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The predictive power of equilibrium exchange rate models

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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 clear trade-off between storytelling and forecast accuracy. The PPP model offers little economic insights, 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 most appealing 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.

JEL classification: C33; F31; F37; F41.

Non-technical summary

Central banks and financial institutions devote a lot of attention to the assessment of equilibrium exchange rates. While the techniques evolve, the concepts underpinning equilibrium exchange rates have remained broadly unchanged. In this paper, we review the three main methods for calculating equilibrium exchange rates, the first two hinging on the concept of mean reversion of real exchange rates and the third on the concept of current account sustainability. The first methodology that we consider is Purchasing Power Parity (PPP), the oldest theory of real exchange rate determination. The second, known in the literature as the Behavioral Equilibrium Exchange Rate (BEER) model, instead links real exchange rates to a set of economic fundamentals. This method could be seen as an extension to the PPP model as it seeks to explain long-term changes in purchasing power among nations. The third method, called the Macroeconomic Balance (MB) approach, extracts equilibrium exchange rates by assuming that relative prices are the main adjustment mechanism of external imbalances.

We argue that there is a clear trade-off between storytelling and predictability of equilibrium exchange rates. In terms of economic intuition, the PPP model offers little else but the notion that real exchange rates are mean reverting. The BEER model is more insightful, as it links the evolution of real exchange rates with that of economic fundamentals. The MB is the most complex approach as it requires a definition of what constitutes an external imbalance and a clear hypothesis on how exchange rates affect trade volumes and prices and hence the current account adjustment process. In terms of predictive power our ranking flips. The PPP model is the most reliable one in forecasting terms. The BEER model has broadly comparable predictive power as PPP, mainly because the equilibrium exchange rate is generally not very distant from the level implied by PPP. The MB model, irrespective of whether we assume perfect or imperfect exchange rate pass-through, is by far the least accurate.

Our paper has a dual message, one positive and one negative. The positive message is the good predictive power of the PPP and BEER models relative to the random walk. The negative message is that exchange rates are only weakly connected to economic fundamentals also in the long-run. We also find that the tendency of flexible exchange rates to help closing current account gaps is limited. Finally, the analysis sends a clear message to equilibrium exchange rate modelers. To the extent that equilibrium exchange rates should help predict exchange rate movements, the ambition of developing comprehensive models with an ever larger set of economic fundamentals could be counterproductive out of sample.

1 Introduction

The proposition that macroeconomic fundamentals and real exchange rates are linked at longer 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 or even financial stability. In relying on the equilibrium exchange rates concepts, however, there is an important ambiguity on whether we are reasoning in "normative" or "positive" terms. In the former case we are interested in the exchange rate level that supports macroeconomic stability. For that purpose we usually rely on fully-fledged macro models that explain the relationship between the exchange rate and the rest of the economy. In the latter case our preferred model should provide meaningful guidance about future exchange rate adjustments. Most of the literature on equilibrium exchange rates hinges on the normative aspect. In this paper we pursue the positive economic perspective by exploring the predictive power of the three most popular equilibrium exchange rate models: the Purchasing Power Parity (PPP), Behavioral Equilibrium Exchange Rate (BEER) and Macroeconomic Balance (MB) models (Williamson, 1994; MacDonald, 1998; MacDonald and Clark, 1998; Driver and Westaway, 2004; Isard, 2007; Bussière et al., 2010; Couharde et al., 2018).

The main aim of this paper is to assess the reliability of each of these three approaches on the basis of their predictive power. This is important as they are regularly employed in international financial institutions and central banks to assess exchange rate misalignments. A strong impetus to this topic was given by the International Monetary Fund (IMF). In the past, the underlying methodological developments have been progressively adapted by the Consultative Group on Exchange Rate Issues (Lee et al., 2008) and, following several important innovations, a major review was brought forward in the context of the External Balance Assessment (EBA) framework (Phillips et al., 2013; Cubeddu et al., 2019). The most recent efforts have gone in the direction of further refining the list of fundamentals in the case of the BEER model and considering alternative exchange rate pass-through assumptions in the case of the MB model.

As regards the PPP model, its predictive power is increasingly acknowledged in the exchange rate literature. The recent contributions of Ca' Zorzi et al. (2016), Ca' Zorzi and Rubaszek (2018) and Cheung et al. (2019) highlight that a simple PPP model produces exchange rate forecasts that in the majority of instances significantly outperform the RW benchmark. These studies show that, in order to derive an accurate forecast, it is 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.

On the contrary, the literature does not provide much evidence about the predictive content of the other two, allegedly more refined, equilibrium exchange rate concepts. For example, the comprehensive survey of the literature on exchange rate forecasting by Rossi (2013) confirms the limited focus assigned by academic studies to the predictive power of the BEER and MB concepts. As far as we are aware, there are just a few studies that are pioneering this issue. The most relevant ones are the analyses by Abiad et al. (2009) and Yesin (2016), which evaluate the predictive content of IMF equilibrium exchange rate estimates. Abiad et al. (2009) show that exchange rate misalignments computed for the years 1997-2006 were followed by gradual exchange rate adjustments that typically absorbed the initial misalignment. Yesin (2016) reaches a similar conclusion for the period between 2006 and 2011, stressing that the BEER model is generally more accurate in forecasting exchange rates than the MB approach. These papers are insightful thanks to their real time nature. Such analyses are however constrained by the limited time span of the data and by the continuous innovation of the underlying IMF models that makes it hard to understand the performance of any specific model. Less positive findings on the predictive power of the BEER model are reached instead by Cheung et al. (2005, 2019).

In this article we contribute to the equilibrium exchange rate literature and to the numerous studies on exchange rate forecasting (e.g. Rossi, 2013; Beckmann and Schussler, 2016; Ca' Zorzi et al., 2017; Eichenbaum et al., 2017; Cheung et al., 2019; Engel et al., 2019) by evaluating the predictive content of the three most popular equilibrium exchange rate concepts using a panel of ten advanced economies and a long time span of quarterly observations from 1975 to 2018. Our main results can be summarized as follows. First, we illustrate that the relationship between real exchange rates and economic fundamentals is usually consistent with the theory, but is also characterized by considerable time variation. Second, we discuss how equilibrium exchange rates calculated with the MB framework are sensitive to a large number of assumptions, including how to define current account norms or calibrate trade elasticities. Third, we present in-sample evidence that exchange rates tend to adjust to close exchange rate misalignments, highlighting that this tendency is much greater for the PPP and BEER models than for the MB approach. Fourth, we demonstrate that if we evaluate equilibrium exchange rate models in terms of their out of sample performance it is hard to outperform the PPP model. Our analysis clearly establishes that, if we apply 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 fundamentals play a limited role.

The key takeaway from our study is that there is a trade-off between storytelling and predictive power of equilibrium exchange rate models. The BEER and MB models suggest the existence of a relationship 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. The most effective approach to predict real exchange rates in the long run is given by the PPP model. The BEER model has broadly comparable predictive power as PPP, mainly because the equilibrium exchange rate is generally not very distant from the level implied by PPP. The MB model, irrespective of whether we assume perfect or imperfect exchange rate pass-through, is by far the least accurate. We conclude with a note of caution on the ambition of developing comprehensive models that 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

The ongoing discussion on equilibrium exchange rates is dominated by three frameworks, which we review briefly in this section.

Purchasing Power Parity

It seems only appropriate to start with PPP, since it is the oldest theory of exchange rate determination. Theory tells us that nominal exchange rates should evolve to neutralize competitiveness changes induced by movements in price indexes across nations, so that real exchange rates are mean reverting processes (e.g. Lothian and Taylor, 1996; Taylor and Taylor, 2004; Norman, 2010; Curran and Velic, 2019). This theory 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, while calculating the appropriate exchange rate parities following the end of the gold standard at the outset of the First World War. From that point onward PPP became the standard methodology for assessing exchange rate parities for fixed regimes and exchange rate misalignments for flexible ones. PPP has never really been thought to be a short-run theory of exchange rate determination, 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 (se e.g. Engel, 2016; Ca' Zorzi et al., 2017).

The relative version of PPP theory is the most appealing one from the economic point view. It does not assume that prices in two economies are exactly the same, but rather that the relative purchasing power of two different monetary units remains broadly unchanged over the long run. The direct implication of this hypothesis is 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}):

$$rer_{it}^{PPP} = \overline{rer}_i. \tag{1}$$

There is also a more extreme version of PPP ("absolute PPP"), which foresees that the same basket of goods should be equally priced across countries when denominated in a common currency. This approach, which implies the convergence in purchasing power of different moneys, is however widely seen as empirically less relevant.

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 very slow, if a full return happens at all. 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 the 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 improves 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 real exchange rate strengthening. 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:

$$rer_{it}^{BEER} = \mu_i + \alpha_1 gdp_{it} + \alpha_2 nfa_{it} + \alpha_3 tot_{it}, \tag{2}$$

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 variables (see for example MacDonald, 1998; Fidora et al., 2017; Miyamoto et al., 2019). We have decided to restrict our model to the above three variables for the following reasons. First, our reading of the literature is that they are the most relevant factors influencing long-term movements in real exchange rates. Second, 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.

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, if output gaps at home and abroad are closed. This definition is closely connected with the debate on global imbalances and

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

the role played by the exchange rate to unwind them. For this reason the MB approach is considered to be a normative concept.

To calculate the equilibrium exchange rate within the MB framework the 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:

$$rer_{it}^{MB} = rer_{it} - \frac{\widetilde{ca}_{it} - ca_{it}^{norm}}{\eta_{it}}. \tag{3}$$

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, the 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 in the first instance to assume that the predicted current account deficit remains unchanged at $\widetilde{ca} = -0.04$. 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 by 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 for the estimated misalignment of 10% to 40%. 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, in the baseline we follow the literature on global imbalances and derive its value from 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}):[2]

$$ca_{it}^{norm} = \omega + \beta_1 gdp_{it} + \beta_2 nfa_{it} + \beta_3 tot_{it}^{hp}. \tag{4}$$

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.

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 1% exchange rate appreciation on prices expressed in domestic currency). Using the data of import and export shares in GDP (μ_x and μ_m), one can calculate the value of η with the following expression:

$$\eta_{it} = \mu_{x,it}(\delta_x + (1 + \delta_x)\gamma_x) - \mu_{m,it}(\delta_m + \delta_m \gamma_m) \tag{5}$$

In the baseline, we follow Isard and Faruqee (1998) and assume producer currency pricing. This means that for export prices the effect of exchange rate changes is zero ($\delta_x = 0$), 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 (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 instance, for a country in which these shares

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

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.

Equilibrium exchange rates and fundamentals

Before proceeding further it is worthwhile to reflect about the practical implications of applying these three methodologies. The ingredients, in terms of economic fundamentals, are always the same, but the way they are accounted for 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 economic explanations become more sophisticated. The increased complexity clearly pays out 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 increased appeal of these models pays out in exchange rate forecasting.

3 Data

Our sample covers ten advanced economies, namely Australia (AUS), Canada (CAN), Switzerland (CHE), the euro area (EA),[3] the United Kingdom (GBR), Japan (JPN), Norway (NOR), New Zealand (NZL), Sweden (SWE) and the United States (USA) over the period 1975:1 - 2018:4. The country selection is based on two criteria, namely having flexible exchange rate regimes for the most part of the sample and a sufficient coverage of quarterly time series for a meaningful forecasting evaluation exercise.

To obtain a consistent set of effective exchange rates for our sample, we construct them manually using nominal bilateral exchange rates and trade weights (available from the BIS). The weights are taken at their 1995 values to avoid exploiting information that was not available to economists ahead of the forecast evaluation period. To derive a real measure of the exchange rate, we deflate the nominal series by consumer prices, while bearing in mind

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

that the choice of the deflator might not be innocuous (Fidora et al., 2017; Chinn, 2006). Our proxy for the Balassa-Samuelson effect, *per capita* GDP, is computed by dividing real GDP, expressed in PPP terms, by population size. As the last series is available only at annual frequency, we derive interpolated quarterly data using cubic splines.[4] Net foreign assets are taken from the IMF Balance of Payments Statistics 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 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 import and exports (goods and services) as a share of GDP. Given the quarterly frequency of our data, all time series are seasonally adjusted. Table 1 provides a detailed description of all our data sources.

4 Equilibrium exchange rate estimates

In this section, by applying the above methodologies, we derive three time series of equilibrium exchange rates for each country. 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 the differences between the full-sample and recursive equilibrium exchange rate measures for the PPP model. The full sample equilibrium, depicted by the dotted line, is the same for all observations as it is simply the mean of the real exchange rate calculated with the data for the period 1975:1–2018:4. The recursive equilibrium, shown by the dashed line and calculated with an initial estimation window of 20 years, evolves over time as incoming observations slowly affect the sample mean. Apart 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 (2), as the exact relationship between real exchange rates and fundamentals is unknown. To tackle the potential feedback of the exchange rate

[4] 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 and this could lead to endogeneity problems. Our choice is consistent with the IMF methodology.

to the right-hand-side variables and the potential non-stationarity of some of them, we opt for the fully-modified least squares estimator, which was originally proposed by Phillips and Hansen (1990). The full-sample estimates, which are presented in the left panel of Table 2, 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 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 2 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-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. Further evidence of this comes from the gradual decline of the economic significance of all three economic fundamentals. This implies that equilibria calculated with the BEER model have increasingly resembled those obtained with the PPP model.

The full set of equilibrium values based on the BEER model are 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 driven only 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 usually small, even if slightly more pronounced in the cases of Norway and the United Kingdom.

Finally, we present the equilibrium exchange rate estimates derived with 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 (4). The full-sample estimates of its parameters, which are presented in the right panel of Table 2, 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 recursive estimates of model (4) 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) baseline assumptions for trade elasticities and (iii) data for trade shares, it is straightforward to apply formulas (5) and (3) 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 models.[5] 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 5) 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 sizable 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. The third feature of the MB model is that exchange rate misalignments tend to be very persistent, 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.

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 equal to -1. Figure 6 shows the results for the three analyzed models and different time horizons. To limit the number of figures in the paper, 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.

[5] Note that the scales of y-axis in Figure 5 are wider than in Figures 1 and 3.

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

$$\Delta rer_{it,h} = \omega_{ih} + \delta_{ih}(rer_{i,t-h} - rer^{M}_{i,t-h}) + \epsilon_{it}, \tag{6}$$

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 3 contains both the estimates of model (6) 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 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 one year horizon, as the MB approach lags behind at 12% compared to 21% for PPP and 27% for the BEER model. At 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 a few cases where exchange rates diverge 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 were 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 property can be exploited to forecast real exchange rates better than with a RW. We neglect data revisions that took place between the period in which a forecast is formulated and the moment in which we collected the data. The reason is that data availability does 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 1975:1-1994:4 for the period 1995:1-1999:4. This procedure is repeated with samples ending in each quarter from the period 1995:1-2018:3. 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:

$$\Delta rer_{it,h} = \omega_{ih} + \delta_h (rer_{i,t-h} - rer^M_{i,t-h|s}) + \epsilon_{it} \tag{7}$$

and calculate the value of the forecast as:

$$rer^f_{i,s+h} = rer_{is} + \omega_{ih|s} + \delta_{h|s}(rer_{is} - rer^M_{is|s}). \tag{8}$$

In comparison to equation (6) 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 the recursive equilibrium exchange rates estimates, $rer^M_{is|s}$, rather than their full sample estimates, rer^M_{is}. The difference between both 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.

We assess the accuracy of forecasts with the most popular ex-post evaluation criterion, the root mean squared forecast error (RMSFE). In Table 4 and Figure 8 we report for each model the RMSFE as a ratio of the same statistics 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. It significantly outperforms the RW in the long run for six countries (CAN, EA, GBR, JPN, NOR and USA) while in three other cases the performance is almost the same (AUS, CHE and NZL). The PPP model clearly loses against the RW for Sweden, as it exhibited a visible depreciation trend throughout the sample.[6] The second finding is that the BEER model is equally competitive as PPP. It is clearly the best model for four countries (AUS, CAN, JPN and NZL). For 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 almost always outperformed by the RW. 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.

We complement the RMSFE analysis by plotting the whole sequences 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.

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. Let us begin with the PPP

[6] 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, in 2018 the price level for individual consumption in Sweden was about 24% higher than in the euro area.

model. Thus far we have imposed a pace of mean reversion given by the recursive estimates from panel regression (7). 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:

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

where the adjustment coefficient δ_{ih} now depends also 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:

$$\Delta rer_{it,h} = \delta_{h}(rer_{i,t-h} - rer^{eqM}_{i,t-h|s}) + \epsilon_{it}. \tag{10}$$

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 so 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 5 show that the DF specification is less accurate than the PDF one, particularly for the cases 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 badly 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. As already highlighted by Ca' Zorzi and Rubaszek (2018) 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 bypasses estimation error.

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 (2), which includes all three fundamentals as before. In Table 6 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 times 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.

Finally, 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 ($\delta_x = 0, \delta_m = -1, \gamma_x = \gamma_m = -1$). In the first robustness check 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 7 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 (4). This could be justified with a long term target for the international investment position of zero, assuming that valuation effects are on average balanced. In the third and final robustness check, we replace the estimated pace of adjustment toward equilibrium (equation 7), which in the case of the MB model is extremely slow (Figure 7), with a calibrated value imposing a half-life of three years for the exchange rate adjustment. 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 8. 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 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 (3) into the adjustment equation (7) yields:

$$\Delta rer_{it,h} = \omega_{ih} + \delta_h \left(\frac{\widetilde{ca}_{i,t-h} - ca^{norm}_{i,t-h}}{\eta_i} \right) + \epsilon_{it}. \quad (11)$$

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 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 hypothesis is twice as large as that calculated with PCP. The second conclusion from Table 8 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 MB implied exchange rate equilibria 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 exchange rates. Under these circumstances the equilibrium exchange rates are irrelevant and the implied forecasts similar to those derived with the RW model. This confirms that the model has only a normative dimension but is unreliable in predictive terms.

8 Conclusions

Central banks and financial institutions are expected to invest time and resources to evaluate the long-term drivers of exchange rates. The choice of the methodological framework has a large bearing on the misalignment estimates, as evidenced by the recent study of Cheung and Wang (2019) for Chinese Renminbi. The open question is how to choose among the different available methodological frameworks.

In this paper we have evaluated the reliability of the three most popular methods for calculating equilibrium exchange rates using alternative criteria. In terms of economic appeal, while easy to compute, the PPP models offers little other than the notion that real exchange rates are mean reverting. The BEER model is more insightful because it provides slow-moving equilibrium exchange rates that can be explained with the evolution of economic fundamentals. The MB model exploits our deeply-rooted economic belief that exchange rates help absorb current account imbalances. The beauty 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 by far the most appealing one, followed by that of the BEER and PPP models.

Out-of-sample the ranking across the models flips. The MB model provides the least accurate predictions irrespective of the modeler's exact specification. The BEER model performs well but not necessarily better than a naïve PPP model, as both derive their forecasting power by similarly exploiting the mean reverting properties of the real exchange rate. A carefully conducted in-sample analysis also reveals the limitations of the MB model in terms of instability and overall reliability.

We draw at least five lessons from our analysis. First, there is a trade-off between story-telling and the predictive power of equilibrium exchange rate models. Second, applying an out-of-sample evaluation criterion the link between real exchange rates and macroeconomic fundamentals is also feeble in the long run. Third, exchange rates fulfill a shock absorbing role, which operates mainly via a mean reversion adjustment process. Fourth, the link between exchange rates movements and current accounts is much less predictable than often assumed. Fifth, having generated equilibrium exchange rates estimates with the PPP or the BEER models, it is reasonable to assume that half of the adjustment will be achieved in about three years. Generating equilibrium exchange rates with the MB model can be instead of interest only from a normative, but not a predictive, perspective.

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Tables and Figures

Table 1: 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 2: 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 the estimates for the panel BEER regression (model 2) (with fixed effects) and its restricted versions as well as pooled estimates for the CA norm regression (model 4). Asterisks ***, ** and * denote, respectively, the 1%, 5% and 10% significance levels. All models were estimated using observations for 10 countries over the period 1975:1-2018:4, i.e. using 1760 observations. NFA and CA data are expressed in terms of each country's GDP

Table 3: In sample adjustment of the 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 the estimates of adjustment parameter δ_h from regressions (6), 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 4: Root mean squared forecast error (RMSFE) for the 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 5: RMSFE for the 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 4. 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 7), for DF it is estimated separately for each currency (equation 9) and for HL it is assumed that the half-life of the deviation from equilibrium is three years (equation 10).

Table 6: RMSFE for the 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 4. Full, GDP, NFA and ToT indicate which variables enter the set of explanatory variables of model (2), 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 7: MB model assumptions.
Current account reaction to a 1% real effective exchange rate depreciation.

	Openess 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

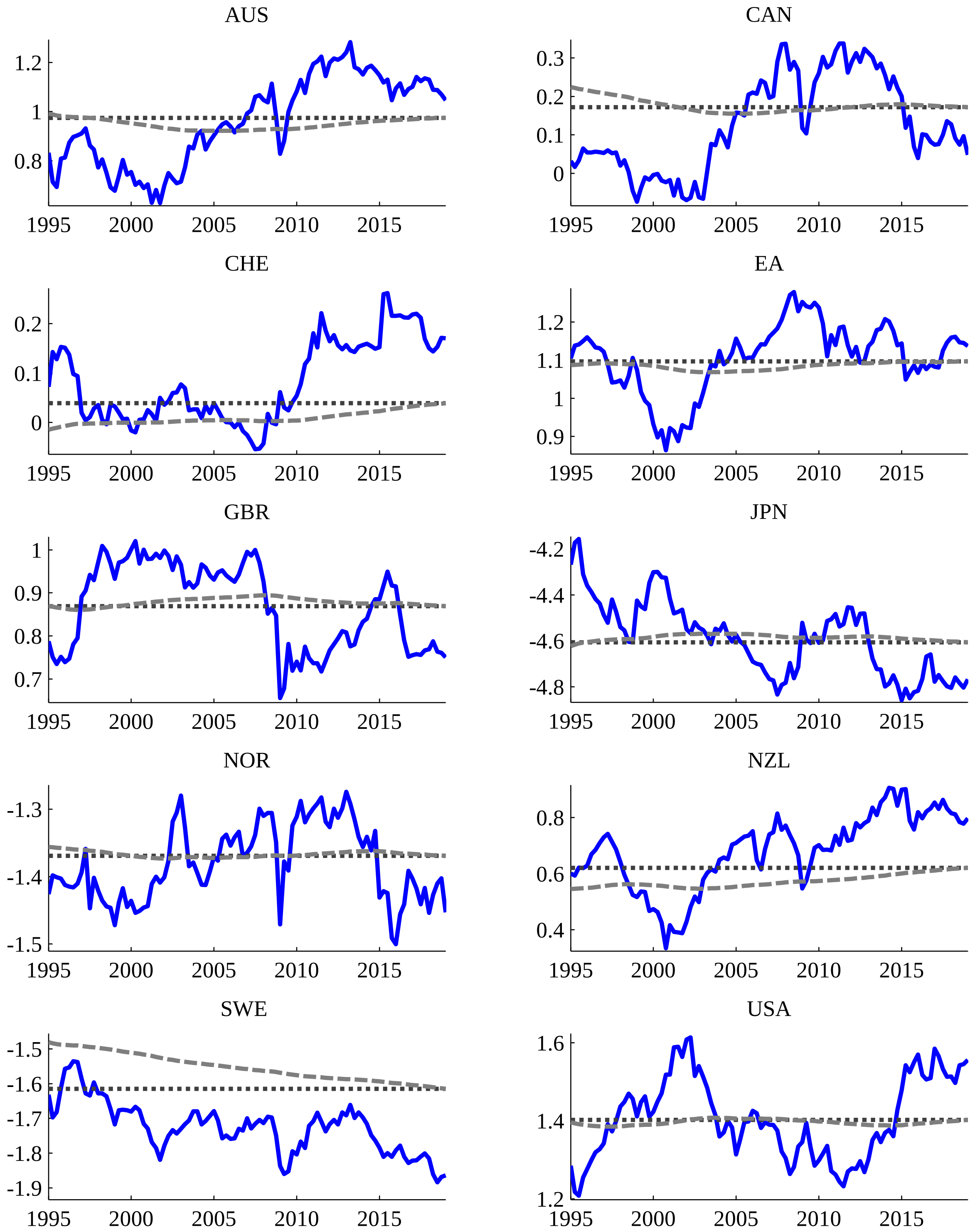
Notes: The table presents the reaction of the current account balance (in % of GDP) to a 1% depreciation of the real effective exchange rate (see formula 5) using trade shares for 2018. PCP and IPT denote Producer Currency Pricing and Imperfect Pass-Through assumptions, whereas IMF indicates values used 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 8: RMSFE for the real effective exchange rates from the MB model.
Sensitivity analysis with respect to models 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

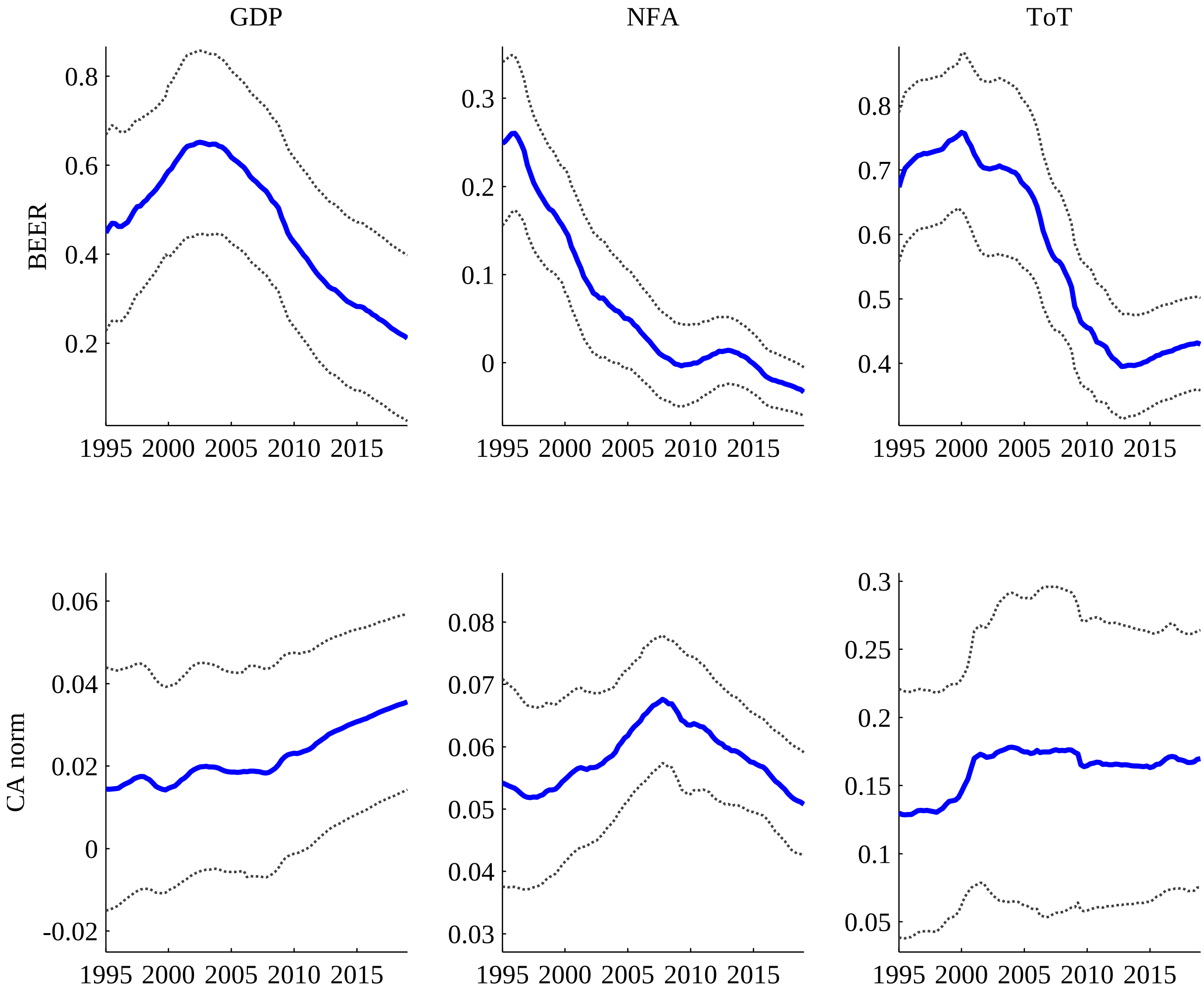
Notes: As in Table 4. PCP and IPT denote the MB models in which the equilibrium value is derived using Producer Currency Pricing (PCP) or Imperfect Pass-Through (IPT) assumptions (see notes to Table 7). In CA0 and HL we use PCP elasticities, but assume that the current account norm is null (CA0) or that the half life of the deviation from equilibrium is equal to three years (HL, as in Table 5).

Figure 1: PPP based equilibrium exchange rates



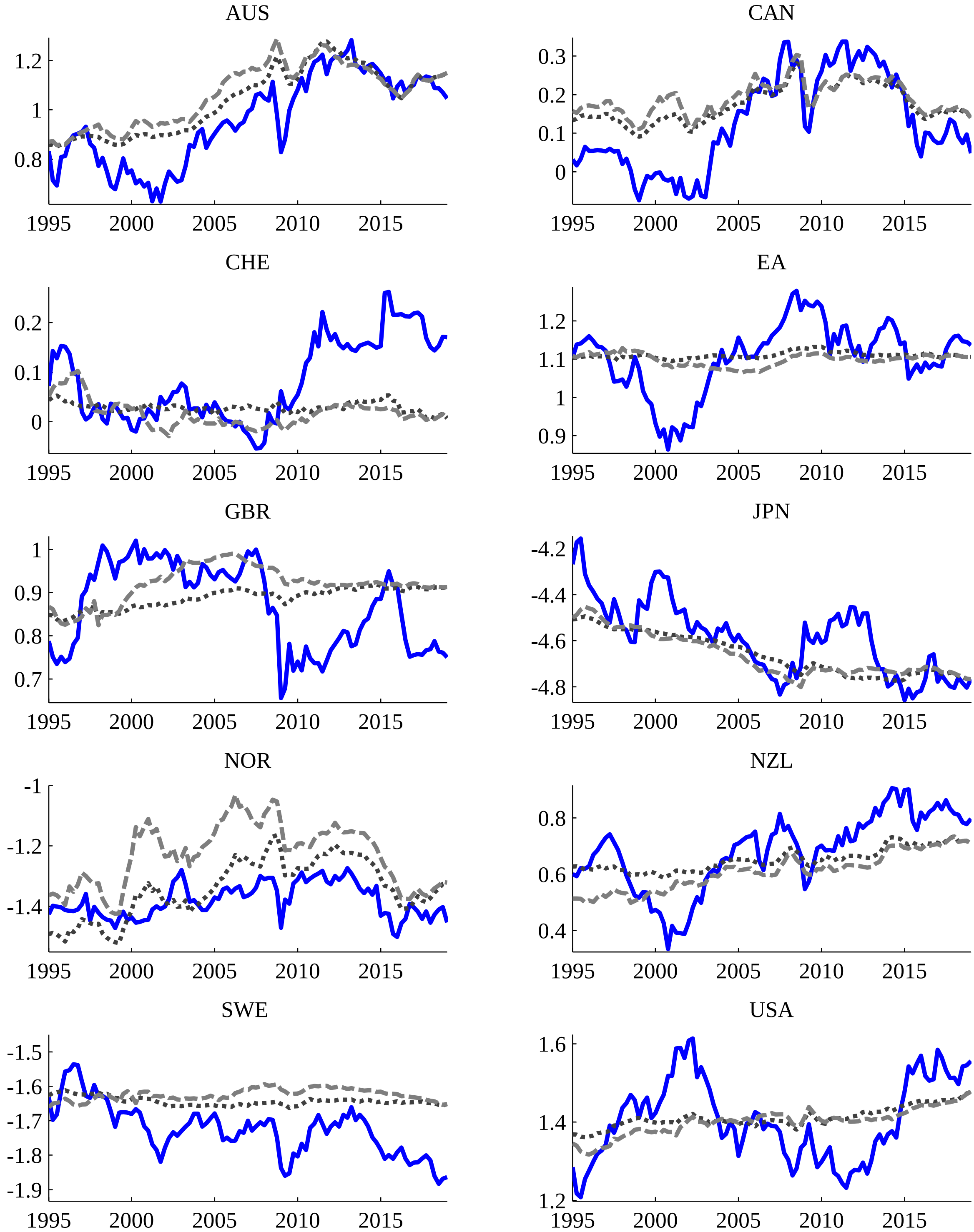
Notes: The figure presents the log of actual real effective exchange rates (solid line) and its equilibrium values (dotted and dashed lines). The dotted and dashed lines denote full and recursive samples estimates of the equilibrium exchange rates, respectively.

Figure 2: Recursive estimates of BEER and CA regressions



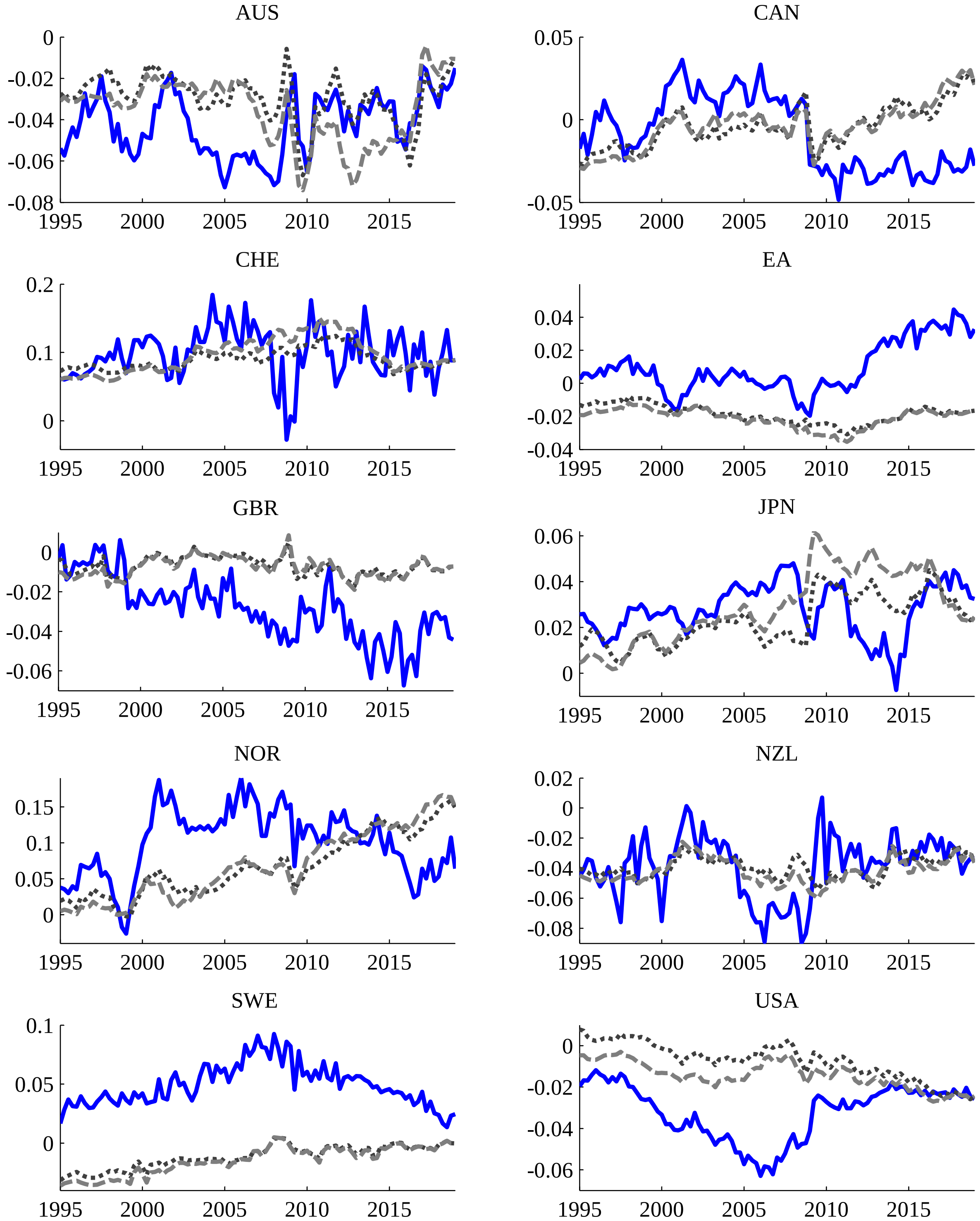
Notes: The upper panels present recursive estimates of the BEER model (equation 2). The lower panels present recursive estimates of the current account model (equation 4). The dotted lines denote the 95% confidence interval.

Figure 3: BEER based equilibrium exchange rates



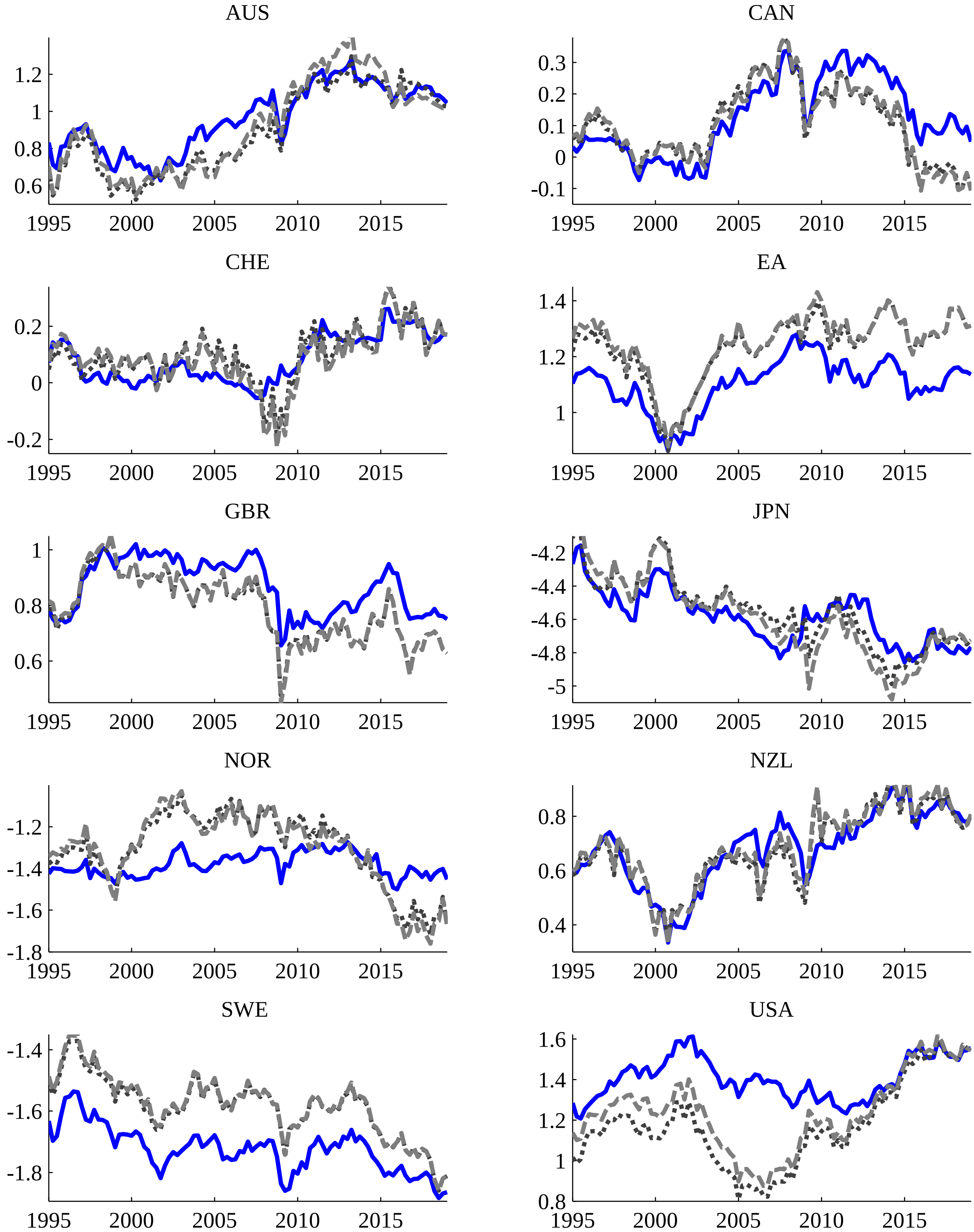
Notes: As in Figure 1.

Figure 4: Current account norms



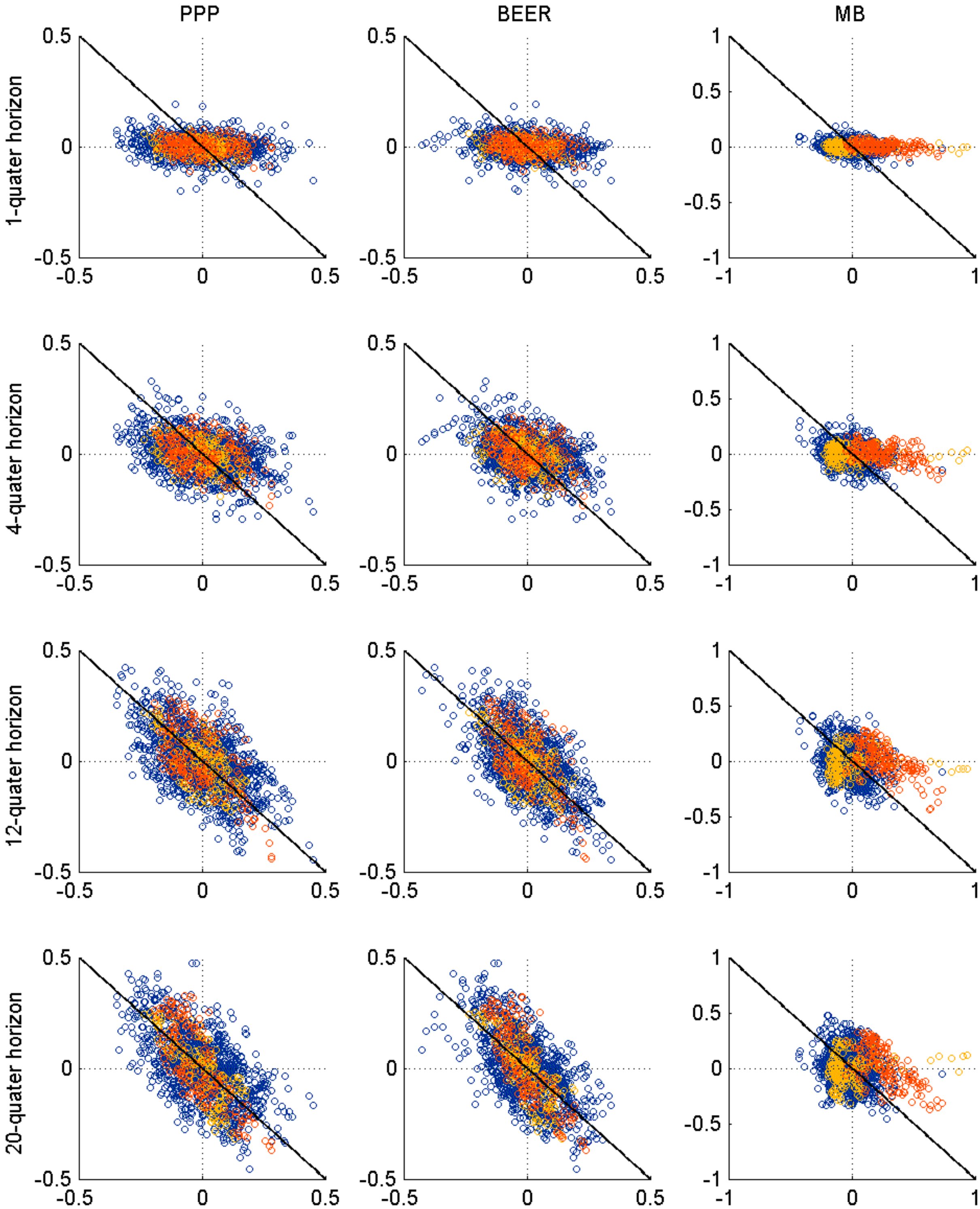
Notes: The figure presents the actual current account to GDP ratio (solid line) and its target values based on the CA norm model. The dotted and dashed lines indicate full sample and recursive estimates of the CA norm, respectively.

Figure 5: MB based equilibrium exchange rates



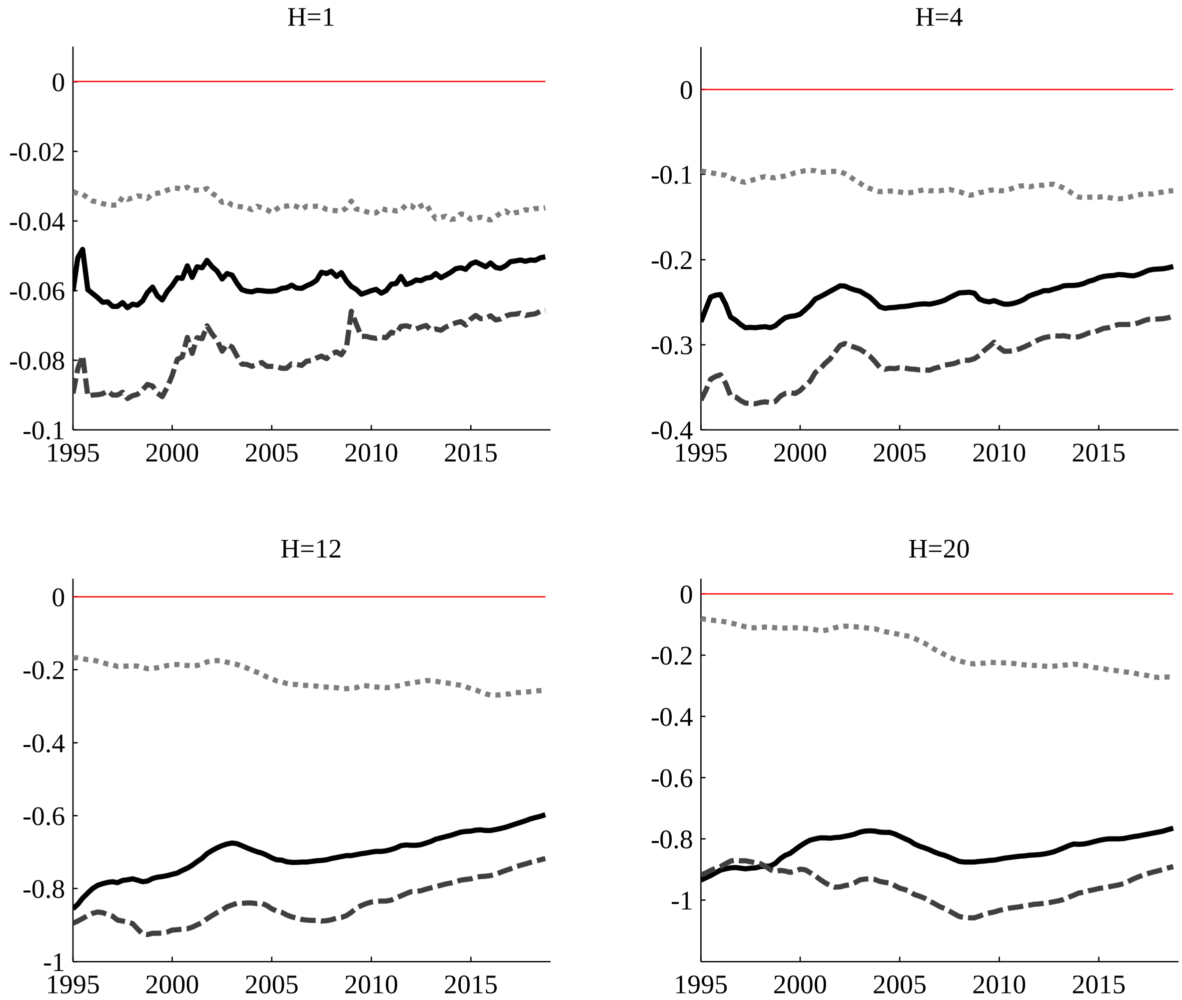
Notes: As in Figure 1.

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



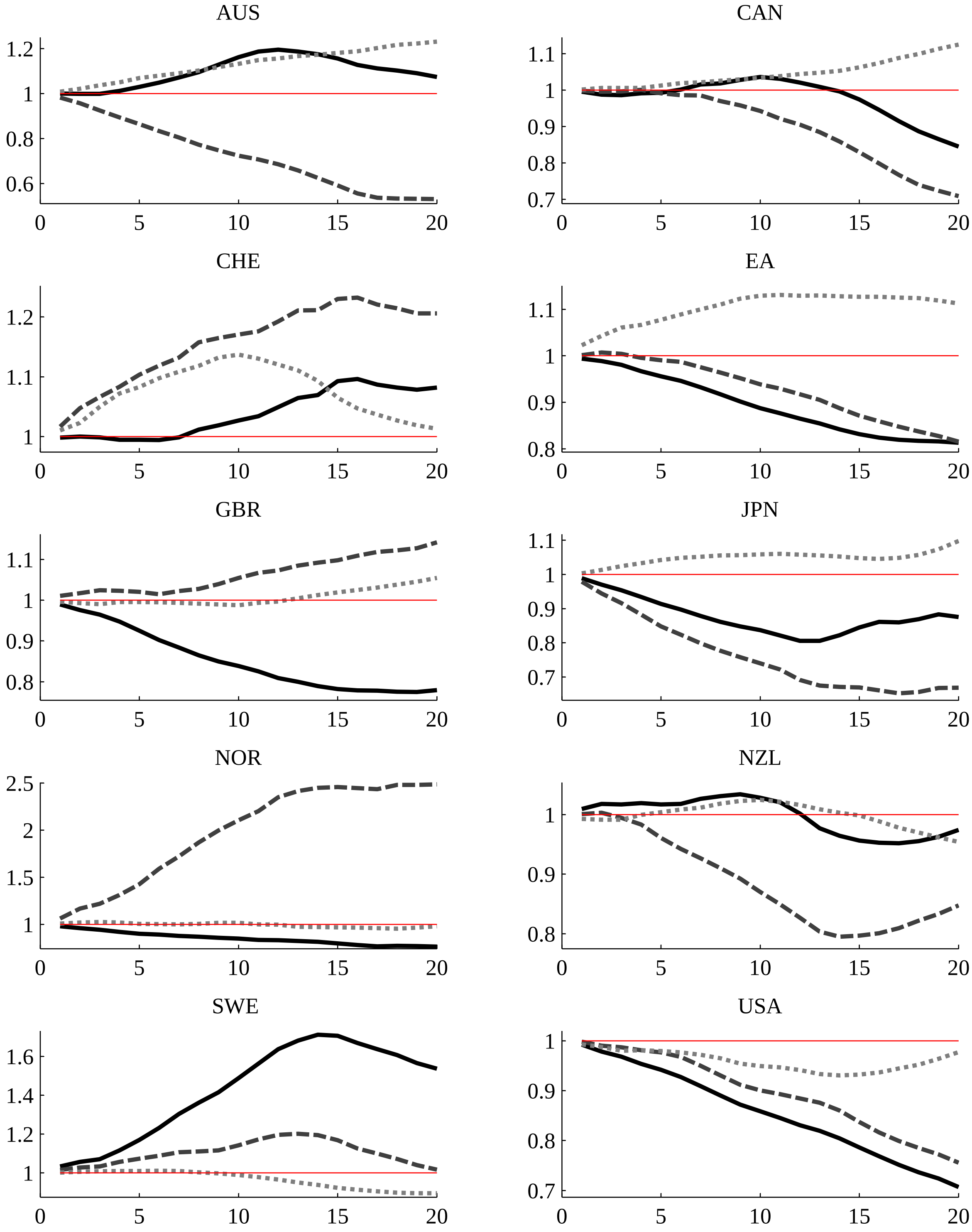
Notes: The x-axis of the figure represents deviations of real effective exchange rates from their full-sample equilibrium, whereas the y-axis represents subsequent real exchange rate adjustments. USD and EUR are marked with red and yellow dots, respectively. The diagonal line represents perfect adjustment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

Figure 7: Recursive panel estimates of the equilibrium adjustment pace



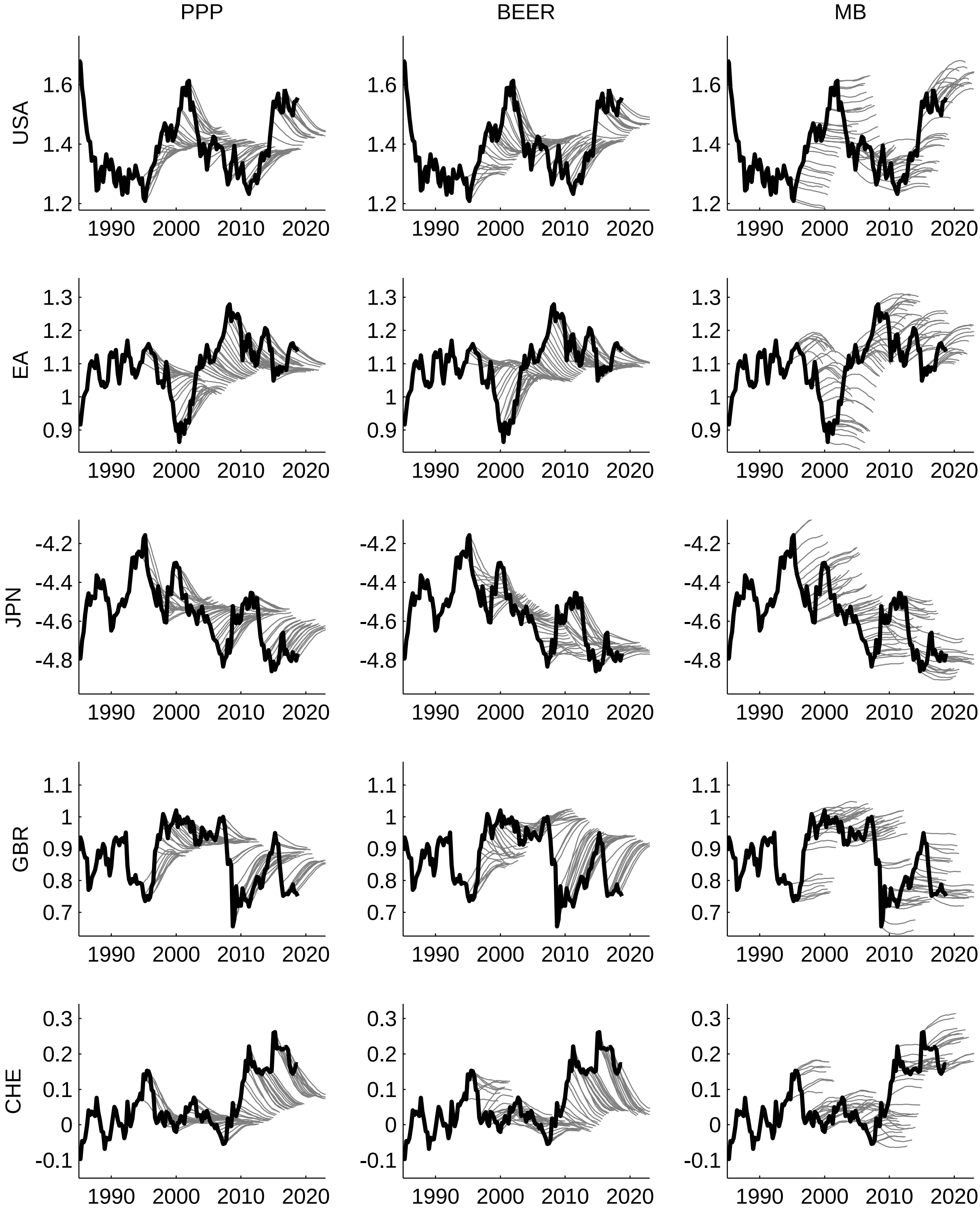
Notes: The figures present recursive panel estimates for the adjustment parameter $\delta_{h,s}$ from regression (7), in which changes in the log real effective exchange rate are explained by exchange rate misalignments. A value of -1 can be interpreted as full adjustment, whereas a value of 0 means no reversion to equilibrium. The solid, dashed and dotted lines represent PPP, BEER and MB models, respectively.

Figure 8: RMSFE ratios against the RW benchmark



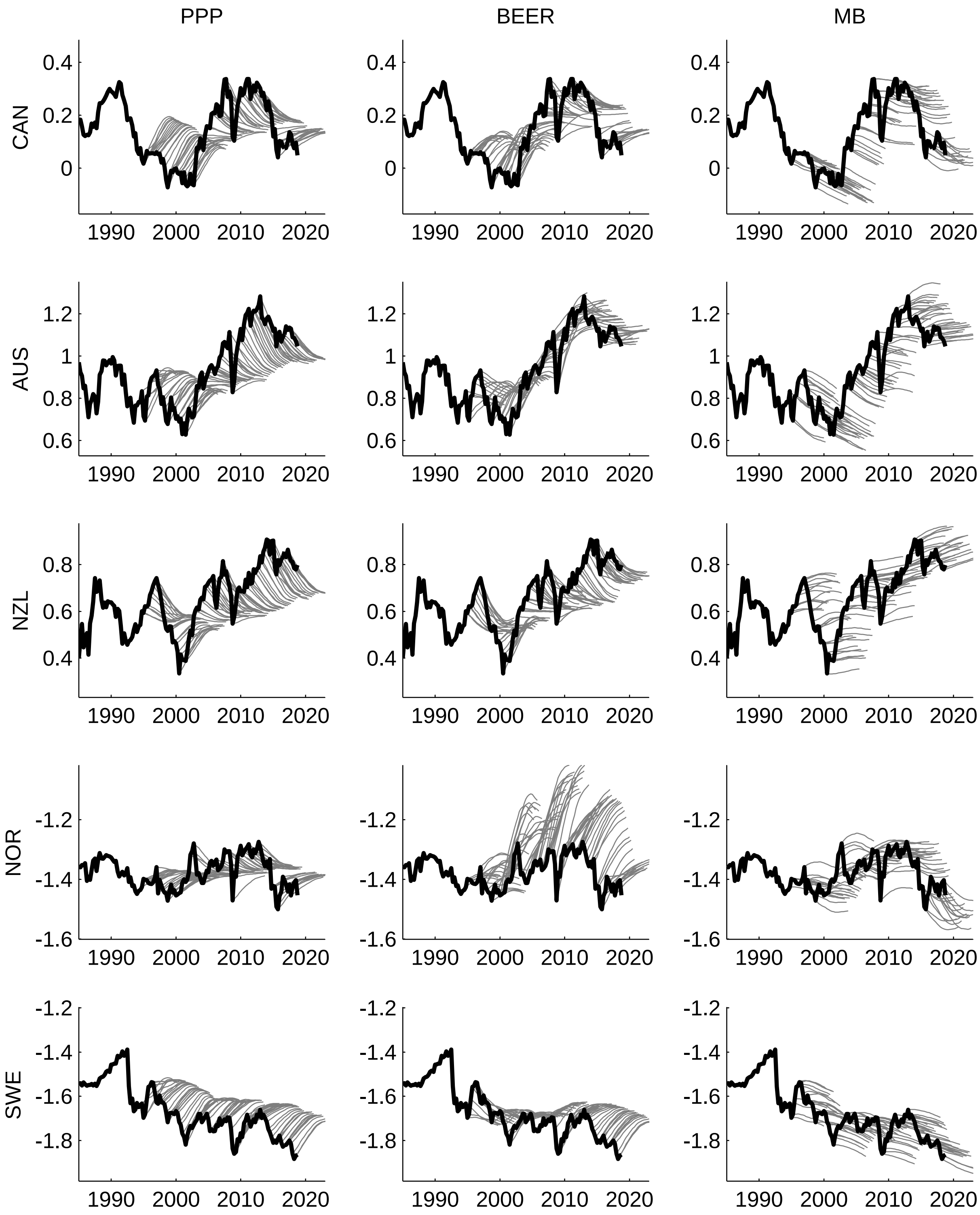
Notes: The figures show the ratios of the RMSFE from a given model over horizon h in comparison to the RW benchmark so that values below unity indicate that forecasts from the model are more accurate than the benchmark. The solid, dashed and dotted lines represent PPP, BEER and MB models, respectively.

Figure 9: Sequential forecasts, part A.



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

Figure 10: Sequential forecasts, part B.



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

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