The reliability of equilibrium exchange rate models: A forecasting perspective*

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Abstract

In this paper we evaluate the predictive power of the three most popular equilibrium exchange rate concepts: Purchasing Power Parity (PPP), Behavioral Equilibrium Exchange Rate (BEER) and the Macroeconomic Balance (MB) approach. We show that there is a trade-off between storytelling and forecast accuracy. The PPP model offers little economic insight, but has good predictive power. The BEER framework, which links exchange rates to fundamentals, does not deliver forecasts of better quality than PPP. The MB approach has the richest economic interpretation, but performs poorly in forecasting terms. Sensitivity analysis confirms that changing the composition of fundamentals in the BEER model or modifying key underlying assumptions in the MB model does not generally enhance their predictive power.

Keywords: Equilibrium exchange rate models; mean reversion; forecasting; panel data.

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1 Introduction

The proposition that real exchange rates and macroeconomic fundamentals are linked at long horizons helps explain why policy makers are highly interested in the concept of equilibrium exchange rates. Strong and persistent departures from equilibrium levels are thought to have a substantial bearing on growth prospects, price dynamics and even financial stability. In relying on equilibrium exchange rate concepts, however, there is an important ambiguity in whether we are reasoning in "normative" or "positive" terms. In the former case, economists are interested in the level of exchange rates that are aligned with other economic fundamentals and hence support macroeconomic stability. In the latter case, equilibrium exchange rates are expected to provide a signal of future exchange rate adjustments.

Most of the existing literature on equilibrium exchange rates hinges on the normative aspect. In this paper we instead follow Milton Friedman's recommendation that "The ultimate goal of a positive science is to develop a theory or hypothesis that yields valid and meaningful predictions about phenomena not yet observed" (Friedman, 1953, p. 7). More specifically, we assess the predictive power of the three most popular equilibrium exchange rate concepts currently employed in central banks and international organizations: the Purchasing Power Parity (PPP), Behavioral Equilibrium Exchange Rate (BEER) and Macroeconomic Balance (MB) approach (Williamson, 1994; MacDonald, 1998; MacDonald and Clark, 1998; Driver and Westaway, 2004; Isard, 2007; Lee et al., 2008; Bussière et al., 2010; Phillips et al., 2013; Couharde et al., 2018; Cubeddu et al., 2019).

The principal purpose of this study is not an exchange rate forecasting "horse race" *per se*, but to conduct a systematic evaluation of the three dominant equilibrium exchange rate methodologies based on their predictive power. We believe this to be the innovative contribution of this paper, which sheds a new light on the reliability of widely used estimates of exchange rate misalignments.

The literature has already examined at length PPP theory as a plausible model of exchange rate determination. A short review of the literature shows that, despite the wide range of contributions, including our own, no consensus has yet emerged between the more optimistic and pessimistic voices in the debate on whether the PPP model possesses predictive power (e.g. Mark, 1995; Rossi, 2013; Ca' Zorzi et al., 2016; Beckmann and Schussler, 2016; Eichenbaum et al., 2020; Cheung et al., 2019; Engel et al., 2019; Ca' Zorzi and Rubaszek, 2020; Engel and Wu, 2021). The source of this disagreement partly depends on the specific characteristics of the different studies, e.g. the emphasis on absolute or relative PPP, the choice of currencies, the forecasting evaluation criterion, the estimation and forecasting horizons and the inclusion of non-linear effects (Rossi, 2013; Manzur, 2018; Cheung et al., 2019; Beckmann et al., 2020). The most decisive factor in explaining the heterogeneity of results, however, is probably the different degree of estimation error when estimating the speed of adjustment to PPP. We proposed in previous studies (Ca' Zorzi et al., 2016; Ca' Zorzi and Rubaszek, 2020) a simple recipe to bypass the estimation error problem by assuming an autoregressive log-linear model and calibrating the half-life adjustment parameter. The calibrated half-life does not need to be set particularly precisely, as anything in the range of two to five years would normally strongly outperform the RW benchmark as long as there is evidence of mean reversion in the real exchange rate data. To derive an accurate real exchange rate forecast, it is generally sufficient to assume that the real exchange rate adjusts slowly back to its historical average. In turn, to derive an accurate forecast for nominal exchange rates, one can simply assume that the required real exchange rate adjustment takes place entirely via the nominal exchange rate. In the baseline of this paper we have decided, however, not to rely on calibration methods but rather to estimate the pace of reversion to equilibrium with a panel regression approach. There is clearly a subtle link between exchange rate predictability and our ability to define equilibrium exchange rates. On the basis of the previous findings of our research we expect PPP to outperform the RW, but only if one controls for estimation error.

For the other approaches to modeling equilibrium exchange rates, the empirical evidence is rather scarce. The comprehensive surveys of the literature on exchange rate forecasting by Rossi (2013) as well as Cheung et al. (2005, 2019) confirm the limited focus assigned by academic studies to the predictive power of the BEER and MB concepts both in terms of nominal and real exchange rate forecasting. Two studies that pioneered this issue are the analyses by Abiad et al. (2009) and Yesin (2016), in which the authors evaluate the predictive content of IMF equilibrium exchange rate estimates. Abiad et al. (2009) show that estimates of exchange rate misalignment computed for the years 1997 to 2006 were followed by a gradual real exchange rate adjustment that typically absorbed such disequilibria. Yesin (2016) reaches a similar conclusion for the period 2006 to 2011, stressing at the same time that the BEER model is generally more accurate in forecasting real exchange rates than its MB counterpart. These papers are insightful in view of their real-time nature. However, such analyses are constrained by the limited time span of the data and the real-time innovation of the underlying IMF models which makes it hard to understand the performance of any specific model. More fundamentally, they do not test if the BEER and MB models are able to outperform the PPP model, but only consider the RW as a benchmark, i.e. a weak competitor in the context of equilibrium exchange rate models.

To proceed with our evaluation exercise, we collected quarterly data for a panel of ten advanced economies from 1975 to 2018. Our main results can be summarized as follows. First, we illustrate that in-sample the relationship between real exchange rates and economic fundamentals is generally consistent with the theory. Second, we discuss how equilibrium exchange rates calculated with the MB framework are sensitive to many assumptions, including the definition of current account norms and the calibration of trade elasticities. Third, we present in-sample evidence that exchange rates tend to adjust to close exchange rate misalignments in the case of the PPP and BEER models but not for the MB approach. Fourth, we demonstrate that if we evaluate equilibrium exchange rate models in terms of their out-of-sample performance of predicting the real exchange rate it is hard to beat the PPP model. Our analysis clearly establishes that based on an out-of-sample evaluation criterion, the link between real exchange rates and economic fundamentals is feeble. The main gain in terms of exchange rate forecasting comes from the exploitation of the mean reverting properties of real exchange rates, while additional economic fundamentals are not very helpful in forecasting terms.

The key takeaway from our study is the existence of a trade-off between storytelling and predictive power of equilibrium exchange rate models. The BEER and MB models suggest a link between real exchange rates and economic fundamentals, which is helpful from a normative perspective. However, the higher degree of sophistication does not pay off out-of-sample for the BEER model and is even counterproductive for the MB model. The most effective approach to predict real exchange rates in the long run is given by the PPP model.

The predictive power of the BEER model is broadly comparable to that of PPP, mainly because the equilibrium exchange rate computed with this method is often similar to that implied by PPP. The MB model is by far the least accurate. We also show how switching from real to nominal exchange rate forecasting does not alter our main results. Finally, we conclude with a note of caution on the ambition of developing comprehensive models that go in the direction of greater complexity and include an ever-larger set of fundamentals.

The remainder of the paper is structured as follows. Section 2 discusses the equilibrium exchange rate concepts which are considered in the forecast contest. Section 3 describes the data. Section 4 presents equilibrium exchange rate estimates. Section 5 provides in-sample evidence on the pace of exchange rate adjustment to equilibrium derived with different models. Section 6 presents and explains the main results of the forecasting competition. Section 7 contains a carefully structured sensitivity analysis, which reveals the generality of our results and provides some unexpected additional insights. The last section concludes with the main lessons of our analysis.

2 Equilibrium exchange rate concepts

Equilibrium exchange rate models are used to decompose the real exchange rate (rer) into its equilibrium value (rer^{eq}) and a misalignment component (rer^{mis}):

$$rer = rer^{eq} + rer^{mis}. \tag{1}$$

Such decomposition allows economists at central banks and international organizations to judge whether currencies are over- or undervalued. For this reason, equilibrium exchange rate models, despite their limitations, constitute an important part of the quantitative toolbox used to support economic policy decisions (Cubeddu et al., 2019). Similar models are also employed by the financial industry to develop trading strategies on the foreign exchange market (Menkhoff et al., 2017). The key question, both from the perspective of policy-makers and investors, is therefore how to derive the unobserved component rer^{eq} and how to evaluate the reliability of such estimates.

In this section, we briefly review the three most popular equilibrium exchange rate frameworks and present a short discussion of how they relate to the wider debate on exchange rate determination. Thereafter, we propose a method to assess the reliability of equilibrium exchange rate models based on predictive regressions.

2.1 Purchasing Power Parity

It seems only appropriate to start with PPP, since it is the oldest theory of exchange rate determination. PPP tells us that nominal exchange rates should evolve to neutralize competitiveness changes induced by movements in price indexes across nations. The origin of the PPP model traces back to the 16$^{\text{th}}$ century Spanish scholars of the Salamanca school, according to whom exchange rate movements that reflect changes in relative price indexes are acceptable, also from a moral perspective. The term purchasing power parity has been coined a century ago by Gustav Cassel and employed for calculating appropriate exchange rate parities.

PPP theory can be treated both as a nominal and a real concept. In the former case, the PPP model is employed to check if nominal exchange rate dynamics are driven by relative price developments at home and abroad. In the latter case, PPP implies that real exchange rates are mean reverting processes (e.g. Lothian and Taylor, 1996; Taylor and Taylor, 2004; Norman, 2010; Curran and Velic, 2019). As such, PPP has never really been thought to be a short-run theory of exchange rate determination, not even by Cassel, but rather a long-term concept (Taylor and Taylor, 2004). Nowadays, the majority of macroeconomic models assume PPP to be the equilibrium value for the real exchange rate, while PPP deviations are explained by interest rate disparities or risk premia, as captured by the uncovered interest rate parity (see e.g. Engel, 2016; Ca' Zorzi et al., 2017).

Two versions of the PPP model are prevalent. The strong version foresees that, in equilibrium, the same basket of goods should cost the same across countries when denominated in a common currency. In contrast, the weak version of PPP theory foresees that, in equilibrium, the difference in the cost of the same basket of goods across countries is equal to a constant, which can be explained by several factors such as taxes or transportation costs. The latter is appealing from an economic point of view, as it directly implies that the sample mean of the real exchange rate ($\overline{rer}$) is a good proxy of the PPP-implied equilibrium real exchange rate (rer^{PPP}):

$$rer_{it}^{PPP} = \overline{rer}_i. \tag{2}$$

2.2 Behavioral Equilibrium Exchange Rate

The implication of PPP theory is that real exchange rates should behave as mean-reverting stationary processes. However, many academics argue that the pace of mean reversion is, at best, very slow. This lack of swift adjustment is often referred to as "PPP puzzle" (Rogoff, 1996), prompting several plausible explanations that could justify the sluggishness of the process (Taylor et al., 2001). Other studies have instead investigated the possibility that real exchange rates are non-stationary and hence attempted to explain their dynamics in terms of other economic fundamentals, typically within a cointegrating framework. This methodology has been renamed several times in the literature but is most widely known either as the Behavioral Equilibrium Exchange Rate model (MacDonald, 1998) or, in IMF terminology, as the reduced-form model (Lee et al., 2008).

The literature has discussed at length the most plausible choice of fundamentals and the expected sign and magnitude of the parameters (for a comprehensive literature review see Fidora et al., 2017). In most writings it is taken for granted that a rise of per-capita GDP (gdp) leads to an appreciation of the real exchange rate. The explanation is twofold. From a demand perspective, an increase in relative wealth should lead to stronger demand for domestic non-traded goods and hence to an increase in their relative price. The supply perspective is based on the widely known Balassa-Samuelson effect (Lee et al., 2013; Zhang, 2017).[1] Another popular explanation for long-run trends in equilibrium real exchange rates emphasizes the role of net foreign assets (nfa). The rationale is that a rise in this variable

[1]Recently, Hassan (2016) presented evidence that the relationship between the stage of development and the level of prices might be non-linear and even negative for low income countries. In this study, however, we focus on high-income countries.

increases the interest income on the current account and should hence be counterbalanced by a deterioration in the trade balance. This, in turn, requires real exchange rate strengthening (Lane and Milesi-Ferretti, 2002). The third most commonly used explanatory variable in BEER regressions is terms of trade (tot). A rise in this fundamental should lead to higher wealth and an improved trade balance, and therefore to an appreciation of the real exchange rate. For the above reasons we estimate the level of BEER with the specification used by Faruqee (1995) and Lane and Milesi-Ferretti (2004), so that the value of BEER is given by:

$$rer_{it}^{BEER} = \mu_i + \alpha_1 gdp_{it} + \alpha_2 nfa_{it} + \alpha_3 tot_{it}, \tag{3}$$

where all explanatory variables are expressed relative to foreign values.

The literature on equilibrium exchange rates also discusses other potential regressors in BEER equations, such as interest rate differentials or fiscal and demographic variables (e.g. MacDonald, 1998; Fidora et al., 2017; Miyamoto et al., 2019). We have decided to restrict our model to the three variables listed above for several reasons. First, as we shall discuss shortly, economic theory guides us to only a handful of factors that determine real exchange rates at long horizons, while other variables are more relevant at shorter horizons. Second, from an empirical perspective a larger set of regressors would constrain the country and time coverage of our sample and hence affect the reliability of the out-of-sample forecasting contest. Third, a larger BEER model would be subject to greater estimation error and hence less likely to deliver competitive forecasts.[2]

2.3 Macroeconomic Balance approach

The methodology of the MB approach differs substantially from that of the PPP or BEER models. Instead of looking at past trends in the real exchange rate and its potential explanatory variables, the MB approach requires solving a system of equations to find the level of the real exchange rate compatible with the dual goal of achieving internal and external balance (Williamson, 1994; Lee et al., 2008). The equilibrium exchange rate is defined as the rate at which the current account stabilizes at the target level when domestic and foreign output gaps are closed. This definition is closely connected with the debate on global imbalances and the role played by the exchange rate to unwind them. For this reason, the MB approach is a normative concept.

To calculate the equilibrium exchange rate with the MB framework an economist has to overcome three hurdles. The first one consists of projecting at what level the current account balance would stabilize if exchange rates remained unchanged and output gaps were closed ($\widetilde{ca}$). The second one relates to setting the target level of the current account, which is often referred to as the current account norm (ca^{norm}). The third one is to establish how changes in the real exchange rate affect the current account (η). Having settled these three issues, the equilibrium exchange rate can be simply computed as:

[2] As a robustness check, we replicated a full-scale BEER model very similar to the version proposed by Cubeddu et al. (2019), i.e. a model characterized by a large set of fundamentals and estimated with annual rather than quarterly data. This analysis confirms that in-sample the full-scale BEER model has broadly comparable predictive power to PPP. Out-of-sample, it tends to underperform compared to both PPP and the small-scale BEER model employed in this paper. A caveat to this conclusion is that the number of observations is not large enough to carry out a fully reliable forecasting evaluation exercise out-of-sample.

$$rer_{it}^{MB} = rer_{it} - \frac{\widetilde{ca}_{it} - ca_{it}^{norm}}{\eta_{it}}. \tag{4}$$

The resulting real exchange rate adjustment should guarantee the convergence of the current account to its norm. It should be noted that in the above formula we are not looking at past real exchange rate developments, but only at its current level and the current account imbalance. For this reason, the equilibrium exchange rate consistent with the MB approach might be very distant from the levels implied by PPP or BEER models. In fact, practical experience has taught us that the MB model typically delivers time series for equilibrium exchange rates that are both volatile and disconnected from those of other models.

To shed some intuition on the way this model works let us consider a simple example. Suppose that a country is characterized by a current account deficit of 4% of GDP. Unless that country is experiencing a significant (and predictable) external adjustment process, it is reasonable to assume in the first instance that the predicted current account remains unchanged at $\widetilde{ca} = -4\%$. The easiest possible, and outside the economic profession most popular, current account norm is zero, $ca^{norm} = 0$. Assuming that a 1% exchange rate depreciation leads to a current account improvement of 0.2% of GDP ($\eta = -0.2$, see Cubeddu et al., 2019) the current account gap of -4% of GDP would be absorbed by an exchange rate depreciation equal to 20%. By halving or doubling the value of η, e.g. in order to account for estimation uncertainty, we derive a range of 10% to 40% for the estimated misalignment. While extremely simple, the above example reveals how prone this approach is to large model uncertainty by slightly changing some of its underlying assumptions.

In this paper we use a more realistic version of the model. In particular, for ease of exposition we will maintain the assumption that the predicted current accounts are equal to their current values ($\widetilde{ca} = ca$). This assumption is the most innocuous of the three discussed in the illustrative exercise above. Next, we relax the assumption that the current account norm is equal to zero. Instead, we follow the literature on global imbalances and derive country-specific current account norms by running a regression of current account balances on a set of plausible economic fundamentals (Chinn and Prasad, 2003; Ca' Zorzi et al., 2012). In our list of fundamentals we include *per-capita* GDP, net foreign assets and HP-filtered "structural" terms of trade (tot^{hp}):[3]

$$ca_{it}^{norm} = \omega + \beta_1 gdp_{it} + \beta_2 nfa_{it} + \beta_3 tot_{it}^{hp}. \tag{5}$$

Economic theory provides guidance on the expected correlation between current accounts and each of these fundamentals. As discussed in previous writings, the higher *per-capita* GDP, the larger should be the expected current account surplus. If the global convergence hypothesis holds, capital should in theory flow from developed to developing countries. Countries with large positive international positions are also expected to record positive income flows and hence stronger current account positions. Finally, favorable terms-of-trade shocks should have a direct positive impact on the current account. In other words, we expect positive coefficients for all three fundamentals.

[3]Following the discussion in Chinn and Prasad (2003) we do not allow for fixed-effects in the specification of the model.

Having calculated the current account gaps, in the last step we need to translate them into exchange rate misalignments. In line with the IMF methodology we assume that the response of the current account to exchange rate changes takes place via the adjustment of the trade balance, while the impact on income or transfer balances is assumed to be negligible. As a result, we start at a more granular level searching for a plausible set of export and import volume elasticities (γ_x and γ_m) as well as the exchange rate pass-through to export and import prices (δ_x and δ_m, expressed as the effect of a 1% exchange rate appreciation on prices expressed in domestic currency). Using data on import and export shares in GDP (μ_x and μ_m), one can calculate the value of η with the following expression:

$$\eta_{it} = \mu_{x,it}(\delta_x + (1 + \delta_x)\gamma_x) - \mu_{m,it}(\delta_m + \delta_m \gamma_m). \tag{6}$$

In the baseline, we follow Isard and Faruqee (1998) and assume producer currency pricing. This means that export prices do not react to exchange rate changes ($\delta_x = 0$), whereas import prices are affected one-to-one ($\delta_m = -1$), implying perfect pass-through. Given the large estimation uncertainty over the magnitude of export and import (volume) elasticities as documented in Bussière et al. (2010), we pick plausible long-run volume elasticities equal to $\gamma_x = \gamma_m = -1$, which are close to the values proposed by Isard and Faruqee (1998) and those currently in use at the IMF (Cubeddu et al., 2019). All these assumptions translate into a set of values for η that are both country- and time-dependent as they are a function of the import and export shares, $\mu_{m,it}$ and $\mu_{x,it}$, respectively. For illustration, a country in which these shares amount to 20% of GDP the implied value is $\eta = -0.2$, which means that a 5% depreciation improves the current account by 1% of GDP.

2.4 Equilibrium exchange rates and fundamentals

Before proceeding further, it is worthwhile to reflect on the practical implications of applying these three methodologies. In terms of economic fundamentals, the ingredients are always the same, but the way they are combined is completely different. In the case of PPP, the equilibrium exchange rate is the average of the real exchange rate. This means that we assign zero weight to the remaining economic fundamentals. In the case of the BEER model, we are mapping the values of *per-capita* GDP, net foreign assets and terms of trade into an equilibrium exchange rate using a linear regression. It could be viewed as an extension of the PPP model with an additional component based on economic fundamentals. Finally, the MB approach adds current account data to the same list of fundamentals. Implicitly, the relationship between equilibrium exchange rates and economic fundamentals is highly non-linear. As we move up the ladder from PPP to BEER and further up to the MB approach, the underlying economic mechanisms become more sophisticated. This increased complexity clearly pays off for storytelling purposes. It is highly suggestive to think of exchange rates as intrinsically linked with other economic fundamentals or, even better, to affirm that they help absorb external imbalances. The question that we address in the remainder of this paper is whether the richer narrative of these models pays off in terms of exchange rate forecasting.

It is also worth reflecting how these empirical methods can be interpreted from the perspective of more theoretical approaches that rely on micro-founded, general equilibrium models. In these studies, it is often assumed that over long horizons PPP holds, whereas the short-term dynamics of exchange rates are explained by the uncovered interest rate no-arbitrage condition. By iterating forward the uncovered interest rate parity, it is possible to show that the deviation of the real exchange rate from PPP can be expressed as the present value of the expected real interest rate disparity $(r - r^*)$ adjusted for the risk premium (ρ):

$$rer_t = rer^{PPP} + E_t \left[\sum_{s=t}^{\infty} (r_s - r_s^* - \rho_s) \right]. \tag{7}$$

In the above notation $E_t(r_s) = E_t(i_s - \pi_{s+1})$, where i and π denote the nominal interest rate and inflation, respectively.

The main differences across studies are predominantly driven by how the risk premium ρ_t is modeled. In the benchmark sticky prices, open-economy model of Obstfeld and Rogoff (1995) it is assumed that international financial markets are frictionless, hence the risk premium is zero $(\rho_t = 0)$. This framework therefore implies that the real exchange rate should converge towards PPP as the long-term impact of the business cycle, captured by the real interest rate disparity, is expected to wane. In turn, the imperfect financial markets version of the model, proposed by Benigno (2009) and applied to forecast exchange rates by Ca' Zorzi et al. (2017), assumes an exogenous relationship between the risk premium and net foreign assets, namely $\rho_t = \psi(nfa_t)$. In this framework, real exchange rate deviations from the PPP level are a function of net foreign assets at medium terms horizons (as in the BEER model). Finally, the MB approach can be related to the recent contribution of Gabaix and Maggiori (2015). In particular, the MB model emphasizes the role of exchange rates in closing global imbalances, and hence indicates a link between large current account surpluses (deficits) and the presumption of currency undervaluation (overvaluation). In the Gabaix and Maggiori (2015) model global financiers earn compensation and bear the risks resulting from global imbalances in the demand and supply of international assets. This setup generates a relationship between the risk-premium and net foreign assets $\rho_t = \psi_t(nfa_t)$, which depends on trade flows but also on the time-varying risk-bearing capacity of financial markets. The model implies a micro-founded time-varying relationship between exchange rates and net foreign assets. As shown by Itskhoki and Mukhin (2017), this framework helps to rationalize some international economic puzzles, including the difficulty to forecast exchange rates at short horizons and the limited role played by exchange rates in the absorption of external imbalances in normal circumstances. We shall evaluate this latter point empirically in the remainder of the paper.

3 Data

Our sample covers the group of ten advanced economies that issue so-called G10 currencies, namely Australia (AUS), Canada (CAN), Switzerland (CHE), the euro area (EA),[4] the United Kingdom (GBR), Japan (JPN), Norway (NOR), New Zealand (NZL), Sweden (SWE) and the United States (USA) over the period 1975:Q1–2018:Q4. As such, our sample is comparable to studies evaluating exchange rate trading strategies for the ten globally most traded currencies (e.g. Opie and Riddiough, 2020) as well as recent studies on exchange rate forecasting such

[4]For the period before 1999, we define euro area, where appropriate, as a PPP GDP-weighted average of the eleven founding member states.

as Engel and Wu (2021). Two additional criteria motivate the country selection, namely the presence of flexible exchange rate regimes for most of the sample and sufficient availability of macroeconomic data for a meaningful forecast evaluation exercise.[5]

For each of the ten analyzed economies, the foreign sector is represented by the other nine countries plus Denmark, which is excluded from the analysis in light of its fixed exchange rate regime. The weights are computed on the basis of the narrow effective exchange rate index published by the Bank for International Settlements (BIS). More specifically, we take BIS weights for the year 1995 and adjust them so that they sum to unity. The exact values are presented in Table 1 and cover 75 to 96% of the BIS index. The motivation for using 1995-based weights is that we do not exploit information that was not available to economists ahead of the forecast evaluation period. The use of static weights also avoids the problem of having forecast errors partly determined by changes in weighting over the forecast horizon.[6]

Next, we calculate a set of effective nominal exchange rates using the weights from Table 1 and the end-of-period values of each bilateral exchange rate against the US dollar. To derive a real measure of the exchange rate, we deflate the nominal series by the respective consumer price index, while bearing in mind that the choice of the deflator might not be innocuous (Chinn, 2006; Fidora et al., 2017). Our proxy for the Balassa-Samuelson effect, *per capita* GDP, is computed by adjusting real GDP, expressed in PPP terms, for population size. As the latter series is only available at annual frequency, we derive interpolated quarterly data using cubic splines.[7] Net foreign assets are taken from the IMF Balance of Payments Statistics and complemented, in some cases, with interpolated annual data from the External Wealth of Nations database of Lane and Milesi-Ferretti (2018) to improve the historical coverage of the data and then expressed as a share of GDP. Terms-of-trade series are constructed as the ratio of export to import prices. For the MB model we also include current account data as well as imports and exports (goods and services) as a share of GDP. Given the quarterly frequency of our data, all series are seasonally adjusted. Table 2 provides a detailed description of all our data sources.

4 Equilibrium exchange rate estimates

In this section, we derive three series of equilibrium exchange rates for each country by applying the methodologies presented in the previous sections. As this is a retrospective analysis, we can calculate equilibrium exchange rates for each model using either the full dataset or, in a pseudo-forecasting mode, using historical data available at each given point in time. The comparison between the full-sample and recursive equilibrium exchange rate measures is insightful. Figure 1 illustrates these differences for the PPP model. The full sample equilibrium, depicted by the dotted line, is constant for all observations as it is

[5]G10 currencies are usually classified as floaters (e.g. Shambaugh, 2004; Ilzetzki et al., 2019), albeit some of them were not freely floating for the entire period from 1975.

[6]As a robustness check, we compared our effective exchange rate indices to those provided by the BIS and only found minor differences. Substituting our exchange rate indices by those provided by the BIS did not qualitatively change the main results presented in the next sections.

[7]We choose GDP *per capita* expressed in PPP terms and not in nominal terms as the latter clearly depends on the level of the real exchange rate. This could lead to endogeneity problems. Our choice is consistent with the IMF methodology.

simply the mean of the real exchange rate calculated with data for the period 1975:Q1–2018:Q4. The recursive equilibrium, shown by the dashed line and calculated with an initial estimation window of 20 years, evolves over time as incoming observations gradually affect the sample mean. Except for a few currencies that have been characterized by either an appreciating (CHE and NZL) or depreciating (SWE) trend, the recursive measure is rather stable and not very distant from the full-sample PPP value. The relative stability of the equilibrium exchange rate estimates of the PPP model is a desirable feature, as sizable changes in equilibrium exchange rates are generally difficult to explain and communicate.

Let us turn next to the BEER model. In this case we need to estimate the parameters of the panel regression given by equation (3), as the exact relationship between real exchange rates and fundamentals is unknown. To tackle the potential feedback of the exchange rate to the right-hand-side variables and the potential non-stationarity of some of them, we opt for the fully-modified least squares estimator originally proposed by Phillips and Hansen (1990). The full-sample estimates, which are presented in the left panel of Table 3, reveal that coefficients are of the expected sign, except for net foreign assets. The values of the R^2 coefficient indicate that, even when we include all three fundamentals, the model explains only a quarter of the real exchange rate variation and that most of the explanatory power comes from the inclusion of the terms of trade variable. We complement the results described in Table 3 by plotting the recursive estimates of the coefficients in the upper panels of Figure 2. Although the parameters exhibit some time variation, the signs are generally the expected ones. It is particularly interesting that the coefficient for net foreign assets was until recently positive, in line with the findings of the vast pre-Great Financial Crisis literature on global imbalances. However, at the end of the sample the coefficient is not significantly different from zero. Overall, recursive parameter estimates highlight that the stability of the relationship between real exchange rates and economic fundamentals may be less obvious than commonly asserted. This finding is supported by the gradual decline of the economic significance of all three fundamentals. This implies that equilibria calculated with the BEER model increasingly resemble those obtained with the PPP model.

The full set of equilibrium values based on the BEER model is presented in Figure 3. Compared to PPP, the BEER estimates are clearly more volatile, as can be seen from the cases of Australia, Norway and, to a lesser extent, Canada. The volatility of the full-sample BEER estimates is purely driven by changes in economic fundamentals, while that of the recursive BEER estimates is also affected by the instability of the model parameters. Still, the differences between both series are generally small, even if slightly more pronounced in the cases of Norway and the United Kingdom.

Finally, we present the equilibrium exchange rate estimates derived using the MB model. Once more we need to go through the different steps required by this approach. We begin by calculating time series for the CA norms using formula (5). The full-sample estimates of its parameters, which are presented in the right panel of Table 3, show that all coefficients are significant and positive as predicted by economic theory. The value of R^2 of around 50% reveals that the model fits the data reasonably well. A look at the evolution of the recursive estimates of the model (5) parameters also shows that, despite some time variation, the coefficients remained plausible throughout the sample (bottom panels of Figure 2). The economic importance of *per-capita* GDP and terms of trade increased over time, while that of net foreign assets remained broadly constant. Figure 4, which presents current account data together with their estimated norms, confirms visually that about half of the current account variation can be accounted for by changes in economic fundamentals. The same figure also reveals that for several countries the estimated current account gaps tend to be very persistent.

Using simultaneously (i) the estimated current account gaps, (ii) the baseline assumptions for trade elasticities and (iii) data for trade shares, it is straightforward to apply formulas (6) and (4) to compute equilibrium exchange rates that are consistent with the MB framework. The outcome of these calculations, which is presented in Figure 5, points to three features of this approach. First, the MB model delivers equilibrium exchange rates that are more volatile than those generated by the other two models and, in some cases, even more volatile than the data. Second, the magnitude of the misalignment is typically higher than that measured with the PPP or BEER model.[8] This is especially the case for countries characterized by low degrees of trade openness since this in turn implies a low value for η (see formula 6) and hence a higher required exchange rate adjustment. For instance, the high current account gap in the US observed in the mid-2000s, combined with low trade shares, is interpreted by the MB model as a very sizeable overvaluation of the US dollar, exceeding 50%. Interestingly, the figure shows that this overvaluation was not eliminated by a US dollar depreciation, but through a substantial appreciation of the MB equilibrium exchange rate. A third feature of the MB model is the persistence of exchange rate misalignments, as best illustrated by the case of Sweden. The bottom line of the above discussion is that the popularity of the MB approach might be based more on its economic appeal rather than its ability to consistently deliver reliable estimates of equilibrium exchange rates from a positive perspective.

5 Exchange rate adjustments

A desirable feature of an equilibrium exchange rate model would certainly be the convergence of the real exchange rate to its equilibrium level. A particularly illustrative way to evaluate whether this is the case consists in producing a set of scatter plots showing real exchange rate changes at different horizons against the initial exchange rate misalignment. To the extent that there is adjustment, this relationship should be negative and, in case of full adjustment, the slope of the regression should be equal to -1. Figure 6 shows the results for the three analyzed models at different time horizons. To limit the number of figures, we cluster the results of all countries together, singling out with red dots the observations for the US dollar and with yellow dots those for the euro. The evidence is clear-cut. For both the PPP and BEER models, there is a powerful adjustment mechanism at play, which ensures that the initial exchange rate misalignment is absorbed, especially at longer horizons. For the MB model instead, the adjustment is at best weak.[9]

To evaluate this adjustment process more precisely we estimate the following regressions:

[8] Note that the scale of the y-axis in Figure 5 is wider than in Figures 1 and 3.

[9] As a robustness check we also estimated current account norms as in Cubeddu et al. (2019), i.e. on the basis of a large set of economic fundamentals at annual frequency. This analysis confirms that in-sample there is hardly any evidence that real exchange rates converge to the corresponding equilibria calculated with the MB model.

$$\Delta rer_{it,h} = \omega_{ih} + \delta_{ih}(rer_{i,t-h} - rer^M_{i,t-h}) + \epsilon_{it}, \quad (8)$$

where $\Delta rer_{it,h} = rer_{it} - rer_{i,t-h}$ is defined as the change in the log real exchange rate over horizon h and rer^M_{it} denotes the value of the equilibrium exchange rate from model $M \in \{PPP, BEER, MB\}$. One would expect the estimates of δ_{ih} to be significantly below zero for all horizons and converge to -1 with increasing h.

Table 4 contains estimates of model (8) for all countries individually and for the full panel. First, it can be seen that for almost all models and horizons the estimates of the slope parameter δ are below zero, which confirms that there is an adjustment mechanism at play. Second, the estimated values show that for the PPP and BEER models the magnitude of the adjustment increases with the horizon. Third, there are important differences in the pace of adjustment among the three models. This can be seen clearly by focusing on the panel estimates. At the one-quarter horizon the adjustment is fairly small for all models, between a minimum of 4% for the MB approach and a maximum of 7% for the BEER model. The divergence across models becomes larger at the one-year horizon, where the MB approach lags behind with 12% compared to 21% for PPP and 27% for the BEER model. At the five-year horizon a large fraction of the adjustment is already completed for the PPP and BEER models (77% and 89% respectively). For the MB model the corresponding number is much smaller (27%). A glance at the estimates for individual currencies confirms the higher predictive power of the PPP and BEER models in comparison to the MB approach. While for the PPP and BEER models the adjustment at medium and long horizons is significant for all currencies, for the MB model there are some cases where exchange rates have even diverged further from the corresponding equilibrium. Fourth, there is substantial country heterogeneity in the pace of real exchange rate adjustment for all models and horizons. Finally, a look at the evolution of the recursive estimates of the adjustment parameter derived with the full panel of data (Figure 7) reveals that the differences in the pace of adjustment across models are a constant feature also in earlier data vintages.

The main message of this section is that, using in-sample criteria, the predictive content of the BEER model is the highest followed closely by PPP, while there seems to be evidence of a disconnect between exchange rate realizations and equilibrium estimates for the MB model. In the next section we will review these conclusions on the basis of a true out-of-sample forecasting exercise.

6 Out of sample predictability

The discussion above suggests that real exchange rates do not behave randomly but adjust to close existing misalignments. In what follows we evaluate whether this also holds in an out-of-sample setting. We compare exchange rate forecasts derived from the three equilibrium exchange rate models introduced in section 4 to the RW benchmark. Our analysis does not account for data revisions as data constraints do not allow us to conduct a true real-time exercise. This limitation however should not give a particular advantage to any model.

We evaluate the out-of-sample forecast accuracy for horizons ranging from one to twenty quarters ahead. The models are estimated using recursive samples, where the first set of forecasts is produced with models estimated over the sample 1975:Q1–1994:Q4 for the period

1995:Q1–1999:Q4. This procedure is repeated with samples ending in each quarter from the period 1995:Q1–2018:Q3. As a result one-quarter ahead forecasts are evaluated on the basis of 96 observations, two-quarter ahead forecasts on the basis of 95 observations and so forth with the 20-quarter ahead forecasts comprising 77 observations.

Our procedure is as follows: For each model M, currency i, vintage period s and forecast horizon h we estimate the parameters of the panel model:

$$\Delta rer_{it,h} = \omega_{ih} + \delta_h(rer_{i,t-h} - rer^M_{i,t-h|s}) + \epsilon_{it} \tag{9}$$

and calculate the value of the forecast as:

$$rer^f_{i,s+h} = rer_{is} + \omega_{ih|s} + \delta_{h|s}(rer_{is} - rer^M_{is|s}). \tag{10}$$

In comparison to equation (8) the main differences are twofold. First, the estimation sample stops at period s, instead of T. This means that for forecasting purposes we use time-varying estimates of the adjustment pace, $\delta_{h|s}$, the values of which are presented in Figure 7. Second, we take recursive equilibrium exchange rate estimates, $rer^M_{is|s}$, rather than their full sample equivalents, rer^M_{is}. This difference is illustrated by Figures 1, 3 and 5. By relying on panel regressions, the adjustment parameter δ_h does not depend on currency i but exclusively on the vintage s.

Direct comparisons of forecasts are not always innocuous, as the relative out-of-sample performance across models is affected by their complexity (Green and Armstrong, 2015). In our two-step methodology, this problem is irrelevant for the second step as the number of parameters in the adjustment regression (9) is the same across the three models. But it matters for the first step, as the size of the estimation error in the derivation of the equilibrium exchange rate is higher for the BEER and MB models compared to PPP. This leaves open the possibility that BEER and MB have lower predictive power than PPP not due to misspecification, but rather due to higher estimation error, despite being, hypothetically, a better description of the data-generating process. However, while this is a dilemma from a theorist's view, what generally matters more from the perspective of a policy maker is the precision of the equilibrium exchange rate estimates based on the data available at a given point in time.

We assess the accuracy of forecasts with the most popular ex-post evaluation criterion, the root mean squared forecast error (RMSFE). In Table 5 and Figure 8 we report for each model the RMSFE as a ratio of the same statistic for the RW, so that values below unity indicate that a given method outperforms the benchmark. We also test whether a given method dominates the benchmark using the Clark and West (2006) test.

Several key findings become immediately evident. First, the PPP model generally performs well in forecasting terms. At long horizons it significantly outperforms the RW for six countries (CAN, EA, GBR, JPN, NOR and USA). In three other cases the performance is almost the same (AUS, CHE and NZL) while only in the case of Sweden, the PPP model clearly loses against the RW, as Sweden's currency exhibited a visible depreciation trend throughout the sample.[10] The second finding is that the BEER model is almost as compet-

[10]It is worth noting that despite this depreciation, the price level in Sweden was still much higher than in the euro area at the end of the sample, which suggests that a model based on absolute PPP might have been more successful in this special case. According to Eurostat data from the `prc_ppp_ind` database, the price

itive as PPP, but not systematically better. The attempt to capture the role of economic drivers of the real exchange rate has a mixed impact on forecasting performance depending on the country. It is clearly the best model for four countries (AUS, CAN, JPN and NZL). In two cases it delivers forecasts of similar quality to those derived with PPP (EA and USA). Finally, for three countries it delivers highly inaccurate forecasts (CHE, GBR and especially NOR). The third finding is that the MB model is beaten by the RW six out of ten times. For the United States and the euro area, the predictive power of the MB model is much worse than that of the PPP or BEER models. Paradoxically, the MB model performs slightly better out-of-sample than in-sample. The reason is that the empirical model only detects a very slow pace of adjustment toward equilibrium, i.e. the estimates of the adjustment coefficient δ_h from equation (9) are close to zero. Forecasts generated using the MB model hence tend to be closer to the RW than those generated using the other two models.

We complement the RMSFE analysis by plotting the full sequence of forecasts conducted at each point in time together with the corresponding realized values (Figures 9 and 10). Let us start by investigating the forecasts for the US dollar and the euro. By predicting a gradual reversion of the real exchange rate to the corresponding recursive equilibrium, both the PPP and BEER models usually deliver forecasts that are strongly correlated with subsequent realizations. For Japan and Australia the BEER model is more successful than PPP in gauging the future direction of the real exchange rate over the forecast horizon. The opposite is true for the United Kingdom and Norway, where PPP equilibria are better attractors than BEER equilibria. Although there are cases where the real exchange rate diverges from PPP or BEER equilibria, such as Sweden or, in the second part of the sample, Switzerland, in general both the PPP and BEER models anticipate future real exchange rate adjustments rather well. On the contrary, forecasts from the MB model are only weakly correlated with realizations. This could be explained by the high volatility of the MB implied equilibria and by having estimated a weak pace of adjustment to equilibrium. As a result, forecasts from the MB model resemble those that one would get using a RW model with a drift. This confirms our earlier insight on the limited predictive power of the MB approach.

We conclude this section with a short discussion on how the above findings relate to the exchange rate forecasting literature. The key academic reference in this discussion is the seminal paper by Engel et al. (2008), in which the authors show how model-based forecasts may under certain conditions be less accurate than a random walk benchmark, even when the model is the true underlying data generating process. However, it is often overlooked that in their conclusions Engel et al. (2008) explicitly state that this pessimistic result is likely to be less relevant at longer horizons, especially if estimation error is minimized by using panel data methods. Moreover, in previous work we presented evidence, based on Monte Carlo simulations, that if an open economy DSGE model were the true data generating process, it would out-perform the random walk in exchange rate forecasting (Ca' Zorzi et al., 2017). The exchange rate unpredictability hypothesis has also been questioned recently by a number of papers evaluating trading strategies on foreign exchange markets, which exploit information contained in macroeconomic variables (Colacito et al., 2020) or exchange rate expectations (Beckmann and Czudaj, 2017). Taking into account the above discussion, the relatively good in- and out-of-sample performance of the PPP and BEER models is much less surprising. It

level for individual consumption in Sweden was about 24% higher than in the euro area in 2018.

is at the same time insightful that the MB model, i.e. the only model that does not exploit the mean reverting properties of the real exchange rate, is mostly unreliable.

7 Sensitivity analysis

The purpose of this section is to carefully design robustness checks to evaluate the relative strengths and weaknesses of the PPP, BEER and MB models. We also investigate how changing from a recursive to a rolling forecasting scheme, as well as switching from real to nominal exchange rates influences the results of the forecasting contest.

7.1 Pace of reversion towards PPP-based equilibrium

Let us begin with the PPP model. Thus far we have imposed a pace of mean reversion given by the recursive estimates from panel regression (9). We have also shown in Figure 7 that such estimates have been relatively stable throughout the sample. The use of panel data has the advantage of limiting estimation error but the disadvantage of ignoring country heterogeneity. The first obvious robustness check consists in switching from panel direct forecasting (PDF) to direct forecasting (DF) in order to allow for country heterogeneity. In practice, for each vintage s, we estimate the following equation:

$$\Delta rer_{it,h} = \omega_{ih} + \delta_{ih}(rer_{i,t-h} - rer^{eqM}_{i,t-h|s}) + \epsilon_{it}, \tag{11}$$

where the adjustment coefficient δ_{ih} now also depends on the choice of the country.

As a second check we go to the other extreme, ignoring altogether country heterogeneity but also entirely bypassing the estimation error problem using the following expression:

$$\Delta rer_{it,h} = \delta_h(rer_{i,t-h} - rer^{eqM}_{i,t-h|s}) + \epsilon_{it}. \tag{12}$$

Following Ca' Zorzi et al. (2016) we assume that the exchange rate misalignment is vanishing exponentially. This can be formalized by setting $\delta_h = 1 - \rho^h$ and calibrating ρ such that half of the initial real exchange rate misalignment is absorbed in three years (Rogoff, 1996). As done in previous work, we label this approach the half-life PPP model (HL).

The results presented in Table 6 show that the DF specification is less accurate than the PDF one, particularly in the case of Canada and New Zealand. The HL version is instead considerably more competitive, outperforming the RW eight out of ten times in the long run. The two countries for which the HL model performs poorly are Sweden and to a lesser extent Switzerland, since it cannot anticipate the persistent depreciating trend of the krona and the strong appreciation of the franc at the end of the sample. Overall, among the different forecasting models that rely on the concept of PPP, the HL version of the model is the most competitive one. As already highlighted by Ca' Zorzi and Rubaszek (2020) for the case of real bilateral exchange rates against the US dollar, one of the key ingredients for the success of this model is that it is not subject to estimation error.

7.2 Exchange rate determinants in the BEER model

For the BEER model our robustness analysis aims at evaluating the importance of including all three fundamentals from a forecasting perspective. Our initial baseline is regression (3), which includes all three fundamentals as before. In Table 7 we also include three reduced versions of the same model where each of the three regressors is included separately. At short horizons both the full and reduced versions of the BEER model perform similarly to the RW. At the three- and five-year horizon the full version of the model is the most accurate half of the time but loses against one of the restricted, simpler BEER models in the other half of the cases. In general, adding or removing some fundamentals from the BEER model may (or may not) improve the forecasting performance of the model but it is difficult to identify a systematic pattern. As it turns out the most complete version of the BEER model (with three fundamentals) and the most restricted one, namely PPP (no fundamentals), perform similarly out of sample. Our intuition is that most of the forecasting power comes from their ability to capture the mean reverting property of the real exchange rate while the other fundamentals occasionally help (or harm) the accuracy of the exchange rate predictions but there is no evidence of a systematic pattern.

7.3 Normative assumptions in the MB framework

Next, we turn to the MB model. We propose to conduct three robustness checks and then interpret all the results at once. For the first robustness check let us recall that in the baseline specification of the MB model we had assumed Producer Currency Pricing (PCP) and the following trade elasticities ($\delta_x = 0, \delta_m = -1, \gamma_x = \gamma_m = -1$). Now, we assume imperfect exchange rate pass-through (IPT) to export and import prices, by setting the elasticities $\delta_x = -0.5, \delta_m = -0.5$ in line with the lower estimates from the recent contribution by Boz et al. (2017) on dominant currency invoicing. We incorporate an additional finding of this literature by also postulating lower volume elasticities ($\gamma_x = \gamma_m = -0.5$). Table 8 illustrates the implications of this alternative baseline for the elasticity of the current account with respect to the exchange rate. For all countries, elasticities are approximately halved, reaching levels that are considerably lower than those typically employed by the IMF in the external balance assessment (Cubeddu et al., 2019). In the second robustness check we review another critical assumption of the MB model, i.e. how to set target values for the current account. In what follows we set current account norms equal to zero ($ca^{norm} = 0$) instead of using the values implied by regression (5). This could be justified with a long term target for the international investment position of zero, assuming that valuation effects are on average balanced.[11] In the third robustness check, we replace the estimated pace of adjustment toward equilibrium (equation 9), which in the case of the MB model is extremely slow (Figure 7), with a calibrated value imposing a half-life of three years. It will become soon apparent what lessons can be drawn from introducing such an adjustment path.

The comparison of four versions of the MB model is presented in Table 9. First, insofar as the pace of reversion to equilibrium is estimated, the assumptions on current account elasticities with respect to the real exchange rate do not matter for the accuracy of our

[11]We could alternatively set the current account norm to values required to stabilize the international investment position. This would however not improve the performance of the model.

forecasts. The accuracy of PCP and IPT versions of the model is almost the same. The explanation is straightforward. Substituting the formula for MB misalignment (4) into the adjustment equation (9) yields:

$$\Delta rer_{it,h} = \omega_{ih} + \delta_h \left(\frac{\widetilde{ca}_{i,t-h} - ca^{norm}_{i,t-h}}{\eta_i} \right) + \epsilon_{it}. \tag{13}$$

If the parameter δ_h is estimated, decreasing the values of elasticities η_i by half for all currencies leads to a proportional decrease of the estimates for the δ_h parameter. As a result, the forecast for the real exchange rate is basically unaffected, even if the estimated exchange rate misalignment with the IPT assumption is twice as large as that calculated with PCP. The second conclusion from Table 9 is that setting the current account norm equal to zero has little adverse impact in forecasting terms. Finally, the HL version of the MB model indicates that imposing a gradual reversion of the real effective exchange rate toward the MB implied equilibrium over the forecast horizon usually worsens its forecasting performance. The main implication of this analysis is to highlight the paradox that the MB model performs better when there is no convergence to its estimated equilibrium. Under these circumstances equilibrium exchange rates are irrelevant and the implied forecasts similar to those derived with the RW model. This confirms that the model only has a normative dimension but is unreliable in predictive terms.

7.4 Rolling forecasting scheme

We also investigate whether a change from a recursive to a rolling forecasting scheme affects the baseline findings. For that purpose, we re-estimate all equations using data from a rolling window covering the last 80 quarters for each vintage and equilibrium exchange rate model. Such an approach should, in theory, be a good choice if the relation between exchange rates and fundamentals is subject to parameter instability (Rossi, 2006). It also shortens the sample, however, which increases estimation error. The relative importance of these two effects is ultimately an empirical question, which we discuss below.

Table 10, which presents the RMSFE ratios for the real effective exchange rates in the forecast competition based on the rolling scheme, confirms the thrust of our findings for the three models considered in this paper. In fact, the recursive scheme delivers slightly more accurate exchange rate forecasts than the rolling one. Note that since the forecasts from the benchmark RW model do not depend on the forecasting scheme, the RMSFE ratios from Tables 5 and 10 are directly comparable. A closer look at both tables indicates that for most currencies and PPP/BEER models these ratios are lower for the recursive scheme than the rolling one. This suggests that in our forecast competition forecast accuracy is more affected by parameter estimation error than parameter instability.

7.5 Nominal exchange rates

As a fifth and final robustness check we evaluate the relative forecasting performance of the models by switching to nominal exchange rate forecasting. For each model M, currency i, vintage period s and forecast horizon h we estimate the responsiveness of the nominal effective exchange rate to real exchange rate misalignments with the panel regression:

$$\Delta ner_{it,h} = \omega_{ih} + \delta_h(rer_{i,t-h} - rer^M_{i,t-h|s}) + \epsilon_{it} \quad (14)$$

and use the estimates to compute the forecast for the nominal exchange rate.

In Table 11 we report the performance of each model relative to the RW as before in terms of this alternative evaluation criterion. The overall results do not change substantially as again the PPP and BEER models tend to outperform the RW at longer horizons while the MB model is mostly inaccurate. The intuition behind the robustness of the results is that in the presence of flexible exchange rate regimes, most of the predictable adjustment in the real exchange rate takes place via the nominal exchange rate and not price adjustments.

7.6 Other extensions

One could envisage several further extensions to our analysis.

First, one could focus on non-linear exchange rate adjustment towards equilibrium, for example in the context of the ESTAR framework (see Norman, 2010; Ca' Zorzi and Rubaszek, 2020, for a survey). While there is ample support for non-linear adjustment in-sample (e.g. Curran and Velic, 2019), the evidence is much less compelling out-of-sample. It is easy to misinterpret the evidence that a panel ESTAR model outperforms the RW in exchange rate forecasting (Lopez-Suarez and Rodriguez-Lopez, 2011). Indeed, the good performance of the ESTAR model is probably mainly due to its mean-reverting properties rather than its non-linearity (Ca' Zorzi and Rubaszek, 2020). To put it differently, the RW is not a sufficiently competitive benchmark to establish conclusive evidence of non-linearities.

Second, one could add other explanatory variables to the specification of the direct forecast regression (9). Indeed, Engel and Wu (2021) have recently extended the PPP model to account for other fundamentals such as risk premia. Their study confirms our findings that it is almost impossible to improve the out-of-sample performance of exchange rate models beyond the exploitation of mean reversion.

A third extension could explore if the speed of adjustment towards equilibrium is country-specific or time-varying. For instance, Caputo (2015) shows that the speed of reversion towards BEER can be explained by the level of economic development and exchange rate regime. It might also depend on other time-varying factors such as the monetary policy stance or the phase of the business cycle, etc.

While these extensions would offer additional insights, the direct forecast framework applied in our analysis is very flexible, as the adjustment coefficient is estimated separately for each forecast horizon. Hence, additional forecasting accuracy gains are likely to be marginal and insufficient to improve the poor performance of the MB model.

8 Conclusions

Central banks and financial institutions invest time and resources to evaluate the long-term drivers of exchange rates. In this context, the choice of the methodological framework has a large bearing on the misalignment estimates, as evidenced by the recent study of Cheung and Wang (2020) for the Chinese Renminbi. The open question is how to choose among the available methodological frameworks.

In this paper, we evaluated the reliability of the three most popular methods for calculating equilibrium exchange rates using different criteria. While easy to compute, the PPP model offers little else in terms of economic appeal than the notion that real exchange rates are mean reverting. The BEER model is more insightful in this regard as it provides slow-moving equilibrium exchange rates partly driven by the evolution of economic fundamentals. The MB model exploits our deeply-rooted economic belief that exchange rates help absorb current account imbalances. The appeal of this approach is that one can translate an economic view on the responsiveness of trade volumes and prices into a current account elasticity and, hence, an assessment of an external imbalance into a measure of exchange rate misalignment. The narrative of the MB model is the richest, followed by that of the BEER and PPP models.

Out-of-sample the ranking of the models flips. Misalignments from the MB model provide the least accurate predictions of subsequent exchange rate adjustments, irrespective of the modeler's exact specification. The BEER model performs well but not necessarily better than the simpler PPP model, as both similarly derive their forecasting power from exploiting the mean reverting properties of the real exchange rate. A carefully conducted in-sample analysis also reveals the limitations of the MB model, e.g. in terms of equilibrium exchange rate instability.

The key and novel lesson from our analysis is that there is a trade-off between storytelling and predictive power of equilibrium exchange rate models. Specifically, the richer narrative of complex models does not increase their ability to explain future exchange rate movements. This finding sheds a new light on the relative reliability of the most popular equilibrium exchange rate models. Our results also highlight several recent findings from the literature. First, we show that if one controls for estimation error, mean-reversion of real exchange rates can be exploited in exchange rate forecasting, especially for longer horizons (Ca' Zorzi and Rubaszek, 2020). Second, by applying an out-of-sample evaluation criterion, we demonstrate that the link between real exchange rates and macroeconomic fundamentals is also feeble over longer horizons. In this respect, we add further evidence to the findings of Engel et al. (2008), Cheung et al. (2019) and Engel and Wu (2021) by showing that there is only one fundamental that has clear forecasting power, i.e. the real exchange rate itself. This notion has a direct key implication for our study, i.e. that it is difficult to provide more reliable estimates of equilibrium exchange rates than what one can obtain with the PPP model. Finally, we explain how high correlation of real and nominal exchange rates can be exploited to forecast the latter, which confirms the recent findings of Eichenbaum et al. (2020) and Ca' Zorzi and Rubaszek (2020). In conclusion, we believe that our analysis sheds new light on the strengths and weaknesses of the most popular equilibrium exchange rate concepts.

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Tables and Figures

Table 1: Foreign sector weights

	AUS	CAN	CHE	EA	GBR	JPN	NOR	NZL	SWE	USA	DEN	coverage
AUS		2.0	1.9	21.9	8.1	27.3	0.2	7.6	2.4	28.1	0.6	84.9
CAN	0.3		0.5	7.9	2.1	7.5	0.1	0.1	0.6	80.7	0.1	93.3
CHE	0.5	0.8		68.7	8.0	7.1	0.5	0.1	2.1	11.1	1.2	95.2
EA	1.2	2.3	12.2		27.2	16.9	2.1	0.2	7.1	26.9	4.0	88.9
GBR	1.0	1.5	3.2	62.6		9.0	1.2	0.2	3.3	16.6	1.4	94.1
JPN	2.9	4.1	2.4	30.0	6.4		0.6	0.7	1.6	50.6	0.7	75.9
NOR	0.2	0.9	1.9	45.6	11.8	7.4		0.1	15.5	8.9	7.7	96.2
NZL	29.9	1.6	1.2	14.9	6.7	23.0	0.2		1.7	20.3	0.5	90.9
SWE	0.8	1.1	2.8	54.7	11.2	6.9	5.1	0.2		11.1	6.1	95.8
USA	1.5	28.9	2.0	27.8	7.0	30.0	0.4	0.3	1.5		0.5	75.7

Notes: The table presents the weights used to compute effective exchange rates and foreign sector variables. They are obtained on the basis of weights from 1995 used by the Bank for International Settlements to construct the narrow effective exchange rate indexes. The last column presents the coverage ratio of our foreign sector in comparison to the BIS narrow index.

Table 2: Data and sources

Variable	Details	Source	Ticker
Exchange Rates	Bilateral ER against USD, EOP	BIS	Q???XUSE@BIS
Trade Weights	Based on trade in 1995	BIS	B???X???@BIS
Consumer Price Index	SA	IMF IFS	C???PC@IFS
GDP per Capita	Based on real PPP GDP and interpolated population data, SA	OECD NA, UN	B???GDPC@OECDNAQ C???TB@UNPOP
Terms of Trade	Ratio of export to import goods and services deflators, SA	OECD EO	Q???JX@OUTLOOK Q???JM@OUTLOOK
Net Foreign Assets	% of GDP (in PPP terms), based on balance of payments data, complemented with interpolated data from EWN	IMF IFS, EWN	C???VC@IFS C???VD@IFS
Export, Import Shares	% of GDP, goods and services, SA	OECD EO	Q???XA@OUTLOOK Q???MA@OUTLOOK
Current Account	% of GDP, SA	OECD EO, MEI	S???UBTR@OECDMEI Q???BCAP@OUTLOOK

Notes: BIS - Bank for International Settlements database, IMF IFS - IMF International Financial Statistics, OECD - Organization for Economic Cooperation and Development, UN - United Nations, NA - National Account database, EO - Economic Outlook database, MEI - Main Economic Indicators, EWN - External Wealth of Nations database (Lane and Milesi-Ferretti, 2018), SA - seasonally adjusted, EOP - end of period.

Table 3: The results of BEER and CA norm regressions

Dependent variable	Real Effective Exchange Rate				Current Account Balance			
GDP per Capita	0.320***			0.218**	0.102***			0.036***
Net Foreign Assets		-0.016		-0.033**		0.057***		0.051***
Terms of Trade			0.410***	0.430***			0.159**	0.170***
R^2	0.020	0.002	0.232	0.250	0.207	0.483	0.016	0.521

Notes: The table shows estimates for the panel BEER regression (model 3) (with fixed effects) and its restricted versions as well as pooled estimates for the CA norm regression (model 5). Asterisks ***, ** and * denote, respectively, the 1%, 5% and 10% significance levels. All models were estimated using observations for 10 countries over the period 1975:Q1–2018:Q4, i.e. using 1760 observations. NFA and CA data are expressed in terms of each country's GDP.

Table 4: In-sample adjustment of real effective exchange rate to equilibrium

	PPP	BEER	MB	PPP	BEER	MB
	1-quarter horizon			4-quarter horizon		
AUS	-0.04**	-0.08***	-0.06	-0.16***	-0.30***	-0.23*
CAN	-0.04**	-0.05**	-0.04	-0.18***	-0.24***	-0.15
CHE	-0.07***	-0.06**	-0.03	-0.25***	-0.21***	-0.02
EA	-0.07**	-0.07**	0.00	-0.28***	-0.31***	-0.01
GBR	-0.07***	-0.06**	-0.05	-0.31***	-0.27***	-0.21
JPN	-0.06**	-0.07***	-0.12***	-0.25***	-0.33***	-0.37***
NOR	-0.15***	-0.04*	-0.01	-0.46***	-0.15**	-0.04
NZL	-0.05**	-0.11***	-0.07**	-0.20***	-0.34***	-0.14**
SWE	-0.02	-0.04	-0.03	-0.11	-0.17**	-0.11
USA	-0.05*	-0.06*	-0.05***	-0.22**	-0.27**	-0.20***
Panel	-0.05***	-0.07***	-0.04***	-0.21***	-0.27***	-0.12***
	12-quarter horizon			20-quarter horizon		
AUS	-0.47***	-0.73***	-0.57***	-0.58***	-0.87***	-0.48*
CAN	-0.62***	-0.81***	-0.70***	-0.90***	-1.09***	-1.44***
CHE	-0.47***	-0.38***	0.15	-0.46***	-0.34**	-0.04
EA	-0.72***	-0.79***	0.01	-1.11***	-1.24***	0.10**
GBR	-0.95***	-0.82***	-0.63*	-1.25***	-1.08***	-0.62*
JPN	-0.70***	-0.84***	-0.63***	-0.72***	-0.86***	-0.76***
NOR	-0.92***	-0.22**	-0.16**	-0.91***	-0.22**	-0.18***
NZL	-0.58***	-0.95***	-0.12	-0.74***	-1.11***	-0.10
SWE	-0.29***	-0.44***	-0.26*	-0.35***	-0.55***	-0.24*
USA	-0.80***	-0.94***	-0.54***	-1.30***	-1.52***	-0.72***
Panel	-0.60***	-0.72***	-0.26***	-0.77***	-0.89***	-0.27***

Notes: The table presents estimates of the adjustment parameter δ_h from regressions (8), in which changes in the log real effective exchange rate are explained by exchange rate misalignments. Asterisks ***, ** and * denote, respectively, the 1%, 5% and 10% significance levels.

Table 5: Root mean squared forecast error (RMSFE) for real effective exchange rates
Panel direct forecast method

	PPP	BEER	MB	PPP	BEER	MB
	1-quarter horizon			4-quarter horizon		
AUS	1.00	0.98**	1.01	1.01	0.89**	1.05
CAN	1.00	1.00	1.00	0.99*	1.00*	1.01
CHE	1.00	1.02	1.01	0.99	1.08	1.07
EA	0.99	1.00	1.02	0.97**	1.00*	1.07
GBR	0.99**	1.01	1.00	0.95***	1.02	1.00
JPN	0.99*	0.98***	1.00	0.93**	0.88***	1.03
NOR	0.98***	1.06	1.01	0.92***	1.31	1.02
NZL	1.01	1.00	0.99*	1.02	0.98*	1.00
SWE	1.03	1.02	1.00	1.12	1.06	1.01
USA	0.99*	1.00	0.99*	0.95**	0.98*	0.98*
	12-quarter horizon			20-quarter horizon		
AUS	1.20	0.69***	1.16	1.07	0.53***	1.23
CAN	1.02	0.90***	1.04	0.84***	0.71***	1.12
CHE	1.05	1.19	1.12	1.08	1.21	1.01
EA	0.86***	0.92**	1.13	0.81***	0.82***	1.11
GBR	0.81***	1.07**	1.00	0.78***	1.14	1.05
JPN	0.81***	0.69***	1.06	0.88***	0.67***	1.10
NOR	0.83***	2.35	1.00	0.76***	2.49	0.98*
NZL	1.00	0.83***	1.02	0.97**	0.85***	0.95**
SWE	1.64	1.20	0.97*	1.54	1.02	0.90***
USA	0.83***	0.88**	0.94**	0.71***	0.76***	0.98

Notes: The table shows the ratios of the RMSFE from a given model in comparison to the RW benchmark so that values below unity indicate that forecasts from the model are more accurate than the benchmark. Asterisks ***, ** and * denote, respectively, the 1%, 5% and 10% significance levels of the Clark-West test, where the long-run variance is calculated with the Newey-West method.

Table 6: RMSFE for real effective exchange rates from the PPP model
Sensitivity analysis with respect to the pace of equilibrium reversion

	PDF	HL	DF	PDF	HL	DF
	1-quarter horizon			4-quarter horizon		
AUS	1.00	1.00	1.00	1.01	0.98**	1.01
CAN	1.00	1.00	1.00	0.99*	0.98**	0.99
CHE	1.00	1.01	1.05	0.99	1.01	1.16
EA	0.99	0.99	1.00	0.97**	0.95**	0.98*
GBR	0.99**	0.99**	0.99*	0.95***	0.94***	0.95***
JPN	0.99*	0.98**	1.00	0.93**	0.90**	0.96**
NOR	0.98***	0.98***	0.97***	0.92***	0.92***	0.90***
NZL	1.01	1.01	1.05	1.02	1.01	1.11
SWE	1.03	1.06	1.02	1.12	1.16	1.05
USA	0.99*	0.99*	1.00	0.95**	0.94**	0.97**
	12-quarter horizon			20-quarter horizon		
AUS	1.20	1.03	1.13	1.07	0.93**	1.08
CAN	1.02	0.93**	1.24	0.84***	0.79***	1.08
CHE	1.05	1.04	1.21*	1.08	1.07	1.08
EA	0.86***	0.85***	0.89***	0.81***	0.77***	0.86***
GBR	0.81***	0.83***	0.85***	0.78***	0.77***	0.87***
JPN	0.81***	0.80***	0.84***	0.88***	0.78***	0.91**
NOR	0.83***	0.84***	0.91***	0.76***	0.77***	0.81***
NZL	1.00	0.98**	1.25	0.97**	0.97**	1.22
SWE	1.64	1.57	1.34	1.54	1.68	1.24
USA	0.83***	0.84***	0.84***	0.71***	0.74***	0.61***

Notes: As in Table 5. PDF, DF and HL indicate panel direct forecast, direct forecast and half-life, respectively. These abbreviations describe the method of calculating the pace of equilibrium reversion. For PDF the pace is estimated using panel data (equation 9), for DF it is estimated separately for each currency (equation 11) and for HL it is assumed that the half-life of the deviation from equilibrium is three years (equation 12).

Table 7: RMSFE for real effective exchange rates from the BEER model
Sensitivity analysis with respect to the set of regressors

	Full	GDP	NFA	ToT	Full	GDP	NFA	ToT
	1-quarter horizon				4-quarter horizon			
AUS	0.98**	0.99*	0.99	1.00	0.89**	0.99**	0.91*	1.01
CAN	1.00	0.99	1.00	1.00	1.00*	0.98*	0.99*	1.01
CHE	1.02	1.02	1.00	1.01	1.08	1.08	1.01	1.05
EA	1.00	1.00	1.00	1.00	1.00*	0.98*	0.97**	0.97*
GBR	1.01	0.99*	1.00*	0.99*	1.02	0.96***	0.97***	0.96***
JPN	0.98***	0.99*	0.98*	0.99***	0.88***	0.93**	0.89**	0.95***
NOR	1.06	0.98***	1.03	0.99	1.31	0.94***	1.11	1.00
NZL	1.00	1.01	1.00	1.01	0.98*	1.03	0.99	1.03
SWE	1.02	1.04	1.01	1.03	1.06	1.15	1.04	1.10
USA	1.00	0.99*	0.99	1.00	0.98*	0.94***	0.96*	0.97**
	12-quarter horizon				20-quarter horizon			
AUS	0.69***	1.14	0.77*	1.19	0.53***	0.99**	0.67**	1.07
CAN	0.90***	0.99**	0.93**	1.08	0.71***	0.82***	0.80***	0.83***
CHE	1.19	1.42	1.01	1.12	1.21	1.55	0.96*	1.07
EA	0.92**	0.89***	0.88***	0.88**	0.82***	0.83***	0.81***	0.83***
GBR	1.07	0.87***	0.92***	0.84***	1.14	0.89***	0.94***	0.80***
JPN	0.69***	0.76***	0.70***	0.84***	0.67***	0.81***	0.66**	0.94***
NOR	2.35	1.00	1.68	1.24	2.49	0.88***	1.85	1.16
NZL	0.83***	1.04	0.91**	0.98**	0.85***	1.04	0.87**	0.97**
SWE	1.20	1.72	1.22	1.54	1.02	1.57	1.08	1.41
USA	0.88**	0.81***	0.84**	0.88***	0.76***	0.70***	0.74***	0.72***

Notes: As in Table 5. Full, GDP, NFA and ToT indicate which variables enter the set of explanatory variables of model (3), which is used to derive the values of BEER. Full describes the specification with all three variables, whereas GDP, NFA and ToT the specifications with individual variables.

Table 8: MB model assumptions
Current account reaction to a 1% real effective exchange rate depreciation

	Openness in 2018 (% GDP)		CA to RER elasticity ($-\eta_i$)		
	Export	Import	PCP	IPT	IMF
AUS	23	22	0.23	0.12	0.20
CAN	32	34	0.32	0.15	0.27
CHE	66	53	0.66	0.36	0.53
EA	28	25	0.28	0.15	-
GBR	30	31	0.30	0.15	0.24
JPN	18	18	0.18	0.09	0.14
NOR	38	32	0.38	0.20	0.35
NZL	28	28	0.28	0.14	0.25
SWE	47	44	0.47	0.24	0.36
USA	12	15	0.12	0.05	0.12

Notes: The table presents the reaction of the current account balance (in % of GDP) to a 1% depreciation of the real effective exchange rate (see formula 6) using trade shares for 2018. PCP and IPT denote Producer Currency Pricing and Imperfect Pass-Through assumptions, whereas IMF indicates values used by the IMF (Cubeddu et al., 2019). For PCP we assume that $\delta_x = 0, \delta_m = -1, \gamma_x = \gamma_m = -1$, whereas for ICP $\delta_x = -0.5, \delta_m = -0.5, \gamma_x = \gamma_m = -0.5$.

Table 9: RMSFE for real effective exchange rates from the MB model
Sensitivity analysis with respect to model assumptions

	PCP	IPT	CA0	HL	PCP	IPT	CA0	HL
	1-quarter horizon				4-quarter horizon			
AUS	1.01	1.01	1.01	1.01	1.05	1.05	1.04	1.06
CAN	1.00	1.00	1.00	0.99*	1.01	1.01	1.01	0.97**
CHE	1.01	1.01	1.01	1.02	1.07	1.07	1.05	1.10
EA	1.02	1.02	1.01	1.04	1.07	1.06	1.03	1.13
GBR	1.00	1.00	1.00	0.99	1.00	0.99	1.01	0.98
JPN	1.00	1.00	1.01	1.00	1.03	1.03	1.06	1.03
NOR	1.01	1.01	1.01	1.03	1.02	1.02	1.03	1.12
NZL	0.99*	0.99*	1.00	0.99**	1.00	1.00	1.00	0.97**
SWE	1.00	1.00	1.00	1.06	1.01	1.01	1.01	1.18
USA	0.99*	0.99*	1.00	1.05	0.98*	0.98*	1.01	1.15
	12-quarter horizon				20-quarter horizon			
CAN	1.04	1.04	1.09	0.90***	1.12	1.12	1.18	0.86***
CHE	1.12	1.11	1.05	1.24	1.01	1.01	0.99	1.19
EA	1.13	1.13	1.08	1.25	1.11	1.11	1.13	1.25
GBR	1.00	0.99	1.03	0.93**	1.05	1.05	1.08	0.96**
JPN	1.06	1.06	1.11	1.06	1.10	1.10	1.19	1.00*
NOR	1.00*	1.00	1.08	1.40	0.98*	0.99	1.20	1.50
NZL	1.02	1.02	1.03	0.97**	0.95**	0.95**	0.98*	0.98*
SWE	0.97*	0.96**	0.95**	1.64	0.90***	0.90***	0.92***	1.80
USA	0.94**	0.92***	1.04	1.24	0.98	0.94**	1.10	1.27

Notes: As in Table 5. PCP and IPT denote the MB models in which the equilibrium value is derived using Producer Currency Pricing (PCP) or Imperfect Pass-Through (IPT) assumptions (see notes to Table 8). In CA0 and HL we use PCP elasticities, but assume that the current account norm is null (CA0) or that the half life of the deviation from equilibrium is equal to three years (HL, as in Table 6).

Table 10: RMSFE for real effective exchange rates from rolling regressions
Sensitivity analysis with respect to forecasting scheme

	PPP	BEER	MB	PPP	BEER	MB
	1-quarter horizon			4-quarter horizon		
AUS	1.02	0.99*	1.02	1.07	0.92**	1.09
CAN	1.01	1.01	1.00	1.04	1.07	1.01
CHE	1.00	1.06	1.01	0.97*	1.26	1.09
EA	0.98**	0.99*	1.02	0.94**	0.95**	1.07
GBR	0.99**	1.01	1.00	0.95***	1.03	1.00
JPN	1.00	0.98**	1.01	0.96*	0.90***	1.04
NOR	0.98**	1.02	1.02	0.93***	1.05	1.07
NZL	1.00	1.00	0.99*	0.99	0.98*	0.99
SWE	1.01	0.98**	1.00	1.01	0.94**	1.01
USA	0.98*	1.00	1.00*	0.92***	0.98**	0.99*
	12-quarter horizon			20-quarter horizon		
AUS	1.40	0.74***	1.25	1.35	0.61***	1.33
CAN	1.16	1.07	1.06	1.01	0.85***	1.13
CHE	0.95**	1.71	1.20	1.00*	1.90	1.12
EA	0.84***	0.81***	1.10	0.77***	0.70***	1.03
GBR	0.83***	1.12	1.00	0.80***	1.21	1.06
JPN	0.90**	0.69***	1.07	1.04**	0.71***	1.10
NOR	0.93***	1.49	1.01*	0.87***	1.35	0.95**
NZL	0.94**	0.79***	1.01	0.97**	0.81***	0.95**
SWE	1.46	0.90***	1.00	1.42	0.75***	0.88***
USA	0.78***	0.89**	0.86***	0.63***	0.77***	0.81***

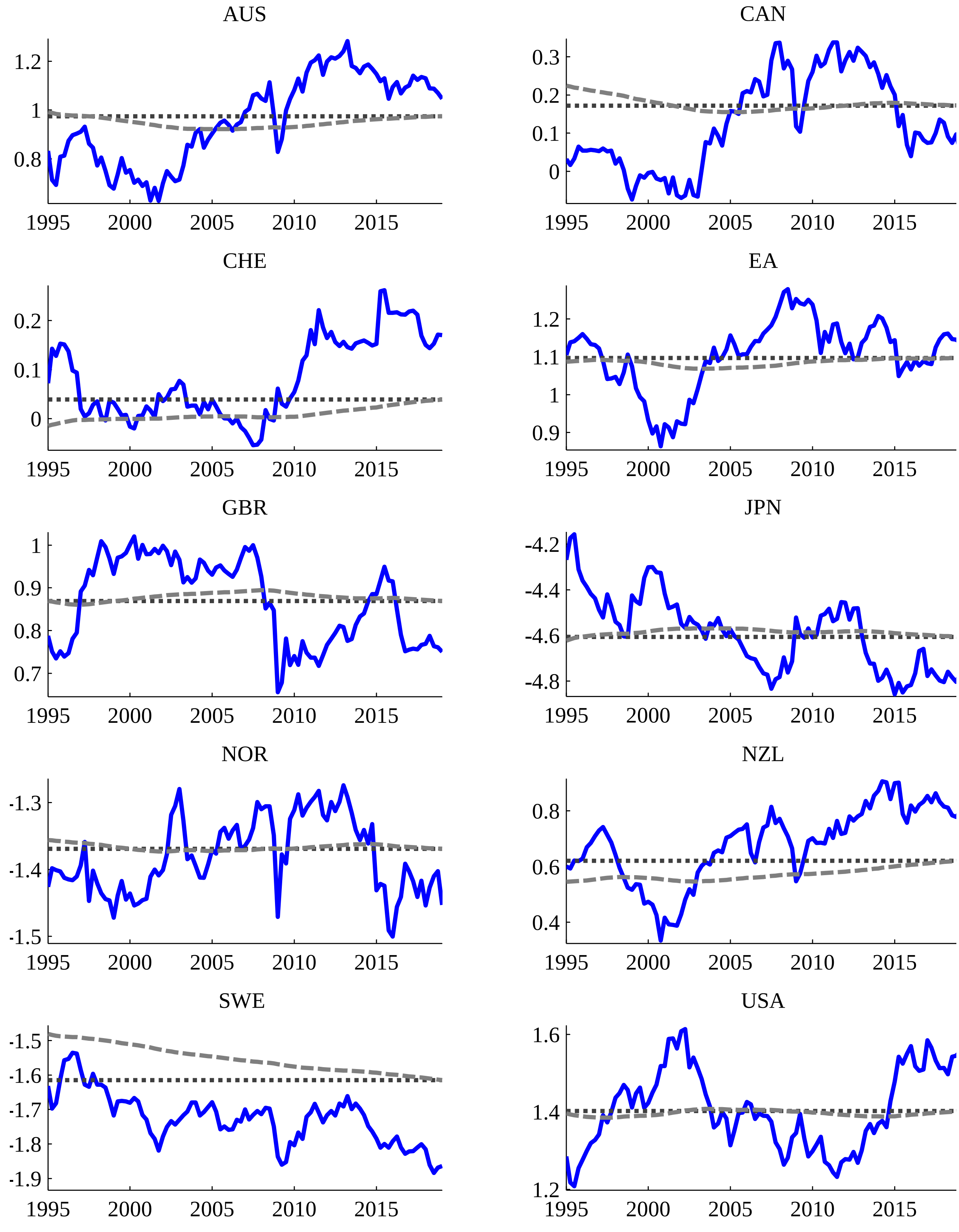
Notes: As in Table 5.

Table 11: Root mean squared forecast error (RMSFE) for nominal effective exchange rates
Panel direct forecast method

	PPP	BEER	MB	PPP	BEER	MB
	1-quarter horizon			4-quarter horizon		
AUS	1.01	0.99*	1.01	1.05	0.92**	1.08
CAN	1.00	1.00	1.00	0.98*	0.98**	1.01
CHE	0.99**	1.00	1.01	0.97**	1.05	1.11
EA	1.00	1.00	1.04	0.97*	0.99	1.11
GBR	1.00	1.01	1.00	0.99**	1.03	1.01
JPN	1.00	0.99*	1.01	1.00*	0.96**	1.05
NOR	0.99**	1.05	1.01	0.95**	1.22	1.01
NZL	1.04	1.03	1.00	1.13	1.10	1.02
SWE	1.00	1.01	1.00	1.01	1.04	1.01
USA	0.99	1.00	0.99*	0.96**	0.98*	0.97*
	12-quarter horizon			20-quarter horizon		
AUS	1.27	0.70***	1.27	1.25	0.67***	1.46
CAN	0.97**	0.86***	1.05	0.81***	0.75***	1.13
CHE	0.89**	1.04*	1.09	0.80***	0.94**	0.87***
EA	0.88***	0.93**	1.19	0.84***	0.87***	1.13
GBR	0.91***	1.09	1.00	0.89***	1.14	1.04
JPN	0.93***	0.83***	1.11	1.08	0.86***	1.23
NOR	0.88**	1.83	0.93**	0.82**	1.90	0.90**
NZL	1.32	1.18	1.08	1.53	1.42	1.23
SWE	1.18	1.08	1.06	0.88**	1.03	1.26
USA	0.85**	0.88**	0.91***	0.73***	0.76***	0.93**

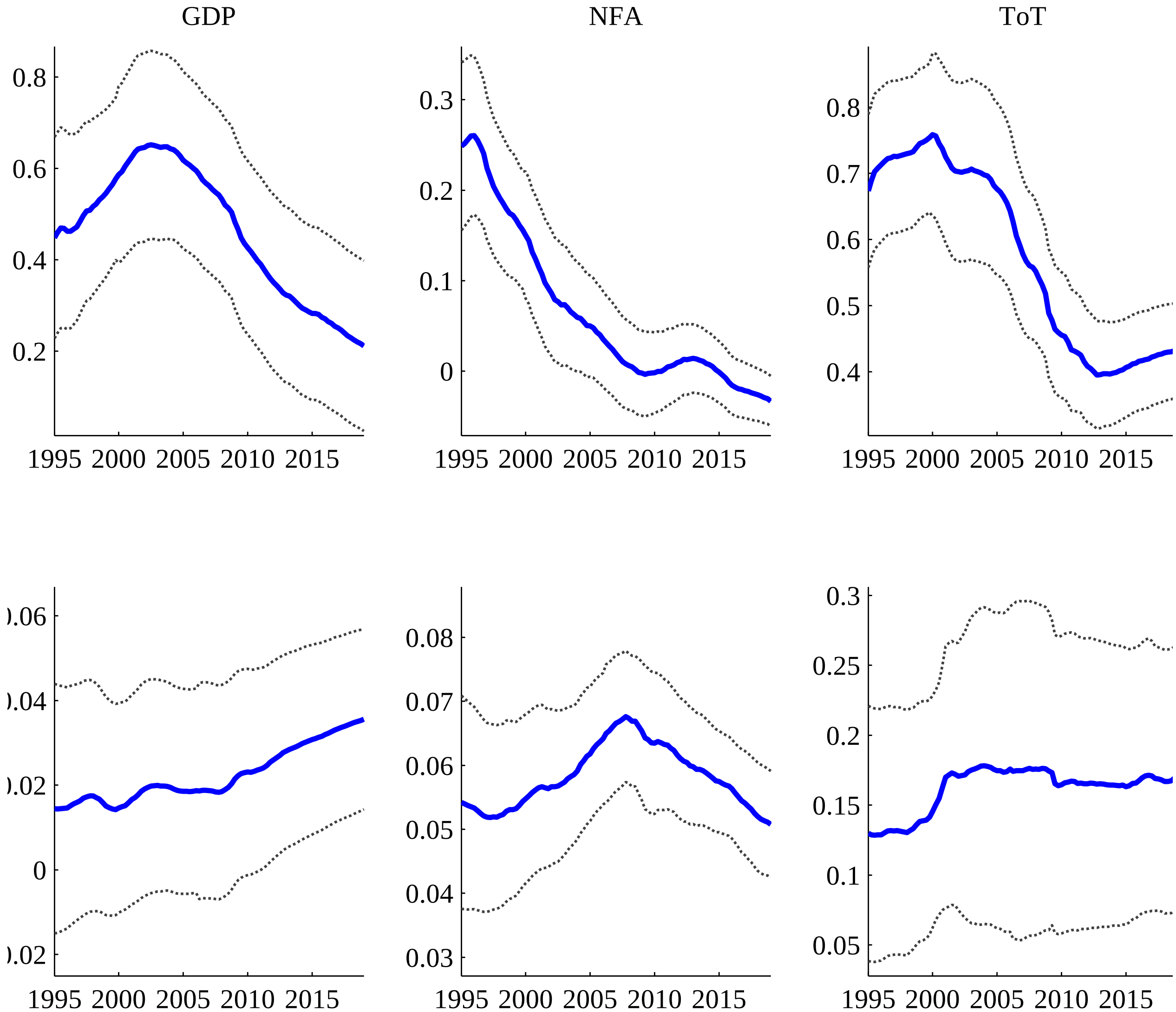
Notes: As in Table 5.

Figure 1: PPP-based equilibrium exchange rates



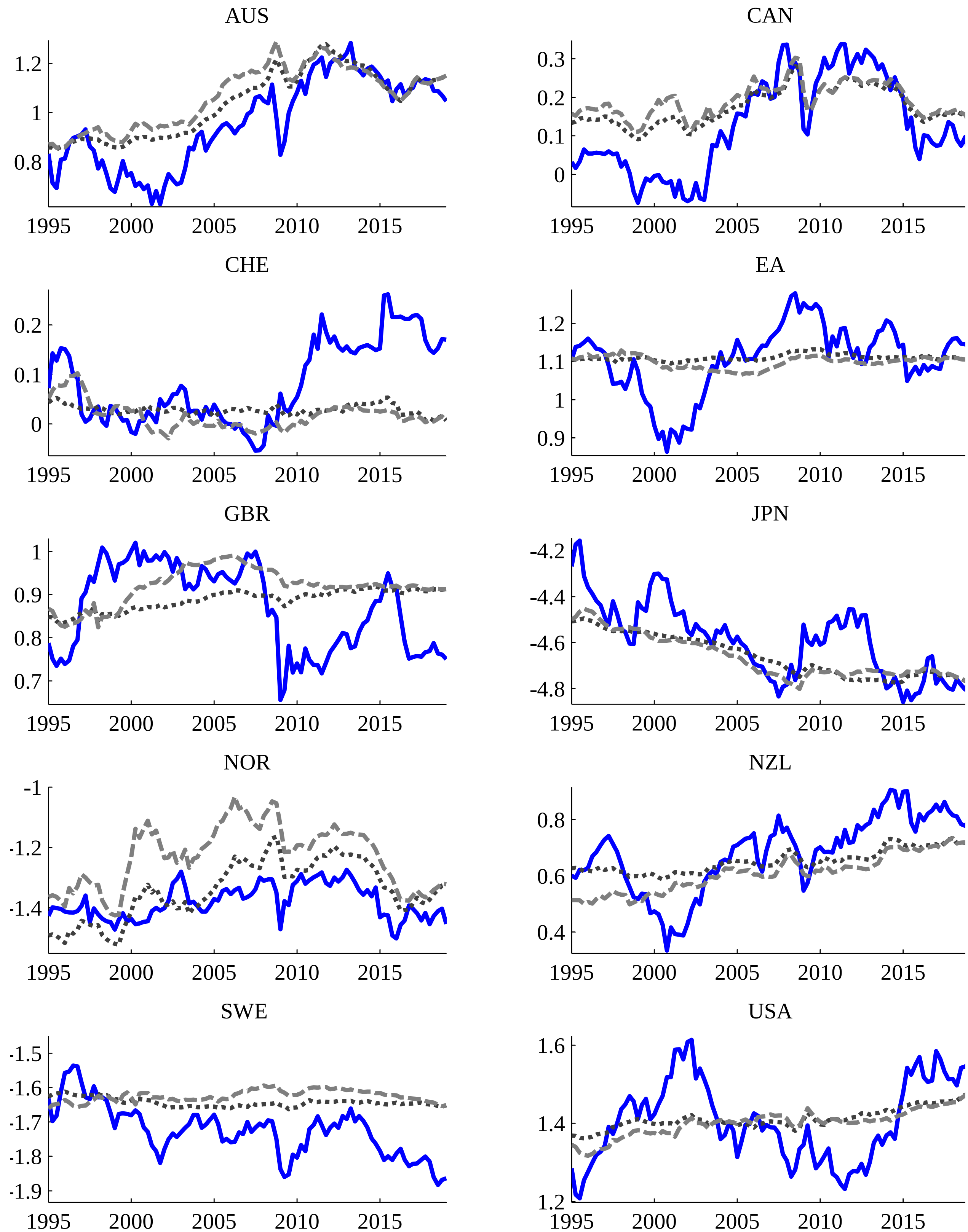
Notes: The figure presents the log of actual real effective exchange rates (solid line) and its equilibrium values (dotted and dashed lines). The dotted and dashed lines denote full and recursive sample estimates of the equilibrium exchange rates, respectively.

Figure 2: Recursive estimates of BEER and CA regressions



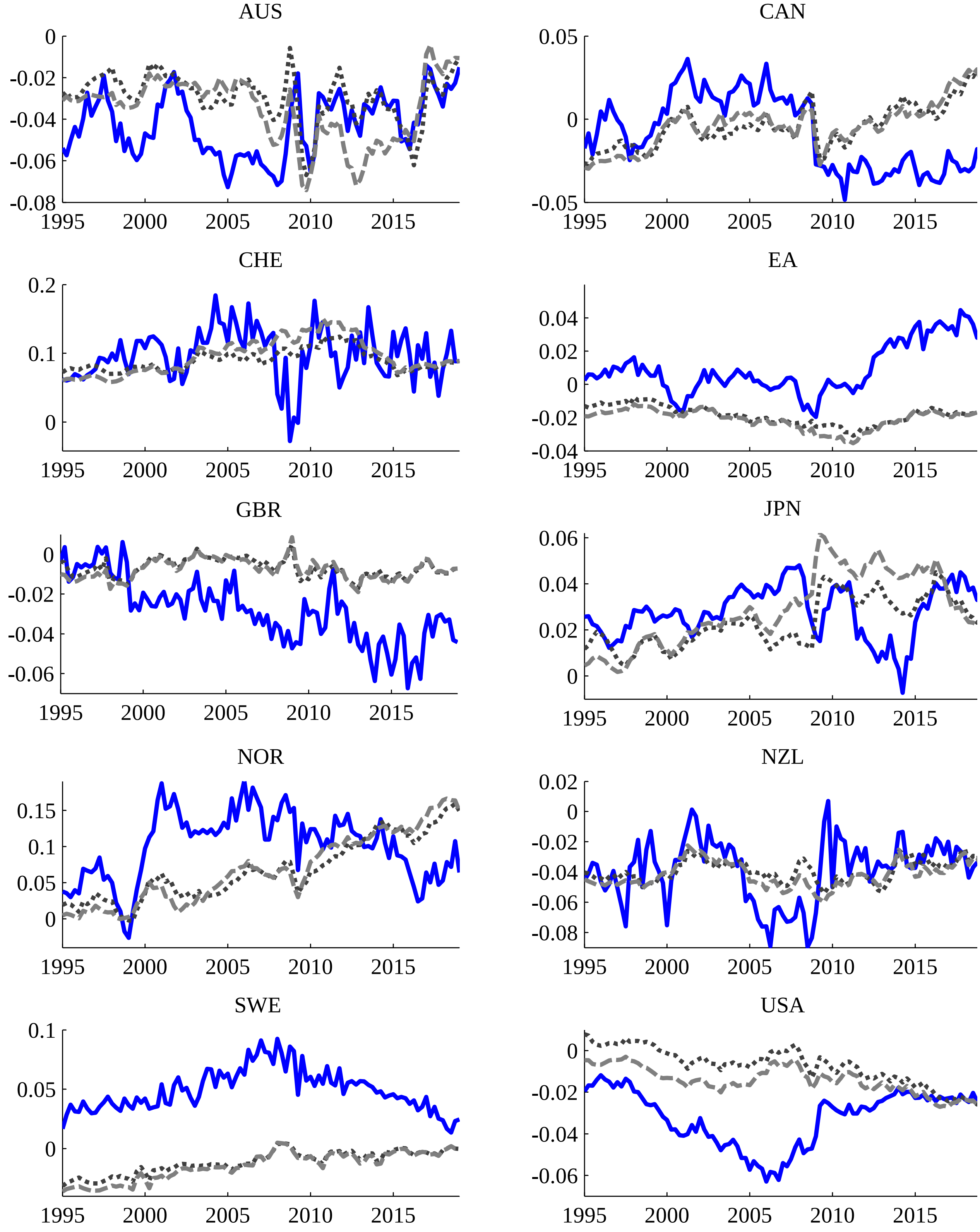
Notes: The upper panels present recursive estimates of the BEER model (equation 3). The lower panels present recursive estimates of the current account model (equation 5). The dotted lines denote the 95% confidence interval.

Figure 3: BEER-based equilibrium exchange rates



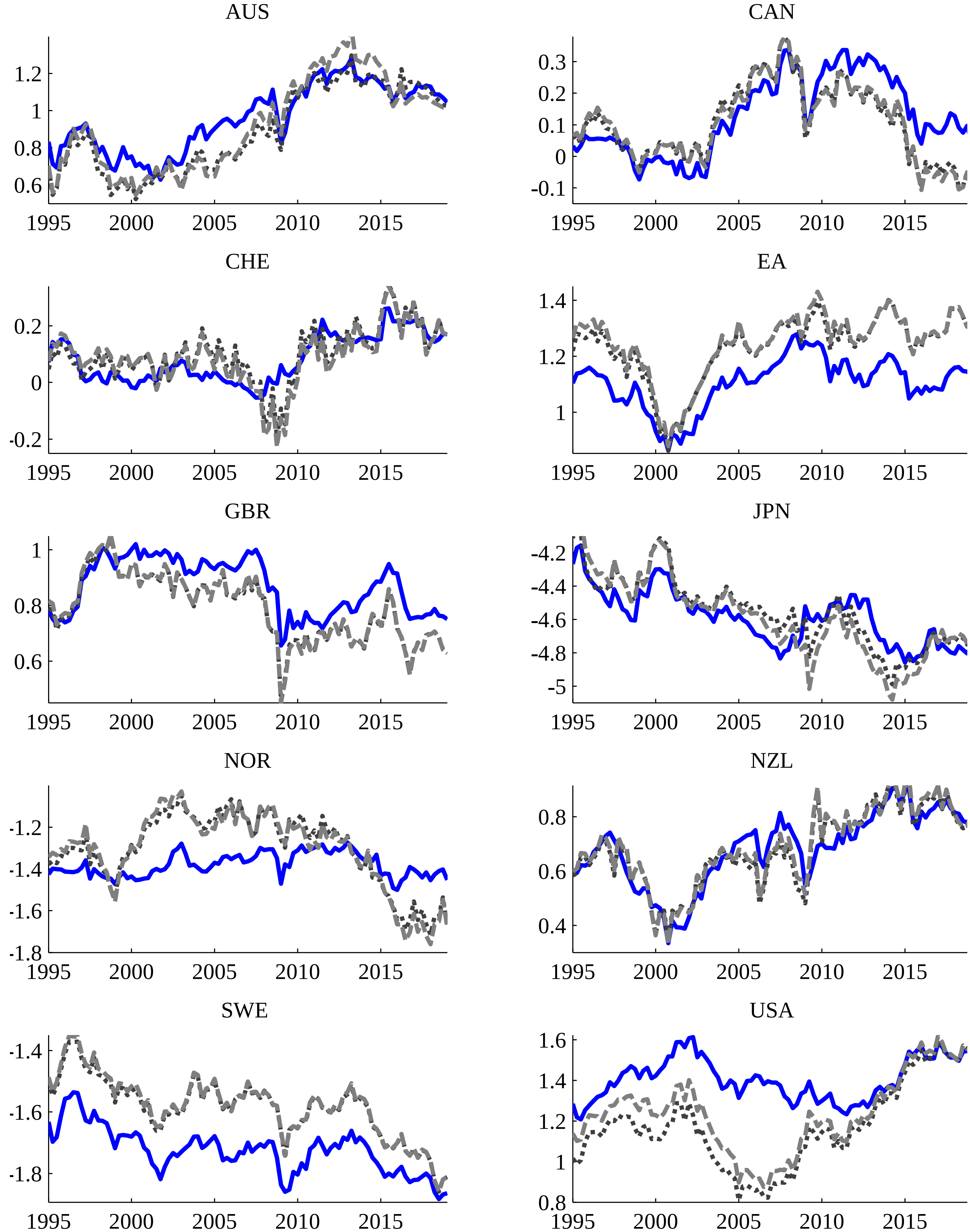
Notes: As in Figure 1.

Figure 4: Current account norms



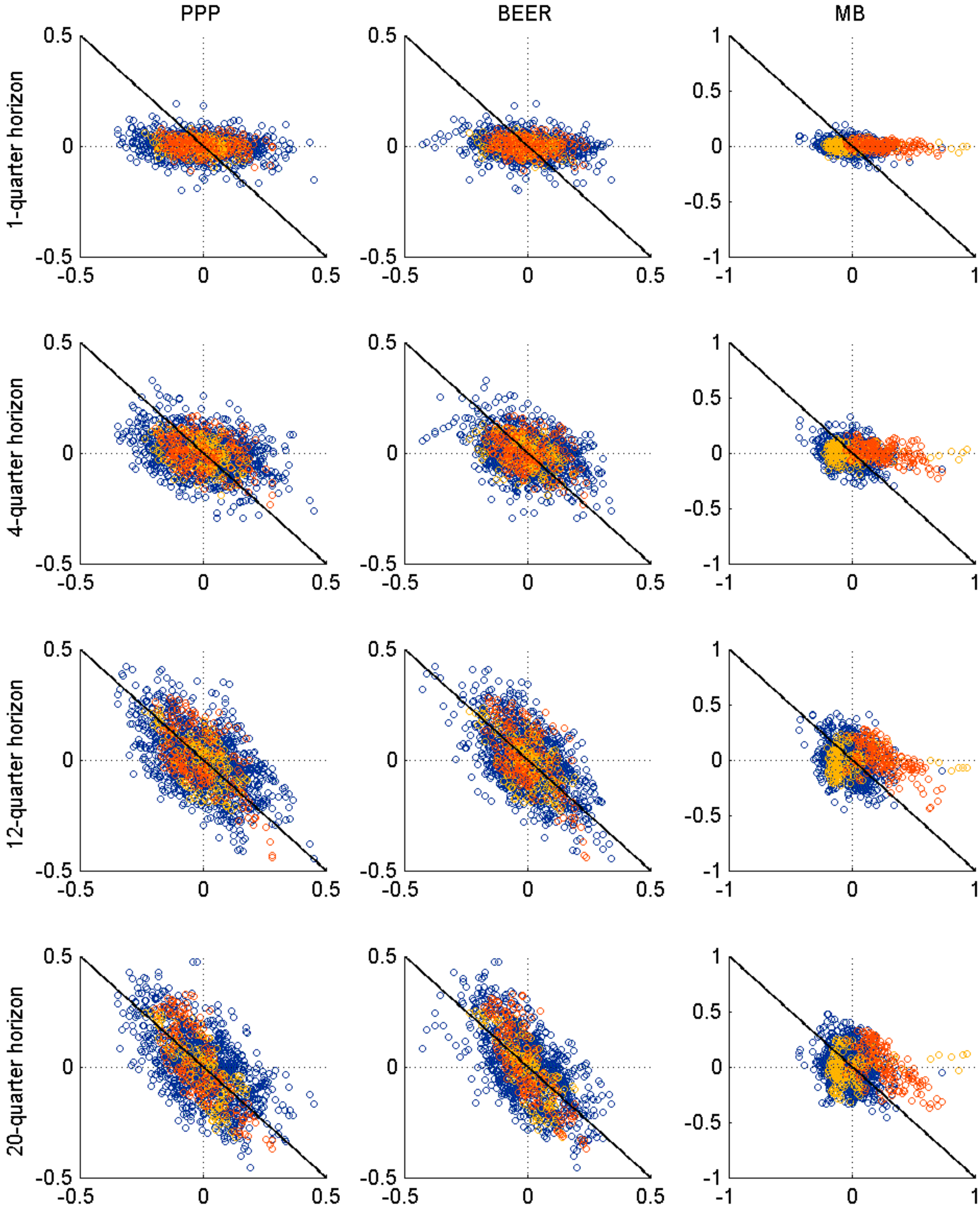
Notes: The figure presents the actual current account to GDP ratio (solid line) and its target values based on the CA norm model. The dotted and dashed lines indicate full sample and recursive estimates of the CA norm, respectively.

Figure 5: MB-based equilibrium exchange rates



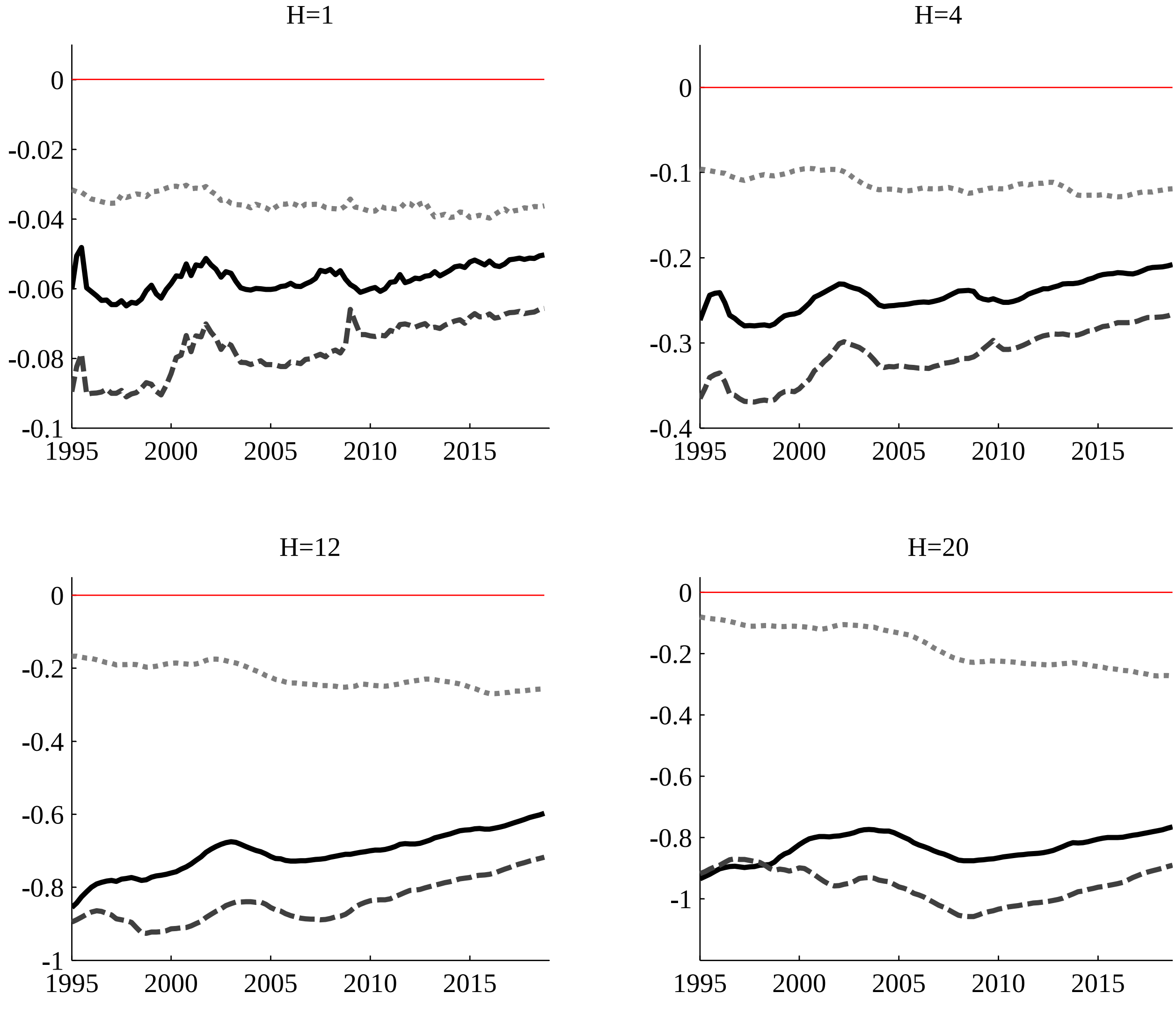
Notes: As in Figure 1.

Figure 6: Scatter plot of exchange rate changes vs. misalignments



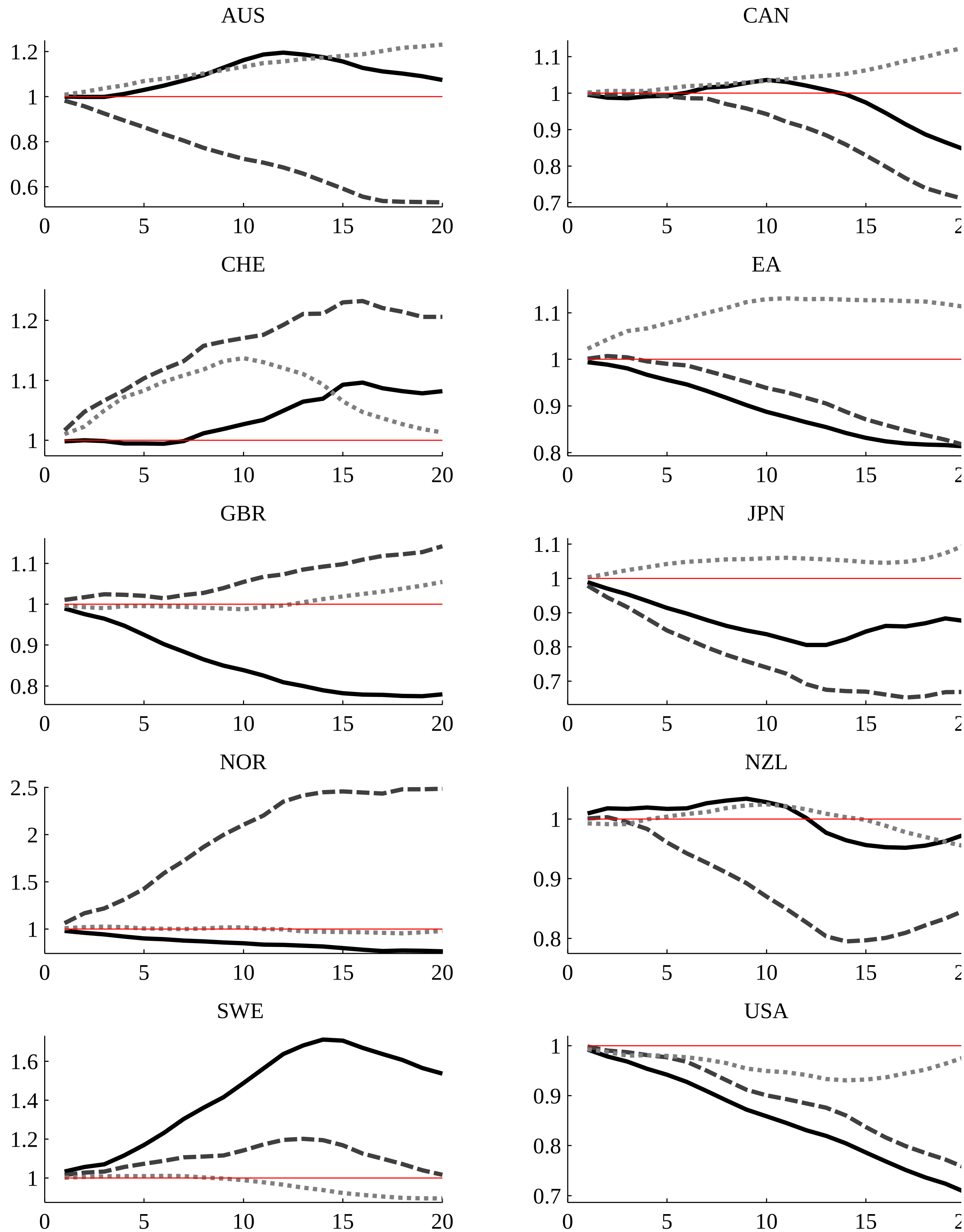
Notes: The x-axis of the figure represents deviations of real effective exchange rates from their full-sample equilibrium, whereas the y-axis represents subsequent real exchange rate adjustments. USD and EUR are marked with red and yellow dots, respectively. The diagonal line represents perfect adjustment to equilibrium.

Figure 7: Recursive panel estimates of the equilibrium adjustment pace



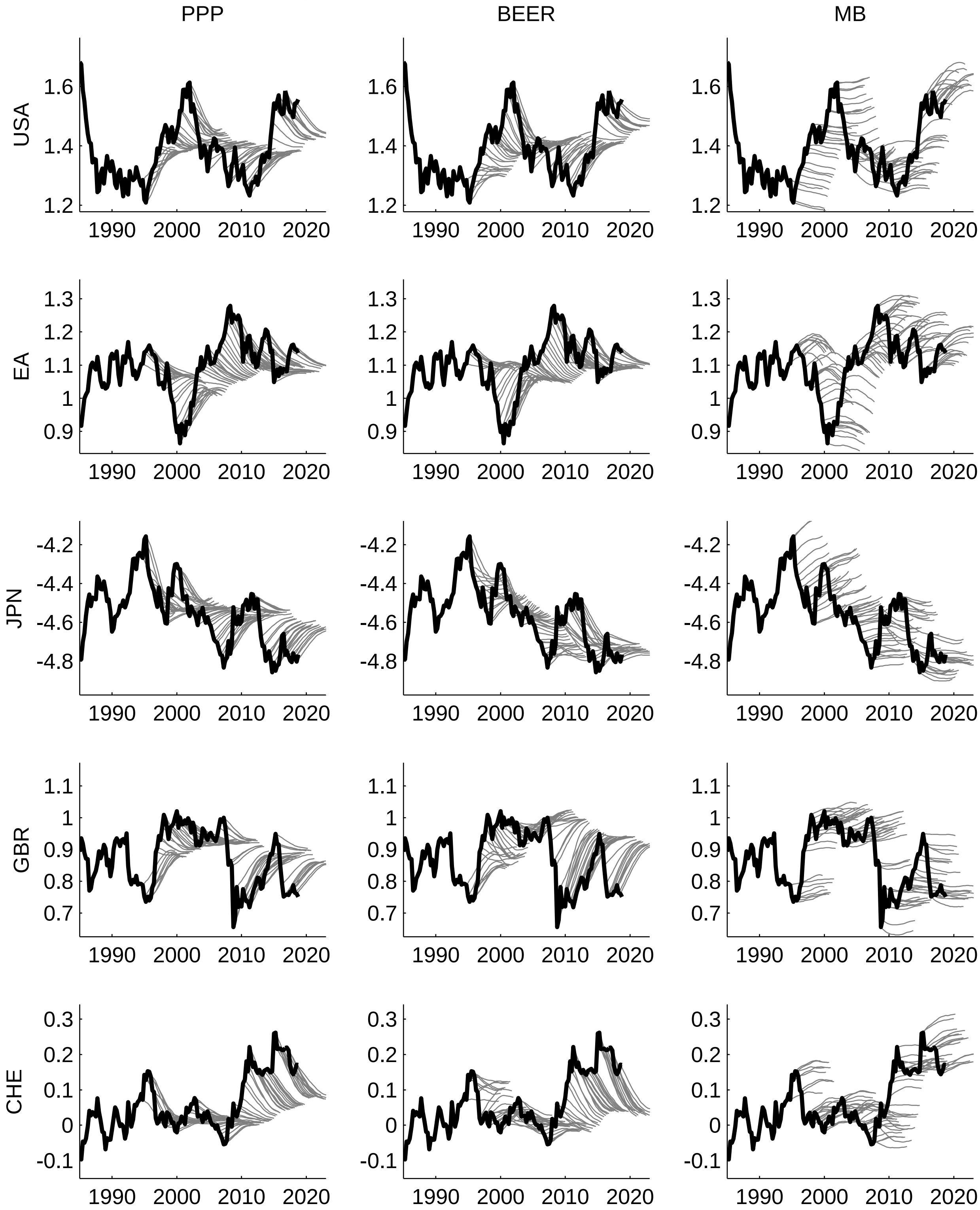
Notes: The figures present recursive panel estimates for the adjustment parameter $\delta_{h,s}$ from regression (9), in which changes in the log real effective exchange rate are explained by exchange rate misalignments. A value of -1 can be interpreted as full adjustment, whereas a value of 0 means no reversion to equilibrium. The solid, dashed and dotted lines represent the PPP, BEER and MB model, respectively.

Figure 8: RMSFE ratios against the RW benchmark



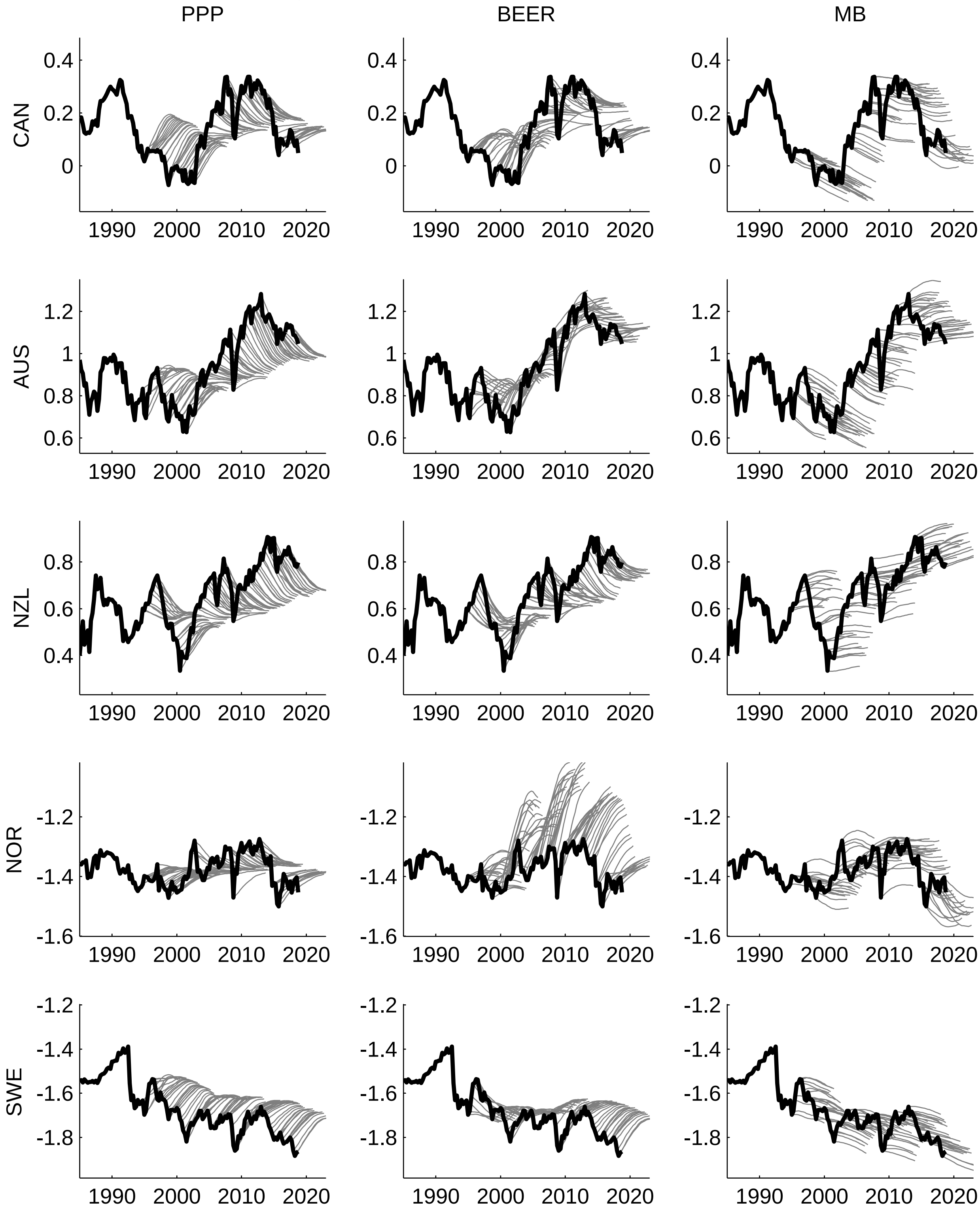
Notes: The figures show the ratios of the RMSFE from a given model over horizon h in comparison to the RW benchmark so that values below unity indicate that forecasts from the model are more accurate than the benchmark. The solid, dashed and dotted lines represent PPP, BEER and MB models, respectively.

Figure 9: Sequential forecasts, part A.



Notes: Values are expressed as the logs of real effective exchange rates.

Figure 10: Sequential forecasts, part B.



Notes: Values are expressed as the logs of real effective exchange rates.