i.e. Cholesky identification) or sign restrictions, we follow [Uhlig \(2003\)](#) and look for the linear combination that has the highest explanatory power for exchange rate fluctuations.

Denote by  $Y_t = B(L)u_t$  the reduced-form moving average representation in the levels of the observable variables, formed by estimating the unrestricted VAR in equation (1). The relationship between reduced-form innovations and structural shocks is given by:

$$u_t = A_0 \varepsilon_t \quad (2)$$

which implies the following structural moving average representation:

$$Y_t = B(L)A_0 \varepsilon_t. \quad (3)$$

We assume that the structural shocks are orthogonal with unitary variance. Therefore, the impact matrix  $A_0$  has to satisfy the condition  $A_0 A_0' = \Sigma$ , where  $\Sigma$  is the variance-covariance matrix of innovations. This restriction is not sufficient to identify the matrix  $A_0$ . In fact, for any matrix  $A_0$  there exists an alternative matrix  $\tilde{A}_0$  such that  $\tilde{A}_0 D = A_0$ , where  $D$  is an orthonormal matrix, thus  $\tilde{A}_0$  also satisfies  $\tilde{A}_0 \tilde{A}_0' = \Sigma$ . Therefore, fixing a matrix  $\tilde{A}_0$  satisfying  $\tilde{A}_0 \tilde{A}_0' = \Sigma$  (e.g., the Cholesky decomposition of  $\Sigma$  is a convenient choice), identification boils down to choosing an orthonormal matrix  $D$ .

Denote the  $h$ -step ahead forecast error of the  $i$ -th variable  $y_{i,t}$  in  $Y_t$  by

$$y_{i,t+h} - \mathbb{E}_{t-1} y_{i,t+h} = e_i' \left[ \sum_{\tau=0}^{h-1} B_\tau \tilde{A}_0 D \varepsilon_{t+h-\tau} \right]$$

where  $e_i$  is a column vector with 1 in the  $i$ -th position and zeros elsewhere, and  $B_\tau$  is the matrix of moving average coefficients at horizon  $\tau$ .

The [Uhlig \(2003\)](#) approach consists of finding the column of  $D$  that isolates the shock

explaining most of the forecast error variance of  $y_i$ . Formally, we solve

$$d_1^* = \underset{d_1}{\operatorname{argmax}} \quad e_i' \left[ \sum_{k=0}^H \sum_{\tau=0}^{k-1} B_\tau \tilde{A}_0 d_1 d_1' \tilde{A}_0' B_\tau' \right] e_i$$

subject to  $d_1' d_1 = 1$ , where  $d_1$  is the first column of  $D$ . The problem is analogous to find the eigenvector associated with the largest eigenvalue of the appropriately rearranged objective function. This procedure involves a choice of forecast horizon  $H$ , which we set to 100 quarters to effectively extract the shock that explains most of the unconditional volatility of the exchange rate.

We report the estimated variance shares accounted for by the main exchange rate shock in the first column of Table 1.<sup>7</sup> Extracting this “main exchange rate shock”  $\varepsilon_{1,t}$ , we find that it is indeed very important for exchange rate fluctuations as it explains 69% of the variation in the real exchange rate. The fact that one shock can be so important to the exchange rate is perhaps intuitive, given the previous literature on the exchange rate disconnect (e.g. [Engel, 1999](#) and [Engel and West, 2005](#)), because it gives the impression that there is indeed an exchange-rate specific shock that accounts for most of the movements. From that point of view, however, one might expect that this shock will not be responsible for significant fluctuations in other macro variables.

However, this is not the case, as it turns out that this shock also explains a significant portion of the variation of the main macro aggregates included in our VAR – specifically it also accounts for almost half of the variance of consumption (both home and foreign) and a quarter of that of TFP.

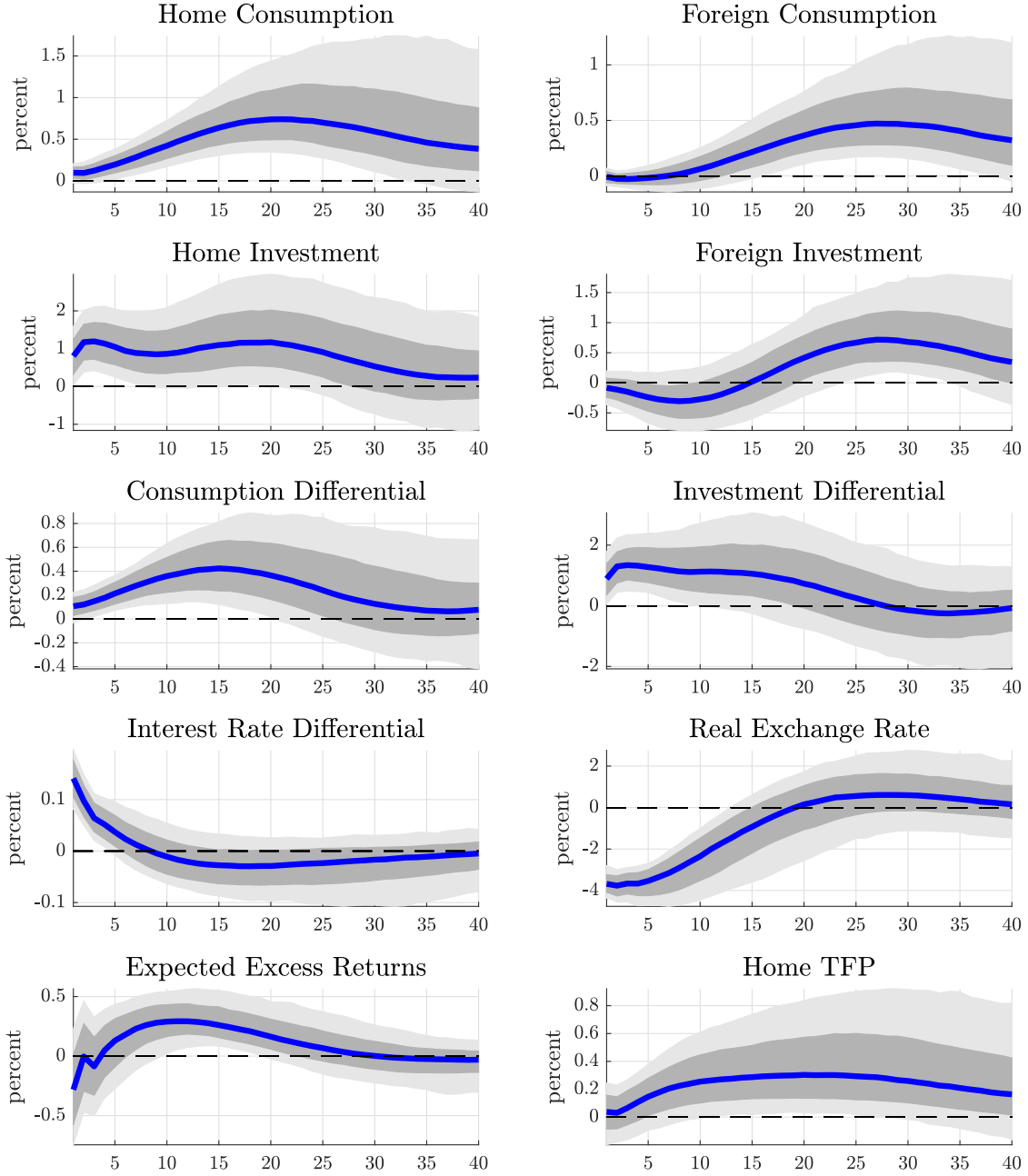
So what gives, in relation to the typical finding of “exchange rate disconnect”? It turns out that there is a difference in the *timing* of the response of exchange rates and the macro aggregates to this shock, with the exchange rate responding significantly on impact, while aggregate quantities only react with a lag. To showcase this, in Figure 1, we plot the impulse response functions of several key variables to this “main exchange rate shock”. The median impulse response is plotted with a dashed blue line, and the shaded areas around it are the 68% and 90% confidence intervals respectively. A number of notable results emerge.

First, the real exchange rate shows a significant response on impact, appreciating by about 3.5% after a one standard deviation increase in the MFX shock. The exchange rate also shows non-monotonic dynamics, remaining at its impact level for one year after the shock.

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<sup>7</sup>To guard against potential non-stationarity, we approximate the unconditional variance as the variance at all frequencies of up to and including 100 quarter periodicity.

Figure 1: Impulse Response Functions to the Main FX shock ( $\varepsilon_1$ )



*Notes:* The figure reports the impulse responses to the main FX shock, along with their 68% and 90% confidence intervals. All units are annualized percents. Each period is a quarter.

Thereafter, the exchange rate steadily depreciates back to its long-run mean. The non-monotonic dynamics we recover are similar to the ones previously emphasized by [Eichenbaum and Evans \(1995\)](#) and [Steinsson \(2008\)](#), and this results in a dynamic response that is very

persistent – with a half life of three to three-and-a-half years – in line with the “excess persistence” puzzle documented by previous studies.

Importantly, the non-monotonicity we estimate is driving a “reversing” or “cyclical” pattern in the deviations from uncovered interest parity, in line with the results of [Engel \(2016\)](#). Specifically, while the shock causes non-monotonic dynamics in the exchange rate, it leads to a monotonic impulse response in the interest rate differential, which increases on impact and gradually returns to its long-run mean. In addition, the shock also causes non-monotonic movements in the *expected* excess return,  $\mathbb{E}_t(\lambda_{t+1}) \equiv \mathbb{E}_t(\Delta q_{t+1} + r_t^* - r_t)$ , with the expectation being defined by the VAR in equation (1). Such predictable variation in the expected excess returns is a violation of the uncovered interest parity (UIP) condition.

In particular, our IRF estimates show that the initial sustained appreciation of the exchange rate leads to an increase in the expected excess return on the dollar – meaning that borrowing in foreign currency and investing in the USD makes money – precisely at times of elevated home (US) interest rates. This is a manifestation of the “classic” UIP Puzzle that currencies are expected to earn higher returns following an increase in their interest rate, or put another way, the observation that exchange rates do not depreciate enough to offset movements in interest rate differentials, leaving potential profit opportunities on the table. In fact, the IRFs show that  $r_t - r_t^*$  and  $\mathbb{E}_t(\lambda_{t+1})$  move in opposite directions at short horizons.

In addition, the eventual depreciation of the exchange rate causes a “reversal” in the UIP violation with the USD being expected to lose money against the foreign currency at horizons of 5 to 25 quarters in the future (which manifests in the the IRF of  $\mathbb{E}_t(\lambda_{t+1})$  turning significantly *positive* at such medium-term horizons). This is in-line with the recent evidence that the UIP puzzle is more involved than the basic observation that “high interest currencies make money,” as there are lower-frequency reversals in that relationship as exemplified by our impulse responses. The fact that the FX shock we identify can explain both the initial increase in excess returns and their eventual drop supports the hypothesis that there is a common driver behind that pattern (e.g. [Valchev, 2020](#)).

Overall, the results suggest that our different empirical procedure is indeed picking up a source of exchange rate variation that is responsible for important and familiar empirical patterns in the exchange rate.

The IRFs of the macro aggregates are crucial and reveling for the question at hand. The main FX shock we identify induces very little short-run movements in consumption; both home and foreign consumption only respond in quantitatively significant terms to the

Table 1: Share of variance explained by the Main FX shock ( $\varepsilon_1$ )

	Unconditional	Q1 $\Delta$	Q4 $\Delta$	Q12 $\Delta$	Q24 $\Delta$	Q40 $\Delta$
Home TFP	0.21	0.01	0.03	0.13	0.25	0.29
Home Consumption	0.39	0.04	0.06	0.24	0.47	0.46
Foreign Consumption	0.41	0.01	0.02	0.04	0.24	0.33
Home Investment	0.24	0.09	0.17	0.20	0.28	0.28
Foreign Investment	0.32	0.01	0.03	0.07	0.16	0.26
Interest Rate Differential	0.32	0.35	0.34	0.25	0.25	0.27
Real Exchange Rate	0.69	0.81	0.90	0.87	0.71	0.66
Expected Excess Returns	0.34	0.15	0.14	0.26	0.35	0.36
Consumption Differential	0.34	0.04	0.09	0.26	0.34	0.30
Investment Differential	0.29	0.09	0.19	0.22	0.24	0.24

*Notes:* The table reports the estimated variance shares accounted for by the main exchange rate shock, both unconditionally and at different horizons.

shock after a couple of years. The effect on both home and foreign consumption peaks at around 25 quarters in the future, with home consumption moving by a significantly bigger amount, achieving a peak of more than 1% increase while foreign consumption increases by about 0.6% at its peak. Interestingly, the effect on home TFP is similarly delayed, with the shock having an insignificant impact on productivity up to 5 quarters in the future, but eventually leads to a sustained 0.3% gain in home productivity. In anticipation of the stronger productivity, rational agents should increase investment. This is precisely what we observe in the impulse response of home investment.

The differences in the timing of effects can also be seen from a different variance decomposition exercise, where we consider what share of the  $h$ -step ahead forecast error of a given variable is explained by the main exchange rate shock for different horizons  $h$ , starting from 1 quarter and going up to 40 quarters (which is close to capturing all of the unconditional variation). These results are reported in columns two through five of Table 1. As can be expected given the shape of the IRFs in Figure 1, while this shock is equally important for both short-run and long-run exchange rate fluctuations, it only explains 4% and 1% respectively of the variation in quarterly growth of US and G6 consumption. In other words, it only affects the aggregates over longer horizons and with a delay.

Taken together, this evidence sheds important light on the “exchange rate disconnect puzzle,” as broadly construed. The dynamic comovement in Figure 1 suggests that the “disconnect” does not emerge because of a separation between FX and fundamentals, but

rather because of a difference in the timing of the responses of exchange rates and macro aggregates to the same macroeconomic surprise(s).

## 2 Expectations of Future TFP and Exchange Rates

One natural hypothesis, given the results so far, is that the “main exchange rate shock” captures news about future fundamentals. Such news will be immediately reflected in forward-looking asset prices like exchange rates, but will only have a delayed impact on macro aggregates, as the real developments that the news are about have not realized yet. The results of our agnostic exercise point towards the general direction of “news,” but do not necessarily tell us what specifically are those news about.

In the rest of the paper, we turn to evaluating the hypothesis that exchange rates are connected to news about future TFP specifically, even if they are only weakly connected to contemporaneous TFP innovations (as the previous literature suggests). Anticipated TFP has a rich modeling tradition in macroeconomics, and previous empirical studies have suggested that news or anticipation about TFP potentially plays an important role in business cycle fluctuations of the main macro aggregates (e.g. [Beaudry and Portier, 2006](#) and [Chahrour and Jurado, 2021](#)). But the empirical content of TFP expectations vis-a-vis exchange rates remains unexplored.

To start, we consider a simple exercise, where we regress the change in the real exchange rate at time  $t$  on leads and lags of the change in TFP. To save on degrees of freedom, we aggregate the leads and lags into annual TFP changes:

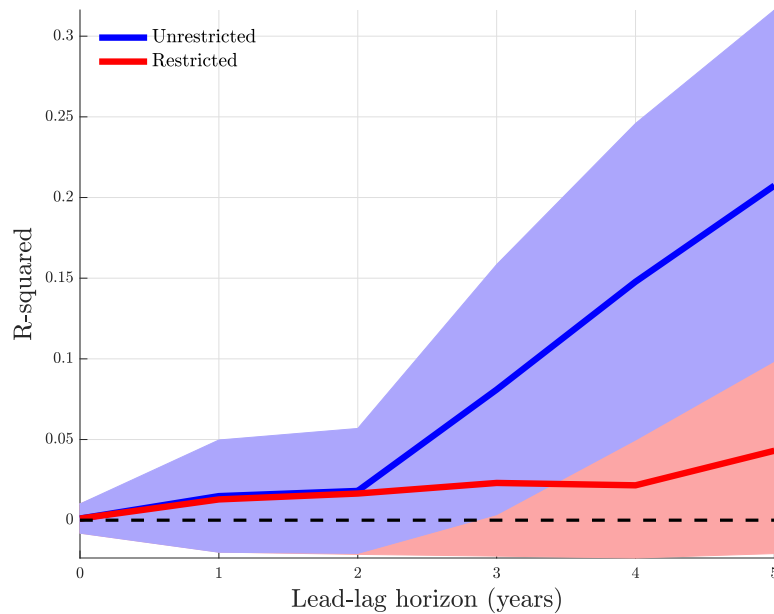
$$\Delta q_t = \alpha + \beta_0 \Delta TFP_t + \sum_{k=1}^h \beta_{-k}^{lag} (TFP_{t-4(k-1)} - TFP_{t-4k}) + \sum_{k=1}^h \beta_k^{lead} (TFP_{t+4k} - TFP_{t+4(k-1)}) + \varepsilon_t \quad (4)$$

Thus, if we include just the first two terms, we have a regression estimating the standard relationship between contemporaneous changes in the exchange rate and TFP, which we know from previous research is virtually nil. If we include the first summation term, then we also consider the additional (potential) explanatory power of lagged changes in TFP of up to  $h$ -years in the past. Lastly, once we include the second summation term, we also consider a potential relationship with *future* TFP changes, of up to  $h$ -years forward. Such a relationship might exist if the marginal investor has some information on likely future developments to TFP (e.g. some advance notice of the likely productivity of new technologies).

In Figure 2 we report the resulting  $R^2$  of two versions of the above regression – a “Re-

stricted” backward-looking version that only includes current and lagged TFP growth terms and an “Unrestricted” version that includes all terms on the right-hand side. The first version captures the typical direction of the relationship between TFP and exchange rates that the previous literature has focused on, and its resulting  $R^2$  (and its associated 90% confidence interval) are plotted with the red line and bands. The  $R^2$  of this purely backward looking regression is statistically insignificant no matter how many lags of TFP growth we include, embodying the typical “disconnect” result.

Figure 2: RER growth and leads and lags of TFP growth



*Notes:* The figure reports the  $R^2$  of a regression of exchange rate changes on present and past TFP (Restricted), and the  $R^2$  of a regression of exchange rate changes on present, past and future TFP (Unrestricted), depending on the number of lead/lags included in regression equation (4).

On the other hand, the result changes substantially once we also include terms capturing *future* TFP growth – the resulting  $R^2$  of this “Unrestricted” regression is plotted with the blue line. The relationship between FX and TFP growth is similarly insignificant if we only include TFP growth of up to 3 years in the future, but becomes highly significant once we include TFP growth four and five years out. Thus, the evidence speaks to the fact that exchange rates contain a substantial amount of information about future TFP growth in the medium-run to long-run.

While, we find an interesting relationship between current exchange rates and future TFP changes, this exercise is limited in scope because it can only capture expectations of future

TFP that are indeed actually realized. Realistically, however, it is unlikely that the advance information economic agents possess is perfect and always comes true – in other words, the world is likely characterized by *noisy* expectations of TFP, where some expectations do not come true. Think, for example, about the uncertainty in forecasting the productivity impact of new technologies such as the internet in the 1990s. Certain expectations, like those of *pets.com* did not come to pass, but they certainly affected asset prices in the short-run, before their true impact became clear. A substantial amount of noise in expectations could also help further clarify the “disconnect” puzzle, as such expectational noise is likely to drive asset prices in the short-run (before investors realize expectations were wrong), but will have little effect on macro quantities, as the fundamental productivity possibilities never change.

In order to separately identify and isolate this “noise” in expectations, we follow the recently developed identification approach of [Chahrour and Jurado \(2021\)](#). This approach is specifically designed to independently identify the “fundamental” disturbances driving realized changes in productivity and expectational “noise” disturbances, which explain changes in productivity forecasts that are never realized. We stress that the expectational “noise” recovered this way does not constitute a predictable bias in expectations, but is consistent with the paradigm of rational expectations. As explained below, estimating a significant noise in expectations component is instead evidence of noisy information, something that rational agents would optimally take into account and adjust expectations accordingly.

The [Chahrour and Jurado \(2021\)](#) approach to identification is especially well-suited for our question for several reasons. First, it separates the effects of actual changes in technology from the effects of “pure beliefs” by construction, a feature that is central to our objective in this paper, given the predominant view in the literature that “noise” matters for exchange rates. This contrasts with the family of “news shock” identification schemes, such as [Barsky and Sims \(2011\)](#), which necessarily commingle the effects of beliefs with fundamentals. Second, it avoids the assumption that the underlying structural data generating process has an invertible representation, which is often violated in models of economic foresight ([Blanchard et al., 2013](#)). Finally, as we discuss below, this procedure allows for an arbitrary structure for the fundamental process and for the signal thereof, so that we need make essentially no assumptions about what aspects of productivity people learn about, or when they do so.

To fix ideas, we present a simplified discussion of the [Chahrour and Jurado \(2021\)](#) procedure here. The main assumption is that agents in the economy receive a noisy signal  $\eta_t$  about future TFP, with the signal being *any* linear combination of future innovations



to TFP plus an orthogonal noise component  $v_t$ :

$$\eta_t = \sum_{k=1}^{\infty} \zeta_k \varepsilon_{t+k}^a + v_t,$$

where  $\varepsilon_{t+k}^a$  are the Wold representation innovations to the TFP process  $a_t$ :

$$a_t = A(L)\varepsilon_t^a. \quad (5)$$

Further assumptions on the particular structure of the TFP process or on the coefficients  $\zeta_k$  are not necessary. Moreover, the noise component of the signal is also allowed to have an arbitrary lag structure:

$$v_t = \sum_{k=1}^{\infty} \nu_k \varepsilon_{t-k}^v.$$

The assumptions of the [Chahrour and Jurado \(2021\)](#) procedure are that (i) the productivity disturbances  $\varepsilon_t^a$  explain 100% of the variation in TFP (i.e. they are indeed the Wold innovations in equation (5)) and (ii) the signal-noise innovations  $\varepsilon_t^v$  are orthogonal to TFP at all leads and lags. In the case of a two-variable var in  $[a_t, \eta_t]$ , the restrictions we impose amount to placing zeros in the MA representation of the data in the following:

$$\begin{bmatrix} a_t \\ \eta_t \end{bmatrix} = \dots + \begin{bmatrix} 0 & 0 \\ * & 0 \end{bmatrix} \begin{bmatrix} \varepsilon_{t+1}^a \\ \varepsilon_{t+1}^v \end{bmatrix} + \begin{bmatrix} * & 0 \\ * & * \end{bmatrix} \begin{bmatrix} \varepsilon_t^a \\ \varepsilon_t^v \end{bmatrix} + \begin{bmatrix} * & 0 \\ * & * \end{bmatrix} \begin{bmatrix} \varepsilon_{t-1}^a \\ \varepsilon_{t-1}^v \end{bmatrix} + \dots$$

In words, this structure imposes that the productivity series  $a_t$  is orthogonal to the signal noise disturbances  $\varepsilon_t^v$  at all leads and lags, while the signal  $\eta_t$  can contain information about future productivity  $\varepsilon_{t+k}^a$ .

This strategy has several benefits. First, it separately identifies the fundamental disturbances,  $\varepsilon_{t+k}^a$ , from the “noise” component of expectations,  $v_t$ . By examining the responses of economic variables, like the exchange rate, to the “fundamental” disturbance  $\varepsilon_{t+k}^a$ , we therefore see an indication of how (and if) fundamental disturbances are anticipated. By examining responses to the second type of disturbance,  $\varepsilon_t^v$  we learn how much of economic fluctuations are associated with movements in expectations that are completely orthogonal to productivity – e.g. misplaced optimism or pessimism (but again in the form of a rational mistake, not a behavioral bias). This is especially useful for deriving insights that can guide model development, as the estimates can help recover the information sets of economic

agents, and thus put tight restrictions on the modeling framework and its parameters.

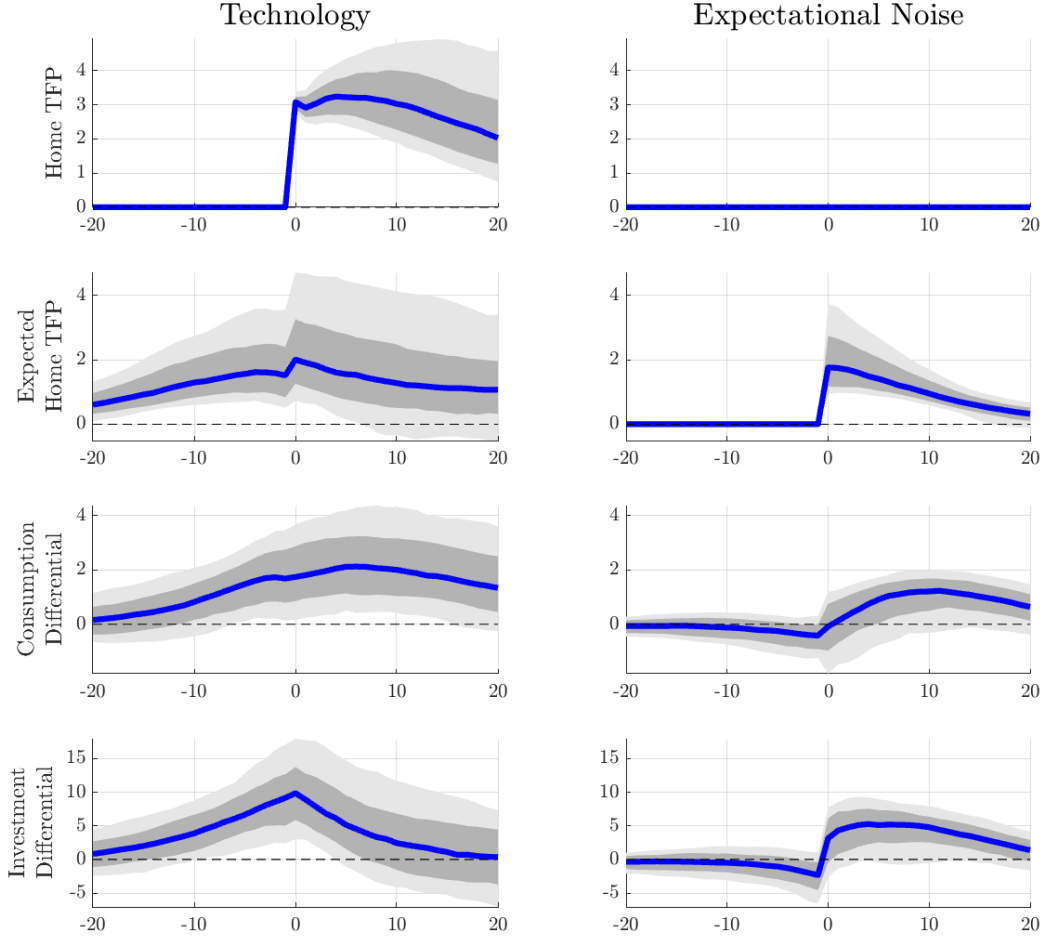
Second, in practice, we do not need to directly observe the agents’ expectations or actual signals  $\eta_t$ . Instead, we rely on (i) the assumption of rational expectations, which implies that the equilibrium variables load on agents’ information, and (ii) that our VAR empirical specification includes enough forward looking variables (in our case not just the exchange rate, but also consumption, interest rates, and prices, which are all “jump” variables in an equilibrium framework) so as to be able to fully span the relevant part of the agents’ information set (i.e. all information relevant to predicting future TFP). Under these auxiliary assumptions, we can identify the fundamental and noise disturbances without making further assumptions about the information structure in the economy, and expectations of any variables in the system can be backed-out using the dynamics implied by the VAR.

**Conditional dynamics** In Figures 3 and 4 we plot the estimate Impulse Response Functions (IRFs) to the separately identified fundamental technological disturbance ( $\varepsilon_t^a$ , left column) and the expectational noise disturbance ( $\varepsilon_t^e$ , right column). As opposed to a standard IRF plot, we start the picture 20 quarters *before* the respective innovation (either  $\varepsilon_t^a$  or  $\varepsilon_t^e$ ) realizes, because the basic hypothesis is that  $\varepsilon_t^a$  is not a pure surprise, but is rather (partially) anticipated. The extent to which this anticipation is true in the data can be evaluated by seeing whether the estimated IRFs respond significantly to  $\varepsilon_t^a$  before its actual realization. In our figure, we plot the  $x$  axis in terms of the quarters before and after the realization of the TFP increase, with 0 denoting the period of realization. Hence, anticipation effects are equivalent to statistically significant IRFs in periods between  $-20$  and  $-1$ . Lastly, we stress that whether or not the endogenous variables respond before productivity actually moves is not assumed but *estimated*. If the estimates show no significant early response of these variables, this would constitute clear evidence against the hypothesis of expectational effects of productivity.

In the first row of Figure 3, we again plot the impulse response of the Home TFP series itself, and we can see that, as expected, the technology disturbance  $\varepsilon_t^a$  only affects TFP from period 0 onwards (since this is its Wold innovation), while the information noise disturbance has no effect on actual TFP at any horizon. We also note that the TFP process appears to be highly persistent with some, but relatively weak, evidence of mean reversion.

To help with the interpretation of our results and IRFs, in the second row of Figure 3 we also plot the response of the estimated agents’ expectation of 20-quarter-ahead productivity  $\mathbb{E}_t(a_{t+20})$ . In the left-column, we can see that the expectations of Home TFP are signifi-

Figure 3: Impulse responses to Technology ( $\varepsilon^a$ ) and Noise ( $\varepsilon^v$ ) disturbances



*Notes:* The figure displays how macroeconomic aggregates respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ . The shaded area are the 68% and 90% confidence intervals. All units are annualized percents. Each period is a quarter.

cantly higher than their long-run mean up to *twenty* quarters before the actual technology disturbance  $\varepsilon_t^a$  is realized. This showcases that the data speaks strongly in favor of anticipation effects, and thus supports the idea that agents have some advance information of future TFP. This information is, however, noisy and imperfect, which can be inferred from the fact that the “noise” disturbance (which is by construction orthogonal to TFP at all leads and lags) also moves expectations up. Thus, our estimates indeed strongly support a

noisy-information paradigm, where agents do have some advance information and thus *partially* anticipate future movements in TFP, yet that information is noisy hence expectations sometimes move even though there is no actual future increase in productivity. We can see a similar dynamic play out in the IRF of the consumption differential. There are significant anticipation movements in US consumption relative to foreign up to 10 quarters before the actual increase in productivity is realized, with the consumption differential increasing smoothly and staying high after productivity actually ticks up. On the other hand, there is not anticipation of the expectational noise disturbance, but once the noise disturbance arrives there is similarly a persistent boom in favor of US consumption. Thus, optimistic expectations about future TFP lead to an increase in consumption today. The quantitative impact of the noise disturbance is very similar to the early (i.e.  $t - 5$ ) anticipation effects in response to the technology disturbance, with consumption increasing by roughly 1.5pp more in the US than in the G6. This is natural, given that no matter how optimistic expectations are today, the actual improvement of technology has not arrived yet, hence the resource constraint of the economy has not been loosened.

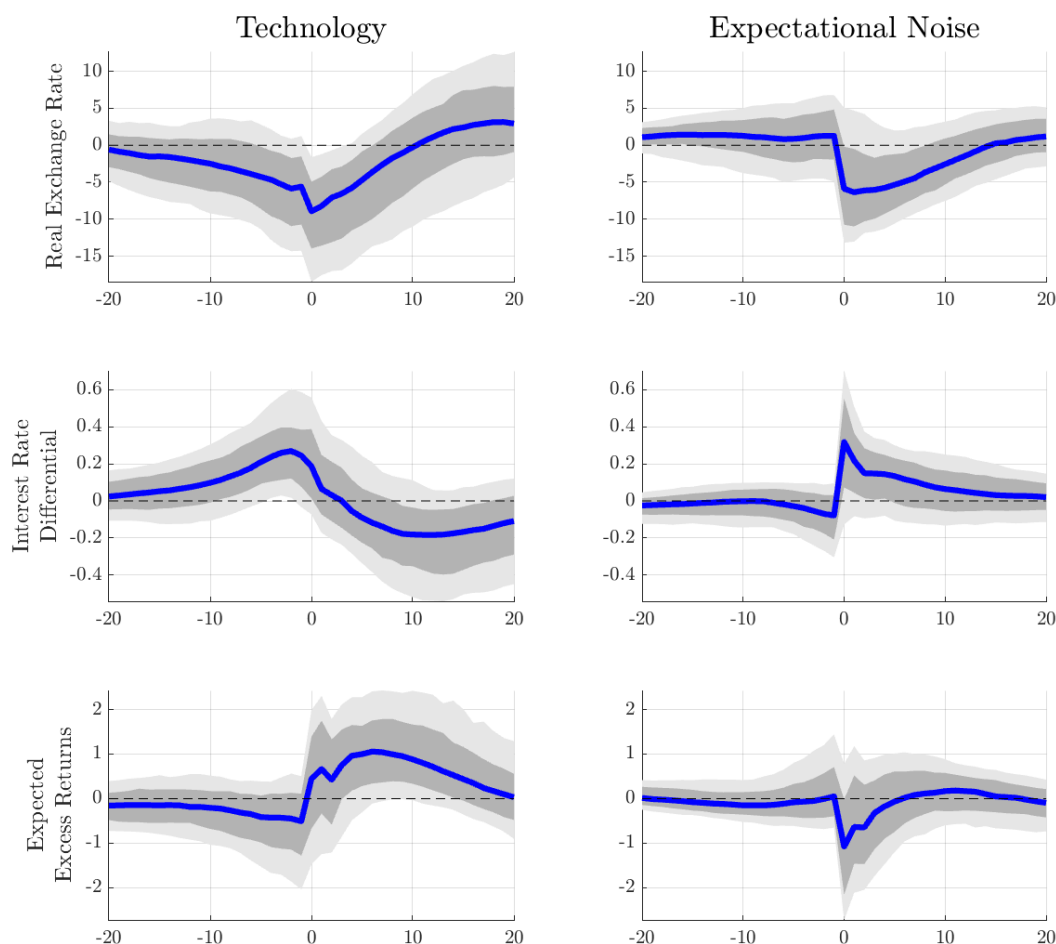
Figure 4 depicts the impulse response functions of the real exchange rate, interest rate differential and the expected currency returns. As expected given the consumption results, the real exchange rate similarly shows anticipation effects, although those are significant much closer to the actual date of the technological improvement – with the real exchange rate appreciating about 5% around 5 quarters before an one standard deviation increase in actual productivity. The peak appreciation of around 10% occurs concurrently with the increase in productivity, and then the exchange rate gradually depreciates back to its mean.

The exchange rate similarly appreciates when expectations of future TFP improve due to a noise disturbance. In that case, the peak impact of 6% is achieved immediately, and then the exchange rate gradually depreciates back to its mean as agents learn gradually that their optimistic beliefs are in fact incorrect.

The interest rate differential similarly shows anticipation effects, gradually increasing up to a peak of around 0.3% around 2 quarters before the actual increase in productivity, then quickly falling below its long-run mean shortly after the TFP increase realizes, and then increasing back to its steady state. A noise disturbance that increases expectations of future productivity similarly increases interest rates immediately and temporarily.

Lastly, we find that the expected excess currency return is depressed and below its mean up to 8 quarters before an actual increase in productivity. Once the productivity improvement realizes, the expected excess return rises quickly, and is significantly above its long-run

Figure 4: Impulse responses to Technology ( $\varepsilon^a$ ) and Noise ( $\varepsilon^v$ ) disturbances



*Notes:* The figure displays how interest rate differential and real exchange rate respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ . The shaded area are the 68% and 90% confidence intervals. All units are annualized percents. Each period is a quarter.

mean for horizons of 4 to 12 quarters following the increase in productivity. The expectational noise disturbance also affects the expected excess returns significantly, with an increase in expected future US productivity leading to sharply lower expected USD returns. The effect is temporary (again as agents learn that the disturbance was indeed simply noise), and returns to steady state after around 4 quarters.<sup>8</sup>

<sup>8</sup>While it might not be immediately obvious, the dynamic responses to  $\varepsilon^a$  and  $\varepsilon^v$ , together, almost per-

**Variance decomposition** Let us now turn to analyzing the respective shares of the variances of the key variables of interest that these two disturbances can explain. The results are reported in Table 2.

Table 2: Variance Decomposition

	Composite	Technology	Exp. Noise
Home TFP	1.00	1.00	0.00
Home Consumption	0.70	0.52	0.18
Foreign Consumption	0.61	0.48	0.13
Home Investment	0.60	0.44	0.16
Foreign Investment	0.64	0.41	0.24
Interest Rate Differential	0.50	0.36	0.13
Real Exchange Rate	0.59	0.39	0.20
Expected Excess Returns	0.50	0.36	0.14

*Notes:* The table reports the estimated variance shares (at periodicities between 2 and 100 quarters) explained by technological disturbances (Technology), expectational disturbances (Exp. Noise), and the combination of both (Composite).

As expected, the technological disturbance we estimate,  $\varepsilon^a$ , accounts for 100% of the variation in TFP, while the expectational noise disturbance is completely orthogonal to it. Besides, the estimates indicate that the technological disturbance explains 52% of the variation in US consumptions, and 48% of the variation in foreign (G6) consumption, while the expectational noise disturbance explains 18% of the variation in US consumption and about 13% of the variation in foreign consumption. Thus, consumption is not driven only by the actual productivity disturbance, but also by disturbances to the expectations of future TFP.<sup>9</sup>

Intuitively, one would expect this latter expectational effect to also have an impact on asset prices. And indeed, Table 2 reveals the shares of the variation in exchange rate (the international asset price of key interest to this study) that are driven by those two disturbances. In the second column, we see that disturbances to productivity are indeed significantly related to the exchange rate and explain 39% of its fluctuations. In the third column, we see

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fectly capture the dynamic exchange rate behavior that the agnostic, Uhlig (2003)-based approach recovered in the previous section. For more details see Appendix A.

<sup>9</sup>Our results about the macro aggregates are very similar to the ones reported in Chahrour and Jurado (2021), where they identify the two disturbances based on domestic US data only.

that expectational noise disturbances are also quantitatively important, explaining another 20% of the exchange rate variation. Thus, disturbances to TFP and expectations of future TFP can account for more than one half of the total variation in the real exchange rate. We find a similar split in the importance of the two disturbances for the interest rate differential, with actual productivity disturbances explaining 36% and the expectational noise disturbances explaining 13% of the interest rate differential fluctuations.

Moreover, these disturbances together explain roughly half the variations in expected currency returns – 36% by TFP disturbances and another 14% by disturbances to TFP expectations. Thus, these two disturbances are affecting the exchange rate not just through variation in interest rate differential, but also by affecting currency returns, which we know to be quite volatile and important to understand. In fact, as we explain below, we find that these two disturbances indeed affect the exchange rate primarily through the expected excess returns channel.

Lastly, we want to quantify the overall role of TFP expectations. To do so, we examine how much of the variation in the exchange rate that our two disturbances can generate (59%) is accounted for by the combination of (i) anticipation of future TFP disturbances and (ii) disturbances to the expectation of future TFP. This specifically answers the question of how much of the exchange rate variation is due to expectations of future productivity. To do so, we use the VAR to simulate an economy with technology and noise disturbances only and compute the  $1 - R^2$  after regressing the change in exchange rate on present and past technological disturbances. We find that roughly two-thirds of the identified exchange rate variation is due to disturbances about future outcomes and expectations, and only one third of the exchange rate variation can be attributed to current and past productivity disturbances.

### 3 Exchange rate puzzles and TFP anticipation

Given the large effect our two identified disturbances play in exchange rate dynamics, it is interesting to consider whether the disturbances are also driving some or all of the three broad exchange rate puzzles we outlined in the beginning. Namely, (i) the UIP puzzle and its reversal, (ii) the Backus-Smith puzzle, and (iii) the exchange rate determination puzzle.

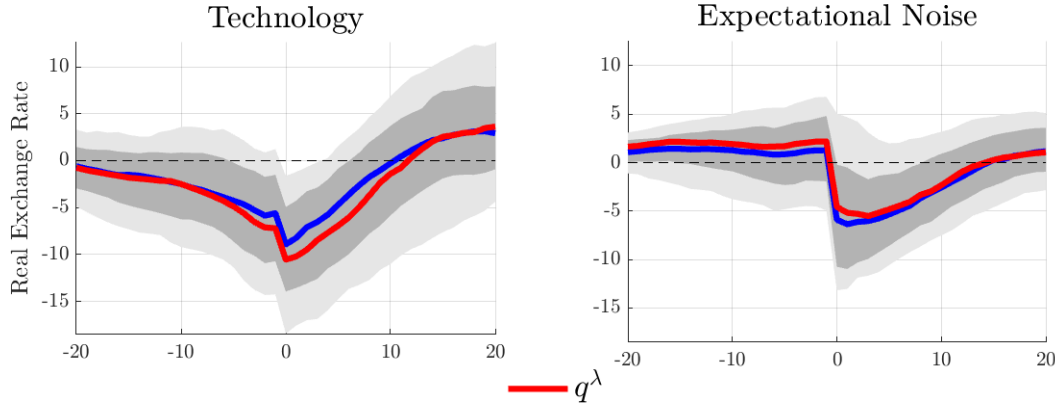
**Deviations from Uncovered Interest Parity** Starting with the UIP puzzle, we can drill down into the exchange rate dynamics further, by decomposing it into its two components:

the one driven by future expected real interest rates and the one driven by future expected excess returns.

$$q_t = - \underbrace{\sum_{k=0}^{\infty} \mathbb{E}_t(r_{t+k} - r_{t+k}^*)}_{=q_t^{UIP}} - \underbrace{\sum_{k=0}^{\infty} \mathbb{E}_t(\lambda_{t+k+1})}_{=q_t^{\lambda}}$$

We call the first component, the one exclusively driven by the interest rate differentials,  $q_t^{UIP}$  to signify that this is a counter-factual exchange rate path that would respect the UIP condition. The actual exchange rate is of course different, because UIP is violated and hence  $\mathbb{E}_t(\lambda_{t+1}) \neq 0$ . To get a sense of the separate impact of our disturbances on the exchange rate through the two channels, in Figure 5 with the red line we plot the portion of the exchange rate driven exclusively by UIP violations:  $q_t^{\lambda} = q_t - q_t^{UIP}$ .

Figure 5: Exchange rate puzzles



*Notes:* The figure displays how real exchange rate and its expected-excess-return component respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ . The shaded area are the 68% and 90% confidence intervals for the real exchange rate response. All units are annualized percents. Each period is a quarter.

As we can see, this quantity displays significant variation both in the anticipation and the realization phase of actual TFP disturbances, and in response to expectational noise disturbances. In fact, in both the left and the right column we see that the overall response of the exchange rate (blue line), is primarily driven by the response and dynamics of  $q^{\lambda}$  itself. In the case of the expectational disturbance, the blue and red line are virtually overlapping, signifying that there is very little response of the exchange rate to the expected future path of interest rate differentials – which is consistent with the fact that the effect on interest



rate differentials is very short-lived. On the other hand, in response to a TFP innovation  $q^\lambda$  appears to “over-react” as compared to the blue line, signifying that the effect of the interest rate differential path is in fact opposite of what we see in the dynamics of the exchange rate. Put differently, if excess returns had not reacted, the exchange rate would have a depreciating pattern. Overall, we can conclude that the identified disturbances to TFP and TFP expectations we recover are indeed affecting the exchange rate predominantly through the UIP deviations channel.

Having established that our disturbances drive significant and important variation in expected excess currency returns, we next examine if this excess return fluctuations correspond to common findings in the previous literature. We start with the “classic” UIP puzzle that high interest rates predict high currency returns, in the sense that the seminal [Fama \(1984\)](#) UIP regression:

$$\lambda_{t+1} = \alpha + \beta_{UIP}(r_t - r_t^*) + u_t$$

where one typically recovers an estimated coefficient  $\beta_{UIP} < 0$ . In our raw data, in the case of the G7 average we find a significantly negative  $\beta_{UIP}$  of  $-2.27$ , in line with previous findings (e.g. [Engel, 2014](#)). Next, we compute the resulting  $\beta_{UIP}$  in a counter-factual dataset where only the two disturbances we identified,  $\varepsilon^a$  and  $\varepsilon^v$ , are active. To obtain this, we simulate our estimated VAR by setting the variance of all other disturbances to zero.

In this counter-factual dataset, we find  $\beta_{UIP} = -2.37$ , revealing that the combination of disturbances to TFP and to expectations of future TFP qualitatively and quantitatively reproduces the classic UIP Puzzle relationship. Drilling down further, we construct similar counter-factual  $\beta_{UIP}$  based on either only-TFP disturbances (including anticipation effects) and only expectational noise disturbances. The results imply that the TFP disturbances by themselves generate a  $\beta_{UIP}$  of  $-2.37$ , while the  $\beta_{UIP}$  based on only expectational disturbances is  $-2.52$ . These results, and others that we discuss below, are reported in [Table 3](#).

In addition to this “classic” UIP Puzzle, the conditional responses of the exchange rate to our identified disturbances also exhibit the [Engel \(2016\)](#) puzzle that the UIP puzzle essentially “reverses” direction at longer horizons. Namely, it is now well known that while the [Fama \(1984\)](#) regression finds a negative association between interest rate differentials and one quarter ahead currency excess returns, the correlation between today’s interest rate differential and currency excess returns 2+ years into the future is actually *positive*.

As a summary statistic of this phenomenon, we consider the [Engel \(2016\)](#) regression

Table 3: Exchange Rate Related Puzzles and TFP Expectations

	Technology	Exp. Noise	Composite	Unconditional
Fama $\beta_{UIP}$	-2.37	-2.52	-2.37	-2.27
Engel $\beta_\Lambda$	13.75	17.56	14.77	15.03
$\sigma(r_t - r_t^*)/\sigma(\Delta q_t)$	0.20	0.10	0.15	0.11
$autocorr(r_t - r_t^*)$	0.96	0.82	0.92	0.81
$corr(\Delta q_t, \Delta(c_t - c_t^*))$	-0.24	-0.36	-0.33	-0.09
$autocorr(\Delta q_t)$	0.54	0.20	0.32	0.15
$autocorr(q_t)$	0.97	0.93	0.96	0.95
$\sigma(\Delta q_t)/\sigma(\Delta c_t)$	5.56	9.25	7.03	7.17

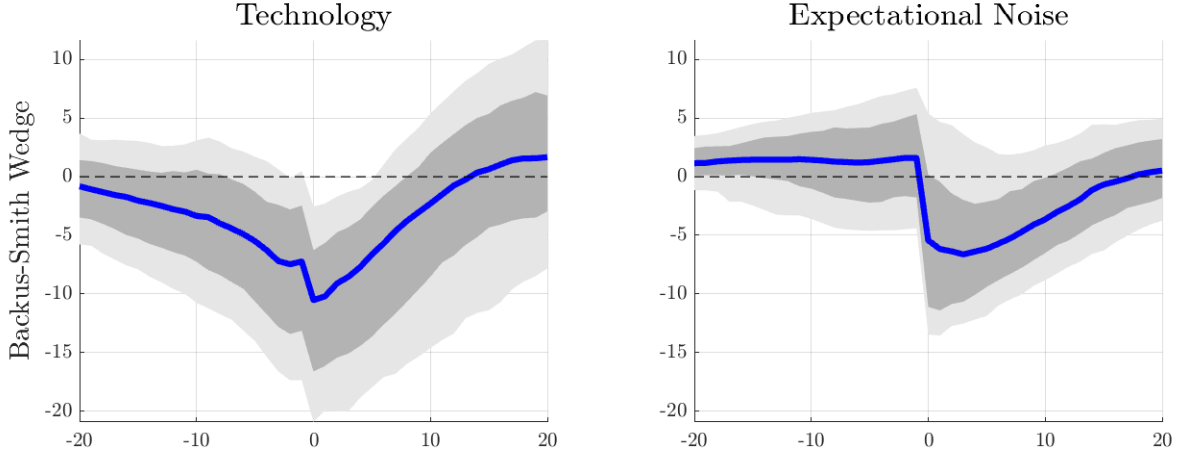
*Notes:* The table reports the estimated moments conditional on technological disturbances (Technology), expectational disturbances (Exp. Noise), and the sum of both disturbances (Composite), along the moments estimated on raw data (Unconditional).

$$\underbrace{\sum_{k=0}^{\infty} \mathbb{E}_t(\lambda_{t+k+1})}_{=-q_t^\lambda} = \alpha_0 + \beta_\Lambda(r_t - r_t^*) + \varepsilon_t$$

In our full sample, we find  $\beta_\Lambda = 15.03$ , which signifies that there must be many horizons  $k > 1$  such that  $Cov(\lambda_{t+k+1}, r_t - r_t^*) > 0$ , given that  $\beta_{UIP} < 0$ . In our counter-factual simulation where both of the disturbances we identify are active, we find  $\beta_\Lambda = 14.77$ , thus these two disturbances can indeed generate the reversal in the UIP puzzle as well. Drilling down further, we see that the dynamic comovements generated by either noise and TFP disturbances individually, are also in line with this puzzle, hence this “reversal” is not a result of just one or the other.

Lastly, it is worth noting that these two disturbances not only generate empirically relevant regression  $\beta$ ’s, but the underlying dynamics of the interest rate differentials (the regressor in these UIP regressions) are also very much in line with the raw data. Hence, obtaining UIP regression coefficients of the same magnitude as in the raw data indeed suggests that the puzzling predictability patterns in excess currency returns that have been identified over the years are largely driven by disturbances to TFP and its expectations.

Figure 6: Exchange rate puzzles



*Notes:* The figure displays the Backus-Smith Wedge responds to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ . The shaded area are the 68% and 90% confidence intervals. All units are annualized percents. Each period is a quarter.

**Risk-sharing Puzzle** Next we turn to the Backus-Smith risk-sharing puzzle. As a first step we consider the IRF of the Backus-Smith “wedge” defined as

$$\text{BS Wedge}_t = \Delta q_t - (c_t - c_t^*)$$

The impulse responses of that variable with respect to a technological and an expectational disturbance are both reported in Figure 6. We can again see a significant anticipation effect in response to the actual TFP disturbance, with the wedge being significantly negative as early as 10 quarters before the actual TFP improvement. The fact that the wedge is negative, means that in anticipation of a US TFP improvement, the dollar does not depreciate sufficiently to offset the gap in the consumption differential (which is positive, as we can infer from the consumption IRFs). This is also directly obvious from Figure 4, where we see that in anticipation of the US TFP improvement the dollar is in fact *appreciating* even though US consumption is high – the opposite of the Backus-Smith implied relation. After the realization of the US TFP improvement, the wedge adjusts gradually towards zero.

The expectational noise disturbance also causes significant effects on the BS Wedge. On impact of heightened expectations of high future productivity, the wedge also moves sharply negative and then converges back to zero over 15-quarters. Thus again, optimistic

expectations of future TFP leads to a situation where the exchange rate does not depreciate sufficiently to offset the resulting boom in domestic consumption.

Overall, this shows that the two disturbances we recover with the [Chahrouh and Jurado \(2021\)](#) procedure are responsible for significant and volatile deviations from the perfect risk-sharing condition of [Backus and Smith \(1993\)](#). To examine this result from a different angle, we also evaluate what has become the benchmark Backus-Smith Puzzle moment

$$\text{Corr}(\Delta q_t, c_t - c_t^*)$$

in the counter-factual simulations based on only two identified disturbances, and compare the resulting moment to the Backus-Smith correlation in the raw data. The results are presented in Table 3.

As is well known from previous research the correlation in the raw data is roughly zero,  $-0.09$  in our sample, while a standard [Backus et al. \(1992, 1994\)](#) model would imply that the correlation should be one. In the counter-factual sample driven by only the two disturbances we identify, the correlation is in fact even further away from one, and equals  $-0.33$ . Thus, the disturbances to TFP and its expectations tend to drive an even bigger risk-sharing wedge than what one can see in the unconditional moments, suggesting that to all other disturbances, the exchange rate indeed responds in a way consistent with a substantial degree of risk-sharing. In other words, understanding the Backus-Smith puzzle also likely boils down to understanding the mechanisms through which the exchange rate responds to disturbances to future TFP.

Thus, overall we find that the disturbances to TFP and its expectation are indeed major drivers of the so called Backus-Smith puzzle as well.

**Excess Volatility and Persistence** Lastly, another set of exchange rate features that are commonly emphasized as “puzzling” are the excess persistence and volatility of the real exchange rate. In both cases, the puzzle is that standard models do not deliver exchange rates that are nearly persistent or volatile enough to match the data. We cannot speak to a specific model, yet, but we are still interested to what extent the high persistence and volatility found in the data might be accounted for based on exchange rate responses to disturbances to TFP and its expectations.

In Table 3, we consider three moments: First, the autocorrelation of quarterly exchange rate changes; second, the autocorrelation of the level of the exchange rate; and third, the

ratio of the standard deviation of quarterly FX changes and consumption growth. The first result is that the exchange rate dynamics conditional on the two disturbances we extract are indeed highly persistent. In the counter-factual simulation with both disturbances active, the autocorrelation of the exchange rate is 0.96 as compared to 0.95 unconditionally, and the autocorrelation of the first difference of  $q_t$  is 0.32 versus 0.15 in the unconditional data. However, while both the actual TFP disturbance and the expectational noise disturbance generate high persistence in the level of the exchange rate, the persistence in the growth rate of the exchange rate is primarily driven by the TFP disturbances themselves.

Lastly, we find that exchange rate growth is indeed highly volatile relative to consumption growth – that ratio is around 7 conditional on the two disturbances we identify as well as in the raw data. This volatility appears to be mostly driven by expectational disturbances, which generate a ratio of around 9.

**Takeaways** Overall, our results indicate that the vast majority of exchange rate variation is in fact closely connected to macroeconomic fundamentals, however, the connection is primarily with *future* fundamentals. Moreover, we find that this connection appears to run primarily through a mechanism of imperfect foresight about future TFP.

Interestingly, the link between TFP fundamentals and noise in expectations thereof runs specifically through *UIP deviations*, as those two disturbances cause significant fluctuations in expected currency returns, which dominate the resulting exchange rate dynamics. Combined with our additional results that the two identified disturbances are also significant drivers of the Backus-Smith and excess volatility and persistence puzzles, this suggests that imperfect foresight might be a common source of both exchange rate fluctuations and puzzles.

Thus, there is promise that a model driven solely by TFP and noisy expectations thereof can help explain a number of exchange rate puzzles, and generate empirically realistic exchange rate volatility.

## 4 Model

Given the key empirical results summarized above, a successful model would have a mechanism of endogenous UIP deviations that are driven by disturbances to noisy TFP expectations, in a way that replicates the conditional dynamics we have estimated thus far. In this section, we develop a dynamic general equilibrium model that rationalizes the observed empirical comovements. The mechanism for UIP deviations we rely on is time-varying bond

convenience yields, which have been proposed as potentially powerful and empirically relevant explanation of the UIP puzzle by previous work such as [Engel \(2016\)](#) and [Valchev \(2020\)](#). However, that previous literature has primarily relied on either exogenous shocks to liquidity or standard, unanticipated monetary shocks as the primary driver convenience yield fluctuations. Our empirical results suggest that these sorts of shocks cannot be whole story. Hence, in this section, we design a revised model where the mechanism is driven by disturbances to noisy TFP expectations, as we have recovered from the data in the previous sections.

## 4.1 Environment

We introduce a standard New-Keynesian open-economy model with two symmetric countries, denoted with H (Home) and F (Foreign). In each country, there is a continuum of households, monopolistically competitive producers, a monetary authority, a fiscal authority, and financial intermediaries. Each country specializes in the production of one type of tradable goods, produced in a number of varieties, with measure equal to the population size. All goods are traded and consumed in both countries. Prices are sticky and set in the currency of the producer. In this context, the law of one price holds, but deviations of the real exchange rate from purchasing-power parity arise because of home bias in consumption preferences.

There are two departures from the standard setting. First, agents hold imperfect information about future TFP. Second, there are equilibrium deviations from UIP due to time-varying convenience yields on government bonds.

**Households** The utility function of the representative household in country H is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{C_t^{1-\sigma} - 1}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \right), \quad (6)$$

where  $\beta$  is the discount factor,  $\eta$  is the inverse of the Frisch elasticity of labor supply and  $\sigma$  denotes the inverse of the intertemporal elasticity of substitution. Thus, households derive utility from consumption,  $C_t$ , and experience disutility from working, where  $L_t$  represents hours worked in the production of domestic varieties.

The representative household uses its revenues in every period to purchase consumption goods or invest in local deposits,  $D_{H,t}$ . These deposits offer a gross return of  $1 + i_t$  (which

corresponds to the gross return on government bonds). The domestic household's budget constraint can be written as:

$$P_t C_t + D_{H,t} \leq W_t L_t + (1 + i_{t-1}) D_{H,t-1} + \Pi_t - T_t. \quad (7)$$

Here,  $W_t$  is the wage,  $\Pi_t$  denotes the nominal profits of domestic firms, and  $T_t$  are government lump-sum taxes. The household's problem is to maximize lifetime (6) subject to the constraint (7), which yields the following optimality conditions:

$$C_t^\sigma L_t^\eta = \frac{W_t}{P_t}, \quad (8)$$

$$1 = \beta(1 + i_t) \mathbb{E}_t \left[ \left( \frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right]. \quad (9)$$

The corresponding foreign household's Euler equation optimal choice of foreign-currency bonds leads to:

$$1 = \beta(1 + i_t^*) \mathbb{E}_t \left[ \left( \frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} \right]. \quad (10)$$

Households consumption consists of domestically produced and imported goods, respectively,  $C_t(h)$  and  $C_t(f)$ . Each good  $h$  (or  $f$ ) is an imperfect substitute for all other goods' varieties, with constant elasticity of substitution  $\nu$ :

$$C_{Ht} \equiv \left( \int_0^1 C_t(h)^{\frac{\nu-1}{\nu}} dh \right)^{\frac{\nu}{\nu-1}}, \quad C_{Ft} \equiv \left( \int_0^1 C_t(f)^{\frac{\nu-1}{\nu}} df \right)^{\frac{\nu}{\nu-1}}.$$

The overall consumption baskets,  $C_t$ , combines Home and Foreign goods according to:

$$C_t \equiv \left( (1 - \gamma)^{\frac{1}{\theta}} (C_{Ht})^{\frac{\theta-1}{\theta}} + \gamma^{\frac{1}{\theta}} (C_{Ft})^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

where  $\gamma \in [0, 1/2]$  governs the home bias in consumption preferences, and  $\theta > 0$  is the elasticity of substitution between home and foreign goods, also referred to as the trade elasticity. The resulting price index is  $P_t = \left( (1 - \gamma) P_{Ht}^{1-\theta} + \gamma P_{Ft}^{1-\theta} \right)^{\frac{1}{1-\theta}}$ , where  $P_{Ht} = \left( \int_0^1 p_t(h)^{1-\nu} dh \right)^{\frac{1}{1-\nu}}$  and  $P_{Ft} = \left( \int_0^1 p_t(f)^{1-\nu} df \right)^{\frac{1}{1-\nu}}$  are the domestic-currency price indices for Home and Foreign goods. The foreign consumption basket,  $C_t^*$ , and associated price indices (in foreign currency),  $P_{Ht}^*$  and  $P_{Ft}^*$ , and  $P_t^*$ , are all defined symmetrically.

We use  $S_t$  to denote the nominal exchange rate expressed in domestic currency per

foreign currency (an increase in  $S_t$  represents a depreciation of the home currency). The real exchange rate,  $Q_t \equiv \frac{S_t P_t^*}{P_t}$ , is the relative consumer price level in the two countries (an increase in  $Q_t$  represents a real depreciation). Because export prices are set in the producer's currency, the law of one price holds so that  $P_t(h) = S_t P_t^*(h)$  and  $P_{Ht} = S_t P_{Ht}^*$ . Home bias in consumption gives rise to fluctuations in the real exchange rate,  $Q_t \equiv \frac{S_t P_t^*}{P_t}$ , from purchasing-power parity, i.e.,  $Q_t \neq 1$ .

**Firms** Domestic producers sell differentiated goods under monopolistic competition, and face the production function:

$$Y_t(h) = A_t L_t(h), \quad (11)$$

where  $L_t(h)$  denotes labor services employed by firm  $h$  in period  $t$ , and  $A_t$  represents aggregate domestic TFP. Firms' prices are sticky in the sense of Calvo (1983). We use  $(1-\tau_p)$  to denote the Calvo probability of price adjustment. When firm  $h$  has the opportunity, it sets the domestic-currency price  $\tilde{P}_t(h)$  to maximize the expected discounted value of net profits:

$$\max_{\tilde{P}_t(h)} \mathbb{E}_t \sum_{s=0}^{\infty} (\tau_p)^s M_{t,t+s} \left[ \tilde{P}_t(h) Y_{t+s}^d(h) - W_{t+s} L_{t+s}(h) \right], \quad (12)$$

**Monetary Authority** Monetary policy is conducted according to a conventional Taylor rule targeting inflation. The monetary authority adjusts the short-term nominal interest rate according to the following rule:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \phi_\pi \pi_t, \quad (13)$$

where  $\pi_t = \Delta \log P_t$  is the (log of) domestic CPI inflation.

Throughout the paper, lower-case letters denote percentage deviations from steady state, assuming symmetric initial conditions.

**Fiscal Authority** The government in each country issues nominal bonds and raises lump-sum taxes. The Home government budget constraint reads:

$$\frac{B_{g,t}}{1 + i_t} = \frac{B_{g,t-1}}{\Pi_t} - T_t$$

We assume that the government's taxes depend on past debt and domestic output:



$$\tau_t = \rho_\tau \tau_{t-1} + (1 - \rho_\tau)(\phi_\tau b_{g,t-1} + \phi_y y_{H,t-1})$$

Thus, the government raises taxes when debt has been rising, and government taxes increase with the level of output (as it is the case with automatic stabilizers).

**International Asset Markets** In our model, households can only save in local currency deposits with local financial intermediaries. In turn, these risk-neutral intermediaries have perfect access to international markets, and can invest the deposits frictionlessly in both domestic and foreign government bonds.

Importantly, these financial institutions earn a convenience yield on their safe asset holdings. We do not model the microfoundation for this convenience yield explicitly, but assume that it is a function of the supply of each type of debt available. For example, this will be the case in a slightly simplified version of the [Chahrour and Valchev \(2021\)](#) model, where safe assets facilitate international trade by providing collateralization and financial guarantees that help bridge cross-border contracting issues. For the purposes of this paper, however, we simply assume that the convenience yields on H and F government debt are given by a decreasing function of the supply of each type of debt respectively,  $\Delta(B_{g,t})$  and  $\Delta(B_{g,t}^*)$ , with  $\Delta' < 0$ .

In turn, the financial intermediaries equalize the rate of return on the two safe government bonds, resulting in the following exchange rate pricing condition (up to first-order log approximation):

$$\mathbb{E}_t \Delta s_{t+1} - (i_t - i_t^*) = \mathbb{E}_t(\lambda_{t+1}) = -\alpha(b_{g,t} - b_{g,t}^*)$$

This representation arises as long as households only deposit with domestic intermediaries, and competition ensures that the return on deposits equals the interest on government bonds (that is  $i_t^d = i_t$  and  $i_t^{d*} = i_t^*$ ). Hence, this is a model with partially segmented financial markets. We share the insight of [Gabaix and Maggiori \(2015\)](#) that households do not have direct access to international markets, but unlike in their model, we assume that there is a deep-pocketed and competitive intermediary sector, such that intermediary balance sheet concerns do not generate any risk-premium fluctuations. Instead, the variation in expected excess currency returns in our model is due to convenience yields, and is thus tightly linked to the relative supply of the two types of safe assets.

Table 4: Model Calibration

Parameter		Value
Discount factor	$\beta$	0.99
Relative risk aversion	$\sigma$	1
Macro Frisch elasticity	$\eta$	1
Elasticity of substitution	$\theta$	1
Trade openness	$\gamma$	0.05
Calvo probability for prices	$\tau_p$	0.75
Taylor rule coefficient	$\phi_\pi$	1.35
Interest rate smoothing	$\rho_i$	0
TFP spillovers	$\phi$	0.05
Elasticity of excess returns to bond diff	$\alpha$	1
Tax rule coefficient (Output)	$\phi_y$	5
Tax rule coefficient (Debt)	$\phi_\tau$	50
Tax smoothing	$\rho_\tau$	0

**Information Structure and TFP Processes** We assume that Home TFP follows a random-walk process:

$$a_t = a_{t-1} + \varepsilon_t^a$$

where  $\varepsilon_t^a \sim \mathcal{N}(0, \sigma_{\varepsilon^a})$

We assume that agents observe  $a_t$  and a noisy signal about future levels of  $a$ :

$$\eta_t = \sum_{j=1}^h \theta_j a_{t+j} + v_t$$

where the noise component of the signal,  $v_t$ , follows  $v_t = \rho_v v_{t-1} + \varepsilon_t^v$  and  $\varepsilon_t^v \sim \mathcal{N}(0, \sigma_v)$

Last, we assume that Home and Foreign TFP are cointegrated, and Foreign TFP tracks the level of Home TFP with some delay, that is:

$$a_t^* = a_{t-1}^* + \phi (a_{t-1} - a_{t-1}^*)$$

**Calibration** Table 4 reports the calibration of our parameter values. We calibrate the parameters of the information structure to reproduce the observed responses of Home TFP and Home TFP expectations to the TFP and expectational disturbances (see Figure 7). The

remaining parameters are calibrated to conventional values in the literature.

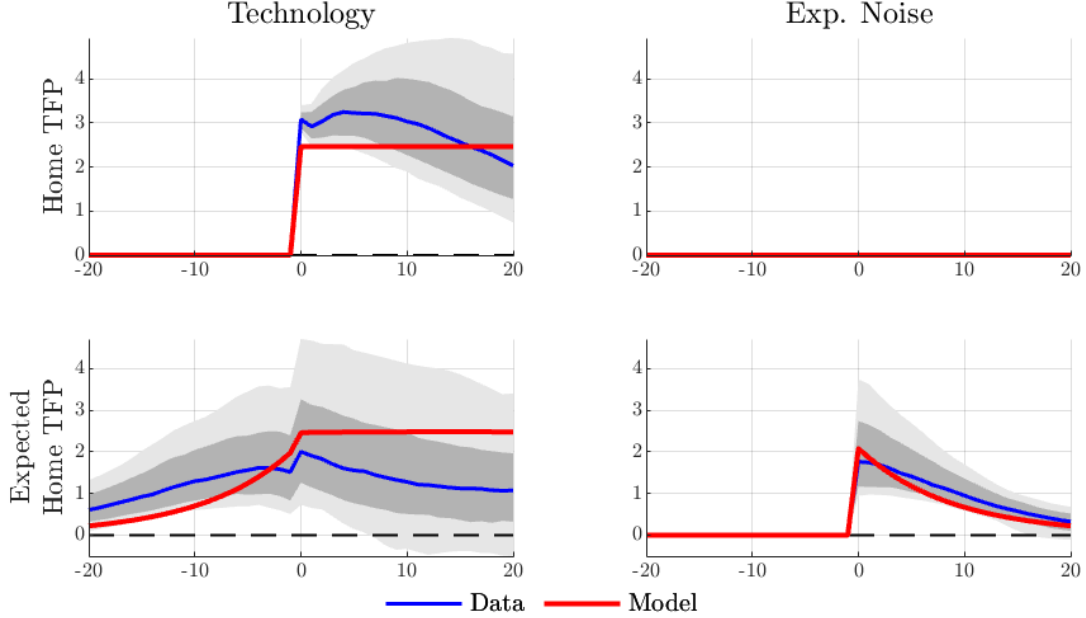


Figure 7: IRFs of TFP and TFP Expectations

*Notes:* The figure displays how TFP and TFP expectations respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ , both in the model and in the data. The shaded area are the 68% and 90% confidence intervals of the empirical responses. All units are annualized percents. Each period is a quarter.

## 4.2 Dynamic Responses to TFP and Expectational Disturbances

Figures 8-9 report the impulse responses to both TFP and expectational disturbances (left and right column, respectively). We report the IRF in both the model and the data. The model reproduces the observed empirical comovements of exchange rates and interest rate differentials quite well.

Let us consider first the responses to a one-standard deviation positive TFP disturbance (left column of Figure 8). Similar to the way we plotted our empirical results earlier, we show the IRF for time periods  $t = -20$  to  $20$ , with the innovation actually occurring at  $t = 0$ . In anticipation of a TFP disturbance the interest rate differential rises as home agents' desire to smooth consumption leads to a positive output gap and inflation (differential). As a result of the positive interest rate differential, the relative supply of government bonds increases due to a deterioration in the financing conditions of the government, in turn leading to an increase

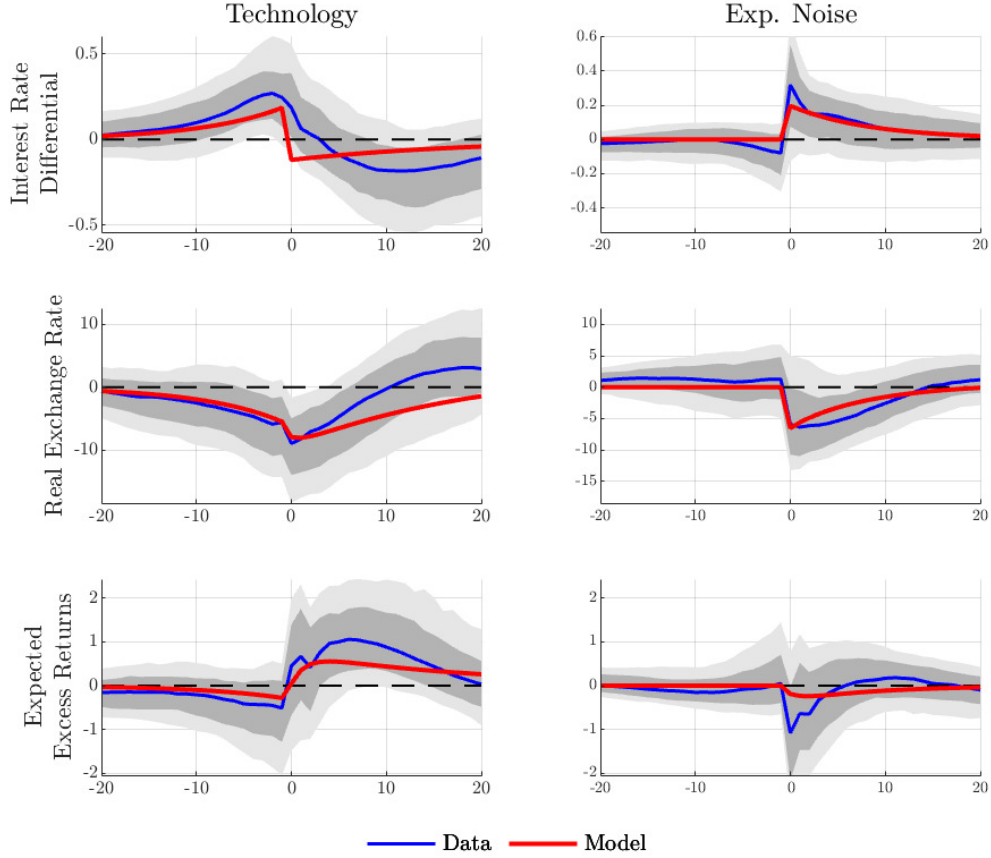


Figure 8: IRFs of Interest Rate Differentials and Exchange Rates

*Notes:* The figure displays how interest rates and exchange rates respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ , both in the model and in the data. The shaded area are the 68% and 90% confidence intervals of the empirical responses. All units are annualized percents. Each period is a quarter.

(decline) in expected excess returns on the home (foreign) bonds. When the TFP disturbance realizes (at time 0), the interest rate differential declines and turns mildly negative because the increase in the supply of the home good leads to a fall in its price and disinflation. As a result of the decline in interest differentials and the increase in output differentials, the relative bond supply decreases (as not the government's financing condition turns favorable) leading to a decline (increase) in expected excess returns on the home (foreign) bonds.

Thus, these impulse responses reveal that our model is capable of generating the observed non-monotonic patterns in expected excess returns conditional on a TFP disturbance in a way that closely aligns with the observed empirical patterns.

These dynamics of expected excess returns shape the model response of the real exchange rate. The appreciated level of the real exchange rate results from agents expecting positive foreign-bond excess returns when the future TFP increase realizes. Yet, in the anticipation phase the exchange rate experiences continuous appreciation because of short-term negative foreign-bond excess returns. The real exchange rate peaks at time 0 when the excess returns switch sign.

Let us consider now the responses to a time-0 one-standard deviation positive expectational disturbance (right column of Figure 8). Agents receive a signal that future TFP will increase, but they gradually learn that such increase will not materialize. As mentioned above, when Home households expect future TFP to rise, they desire to bring future consumption forward. This demand force generates a positive output gap and inflation (differential). In response, the Home interest rate rises more than the foreign interest rate. The resulting increase in the real interest differential generates an increase in the relative supply of home government bonds and thus a decline in the foreign-bond expected excess returns. Despite lower foreign-bond excess returns, the real exchange rate strongly appreciates (i.e. more than what can be accounted for by the expected path of interest rate differentials under UIP). This seemingly conflicting response arise because agents assign a positive probability to the possibility that future TFP will increase, which would be associated with positive foreign-bond excess currency returns. These expectations (which will turn out to be mistaken in the specific case of a signal noise disturbance) account for the sharp appreciation of the real exchange rate following an expectational disturbance.

Figure 9 reports the response of Home and Foreign consumption along with the response of the consumption differential. While this simple model fails to generate enough anticipation in the response of consumption as well as enough international comovement, the response of the consumption differential is qualitatively in line with the data. In particular, the consumption differential is positive in response to both TFP and expectational disturbances, while the real exchange rate is appreciated. These joint responses (see Figures 8 and 9) are associated with a negative correlation between consumption differential and the real exchange rate, as it is the case in the data.

#### 4.2.1 Dynamic Responses of Government Bonds

In this model of time-varying convenience yields, the dynamics of bond supply differentials governs the patterns of expected excess returns and the real exchange rate. If  $\rho_i = \rho_\tau = 0$ , as it is the case in our calibration, the dynamics of the bond differential,  $\tilde{b}_{g,t} = b_{g,t} - b_{g,t}^*$ , are

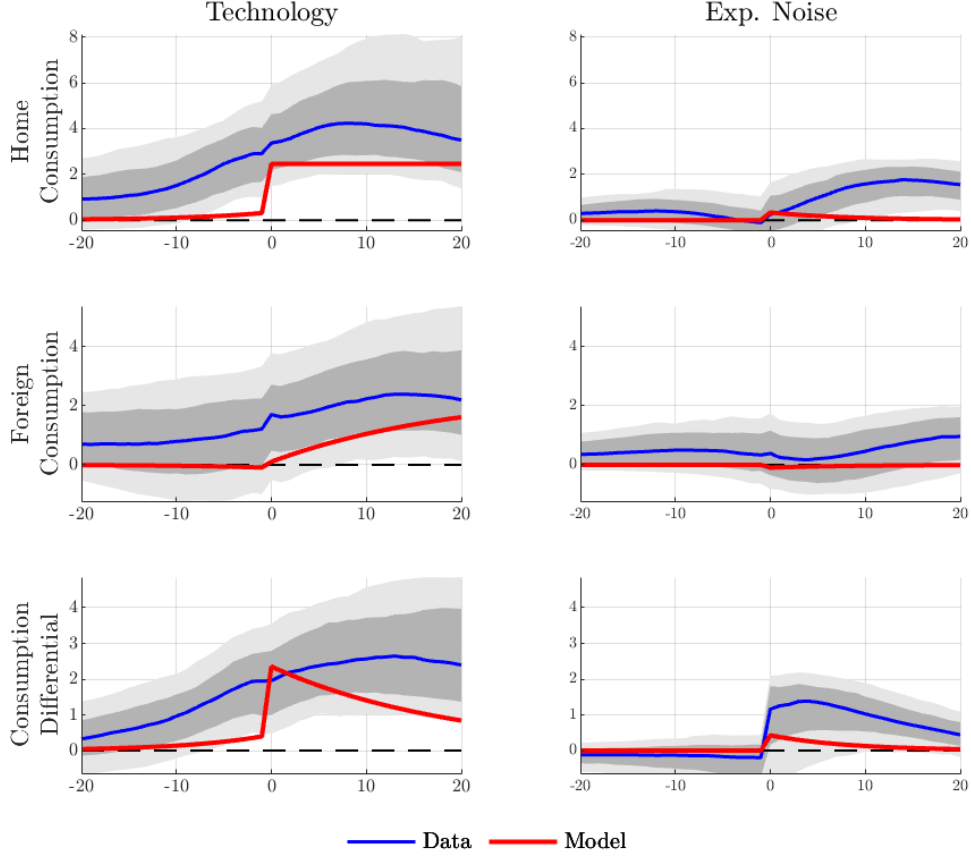


Figure 9: IRFs of Home and Foreign Consumption

*Notes:* The figure displays how macroeconomic aggregates respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ , both in the model and in the data. The shaded area are the 68% and 90% confidence intervals of the empirical responses. All units are annualized percents. Each period is a quarter.

governed by:

$$b_{g,t} - b_{g,t}^* = a_1(b_{g,t-1} - b_{g,t-1}^*) + a_2(i_t - i_t^*) - a_3(y_{h,t-1} - y_{F,t-1})$$

where  $a_1 = \frac{(1-(1-\beta)\phi_\pi)}{\beta} \in (0, 1)$ ,  $a_2 = \frac{\beta\phi_\pi - 1}{\beta\phi_\pi} > 0$  and  $a_3 = (1 - \beta)\phi_y/\beta > 0$ .

Bond differentials are shaped by both nominal interest rate differentials and output differentials. High interest rate differentials lead to high bonds supply differentials, as they require the Home government to issue more bonds to satisfy the budget constraint relative to the Foreign government. Instead, high output differentials are associated with low bond supply differentials as they allow the Home government to run a higher budget surplus relative to

the Foreign government.

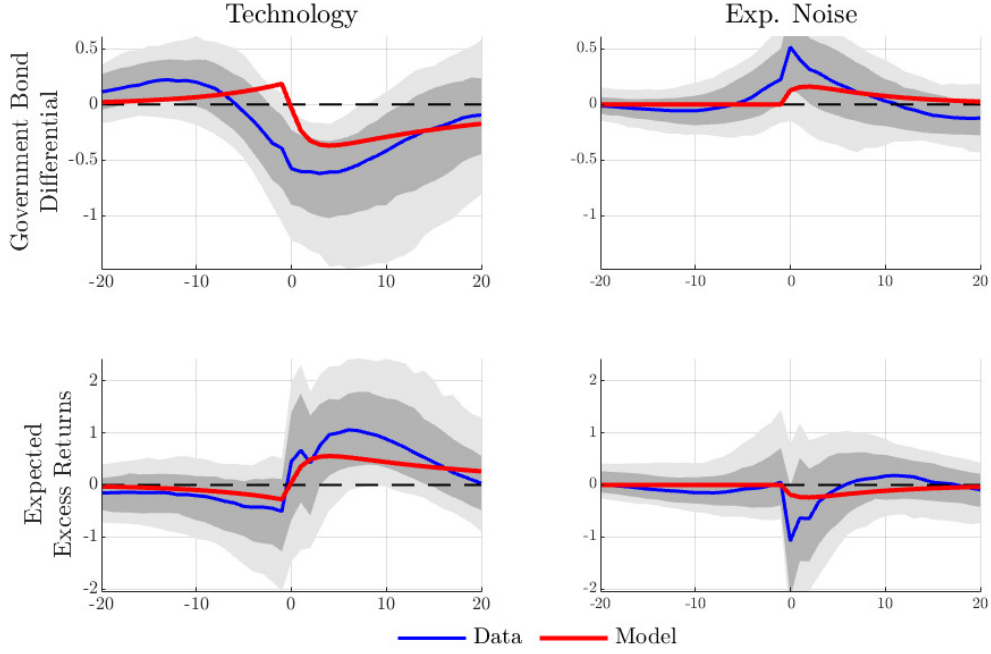


Figure 10: IRFs of Bond Differentials

*Notes:* The figure displays how government bond differential and expected excess returns respond to a one standard deviation impulse in the technological disturbance (left column) and the expectational disturbance (right column) at time  $t = 0$ , both in the model and in the data. The shaded area are the 68% and 90% confidence intervals of the empirical responses. All units are annualized percents. Each period is a quarter.

As shown in Figure 10, the interplay between interest rate differentials and output differentials leads to high bond supply differentials during the anticipation/expectations phase of the impulse responses (when the interest rate differential component dominates), while low bond supply differentials in the realization phase of the impulse response (when the interest rate differentials are low and output differentials are high). In Figure 10 we also plot the empirical responses of government bond differentials, defined as U.S. T-Bills to GDP, to the identified disturbances. These empirical responses support the qualitative predictions of the mechanism that is at the core of our model.

### 4.3 Unconditional Moments

Table 5 reports the unconditional moments both in the model and in the data. The model reproduces a large set of empirical moments of interest, including, but not limited

to, the risk-sharing puzzle (Backus and Smith, 1993), the forward premium puzzle (Fama, 1984), the excess comovement puzzle (Engel, 2016), as well as a positive comovement among Home and Foreign consumption.

	Model	Data	
		Composite	Unconditional
Fama $\beta_{UIP}$	-2.35	-2.37	-2.27
Engel $\beta_\Lambda$	5.70	14.77	15.03
$\sigma(r_t - r_t^*)/\sigma(\Delta q_t)$	0.08	0.15	0.11
$\text{autocorr}(r_t - r_t^*)$	0.82	0.92	0.81
$\text{corr}(\Delta q_t, \Delta(c_t - c_t^*))$	-0.55	-0.62	-0.12
$\text{autocorr}(\Delta q_t)$	0.03	0.32	0.15
$\sigma(\Delta q_t)/\sigma(\Delta c_t)$	3.48	7.03	7.17
$\text{autocorr}(q_t)$	0.94	0.98	0.95
$\text{corr}(\Delta c_t, \Delta c_t^*)$	0.44	0.63	0.23

Table 5: Unconditional moments: Model vs. Data

#### 4.4 Reduced-form Properties of Exchange Rates

Lastly, we close our discussion by circling back to the reduced-form analysis we started the paper with, by showing that in our model, exchange rates predict future macro-fundamentals. To do so, we generate model-simulated data and extract the shock that explains most of the forecast error variance of the real exchange rate, exactly as we did in the agnostic empirical analysis based on Uhlig (2003). Figure 11 reports the impulse responses to the shock that we recover in this way. In the simulations based on our model, such a reduced-form surprise in the real exchange rate predicts future macro-fundamentals, in a way that is in line with the data (cf. Figure 1). In particular, a surprise appreciation of the RER is associated with a Home TFP expansion and a future increase in both Home and Foreign consumption. The patterns of the real interest rate differential and expected excess returns are also in line with the data, indicating that our model successfully reproduces the main reduced-form comovement between real exchange rates and macro-fundamentals.



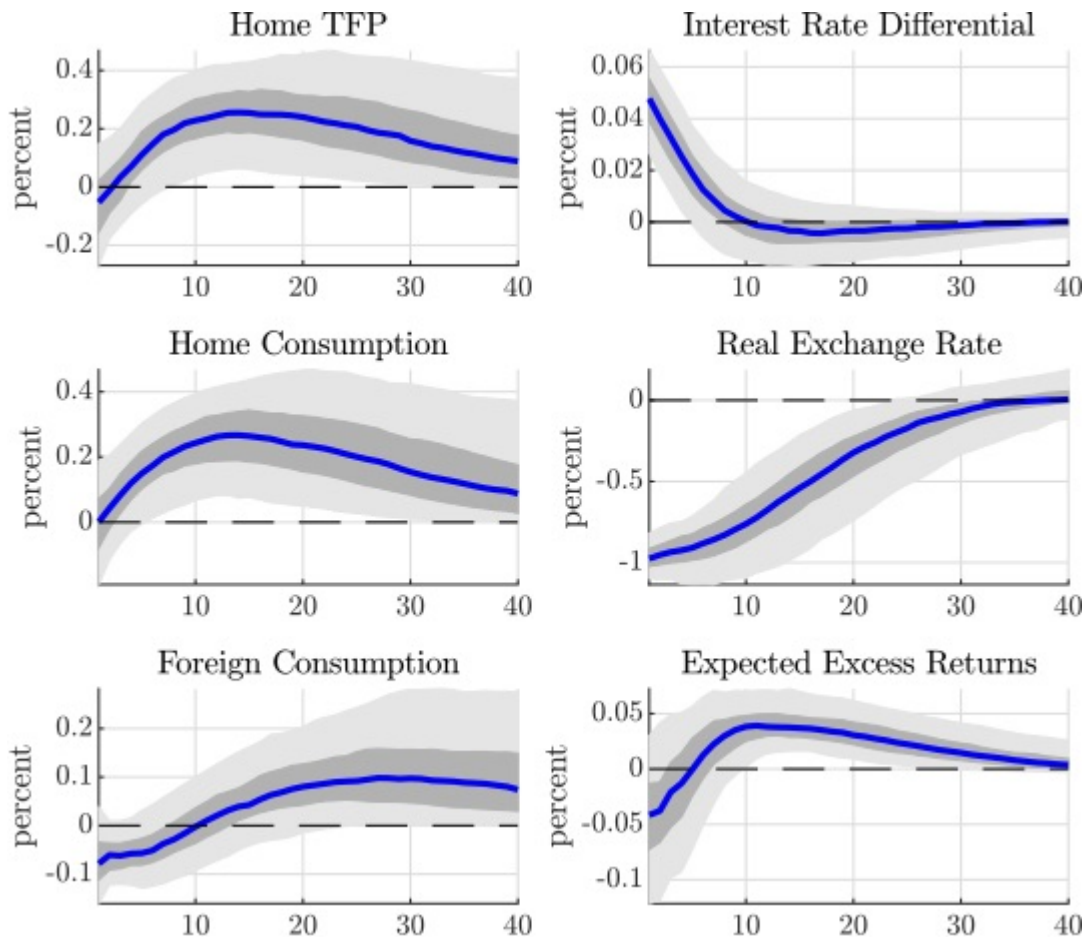


Figure 11: Reduced-form analysis on Model-simulated Data

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## A Connecting back to Uhlig (2003)

The results of Section 2 indicate that both fundamental and expectational disturbances about future TFP are indeed closely related to exchange rates. We were originally motivated to explore this hypothesis due to the initial Uhlig (2003) results we obtained, which suggested the recovered FX shock mainly affects macro aggregates with a delay. The two sets of results align well with each other qualitatively, which is a result in itself, since the disturbances identified by the Chahrour and Jurado (2021) procedure are not guaranteed to span the same space as the shock we recovered first by the Uhlig (2003) procedure.

To get a direct sense of how much of the original Uhlig (2003)-identified shock the two structurally-identified disturbances we recover can account for, we use the estimated VAR to simulate counter-factual data conditional *only* on the Chahrour and Jurado (2021)-recovered technology and expectational disturbances. This gives us a counter-factual dataset driven exclusively by the two identified disturbances. We then perform the Uhlig (2003) maximum-share procedure on this simulated data, and plot the resulting IRFs against the original Uhlig (2003)-IRFs we recovered in Section 2.

The results are displayed in Figure 12. We reproduce the original IRFs and their associated standard errors with blue dashed-line and shaded regions around it, and with the red dashed line we present the resulting IRFs from the counter-factual, simulated sample. Remarkably, the two impulse responses align almost perfectly, especially in the case of the real exchange rate, the currency excess returns and the interest rate differential.

This suggests that, in terms of exchange rates at least, the identified fundamental and noise disturbances we identified separately are essentially perfectly replicating the economic content of  $\varepsilon_{1,t}$ , the “most important” source of exchange rate variation as per Uhlig (2003) procedure. Hence, we have come full circle in our conclusions that anticipation of future TFP is an important driver of exchange rates.

Figure 12: Chahrour and Jurado (2021) vs Uhlig (2003)

