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# The discount factor for expected fundamentals: Evidence from a panel of 25 exchange rates☆

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ABSTRACT

In asset pricing models the exchange rate is the discounted present value of expected economic fundamentals. Engel and West (2005) demonstrate that the well-known weak link between exchange rates and fundamentals, such as money supply, output, inflation and interest rates, is an implication of the model if the discount factor is close to one. Empirical evidence so far is limited. In this paper we estimate the discount factor in the money income model and the Taylor rule model for a large cross-section of 25 currencies, in the period 2001–2018. The results confirm that, on average, the discount factor is indeed close to one, while the estimate is lower for currencies of developing economies and at longer forecast horizons.

## 1. Introduction

The literature on exchange rate modeling is burdened by the low explanatory power of macroeconomic fundamentals based specifications that rely on regression analysis, known as the exchange rate disconnect puzzle. Evidence in favor of the linkage between the nominal exchange rate and macroeconomic fundamentals is rather weak and often not robust, see Neely and Sarno (2002) and Sarno (2005). Forecasts based on such models have also not fared well either, as no-change forecasts based on a random walk often produce a lower mean squared error, see Meese and Rogoff (1983), Cheung et al. (2005) and Rossi (2013).

Seminal work by Engel and West (2005) and Engel et al. (2007) demonstrates that the poor performance of the fundamental-based regressions can be due to the non-stationarity of the fundamental drivers and a discount factor that is close to one. Under these conditions, even if the model is correct, observed macroeconomic fundamentals can only weakly forecast exchange rate returns. The non-stationarity of the fundamentals has been recognized for some time (Engel and West, 2005; Engel et al., 2007). Further, Sarno and Sojli (2009) and Balke et al. (2013) show evidence that the discount factor is close to unity.

Sarno and Sojli (2009) estimate a vector error correction model on 41 monthly observations in the period 2004–2007 for the Euro, Japanese Yen, British Pound and Swiss Franc, using the spot exchange rate and the mean 1-month ahead forecast from *FX Survey* (as the expected future exchange rate), together with the traditional fundamentals, i.e. money supply M1 and real income. Sarno and Sojli (2009) find that the discount factor is indeed near unity for these four currencies, with values ranging from 0.985 to 0.993. Balke, Ma and Wohar (2013) use state-space models with Bayesian methods to see how much economic fundamentals can explain movements in the pound to US dollar exchange rate. In the state-space model the expectations are latent factors, which allows them to have flexible

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dynamics. Balke, Ma and Wohar (2013) use the Kalman filter to extract the representative agent's expectations and decompose the current deviation of the exchange rate from its fundamentals into the contributions of expected future fundamentals and unobserved remainders. They estimate the discount factor using annual data on the pound to dollar exchange rate, money, output, prices and interest rates for the UK and US from 1880 to 2010. The posterior distribution for the discount factor suggests a value around 0.95, for an annual horizon.

The value of the discount factor in asset pricing models of the exchange rate is clearly of great importance for the exchange rate disconnect puzzle. The closer the discount factor is to unity, the higher are the weights that are put on the expected future fundamentals. However, the empirical evidence in the literature so far is limited to a small number of major currencies (Sarno and Sojli, 2009; Balke et al., 2013), as summarized above.

In this paper, we extend the evidence across several dimensions: we provide estimates of the discount factor for a large cross-section of 25 currencies, over a longer time span (2001–2018) and for three different forecast horizons. We also work with two conventional asset pricing models, namely the money income model and the Taylor rule model, indicating the relationship between exchange rates and economic fundamentals, such as relative money supply, output, inflation and interest rates. In addition, we apply panel data models that allow for more accurate inference on the value of discount factor.

We document a robust long-run relationship between exchange rates, fundamentals and consensus forecasts. The results in our extended sample confirm the finding in Sarno and Sojli (2009) that the estimated discount factor is near unity. Furthermore, we add three new findings to the literature, namely that the discount factor is also close to unity for the Taylor rule fundamental, that the discount factor is lower at longer forecast horizons, and that the discount factor in developing countries is significantly lower than in advanced economies.

The next section briefly explains the asset pricing exchange rate models. Section 3 describes the panel dataset and methodology. Section 4 presents the results, providing estimates of the discount factor for a panel of 25 currencies relative to the US dollar and robustness checks. Finally, Section 5 summarizes the findings.

## 2. Exchange rate models

From the rational expectations present-value models, Engel and West (2005) demonstrate that an exchange rate manifests near-random walk behavior if 1) the fundamentals are non-stationary and 2) the discount factor for discounting future fundamentals is near one. As a consequence, they argue that the conventional wisdom that the exchange rate change is not predictable, as documented originally by Meese and Rogoff (1983), is not evidence against the model, but rather an implication of the model.

Following Engel and West (2005), we start with a general-form exchange rate model:

$$s_t = (1-b)f_t + bE_t s_{t+1}, \tag{1}$$

where $s_t$ is the log nominal exchange rate defined as the home currency price of a unit of foreign currency at time $t$, $f_t$ is the log fundamental at time $t$, $b$ is the discount factor, and $E_t$ is the expectation operator conditional on an information set at time $t$.

To solve this linear equation with rational expectations, we apply the law of iterated expectations. The forward solution can then be written as

$$s_t = (1-b)\sum_{j=0}^{k} b^j E_t f_{t+j} + b^{k+1} E_t s_{t+k+1}. \tag{2}$$

The first term on the right-hand-side constitutes the fundamental solution of the exchange rate, while the last term represents the deviation of the actual exchange rate from its fundamental value. In this paper, emphasizing on the economic fundamentals, we impose the transversality condition (no-bubbles condition) $\lim_{k\to\infty} b^k E_t s_{t+k} = 0$. As $k\to\infty$, this yields the present-value relationship as

$$s_t = (1-b)\sum_{j=0}^{\infty} b^j E_t f_{t+j},\ for\ 0 < b < 1. \tag{3}$$

Hence, the exchange rate is the discounted present value of expected future fundamentals. The exchange rate does not only depend on the current fundamentals, but also on sequences of expected future fundamentals discounted back by the discount factor $b$. The closer the discount factor $b$ is to one, the higher are the weights put on the expected future fundamentals. The discount factor thus determines the relative importance of the current fundamentals and the expected future exchange rate (future fundamentals).

In this paper, we estimate the discount factor $b$ for two asset pricing exchange rate models discussed in Engel and West (2005): the money income model and the Taylor rule model. In the monetary model, the fundamental $f_t$ is a function of relative money supply and output, while the discount factor is a function of the interest semi-elasticity of money demand. In the Taylor rule model, the fundamental $f_t$ is a function of relative prices and interest rates, while the discount factor reflects the strength of the central banks' response to the exchange rate.

Further, we estimate the discount factor for three different forecast horizons, using 3-month, 6-month and 12-month ahead forecasts. To illustrate how the discount factor varies with different forecast horizons, we consider the rational expectations model of exchange rates in Equation (1), and assume as in Engel et al. (2007) that the fundamental $f_t$ follows a random walk process: $f_t = f_{t-1} + \varepsilon_t$, with $\varepsilon_t \sim i.i.d.(0, \sigma_\varepsilon^2)$. After some derivations, we can then rewrite Equation (1) as follows: $s_t = (1-b^K)f_t + b^K E_t s_{t+K}$, where $E_t s_{t+K}$ is the

$K$-period ahead forecast. Hence, the model implies that the discount factor is lower at longer forecast horizons.

## 3. Data and methodology

### 3.1. Data

We use spot rates and consensus forecasts for 25 currencies from October 2001 to November 2018 at a monthly frequency (206 months) from *FX4casts*, formerly known as *The Financial Times Currency Forecaster*. All exchange rates are relative to the US dollar. Table A1 in Appendix A provides the full list of countries. Consensus forecasts are available for 3-month, 6-month and 12-month horizons, based on a geometric mean of 50 currency forecasts by analysts at large banks. The spot exchange rates are also from *FX4casts* and measured on the same day as the forecasts. See Ince and Molodtsova (2017) for more information on the *FX4casts* data. The *FX4casts* forecasts are from large financial institutions that have strong incentives to provide accurate forecasts. Further, Ince and Molodtsova (2017) find that the *FX4casts* consensus forecasts generate economically meaningful trading profits.

Following Sarno and Sojli (2009), we use the traditional fundamentals $f_{it}^{TF}$ from the money income model, defined as:

$$f_{it}^{TF} = \left(m_{it} - m_{it}^{*}\right) - \gamma\left(y_{it} - y_{it}^{*}\right), \tag{4}$$

where $f_{it}^{TF}$ is the fundamental of country $i$ in month $t$, $m_{it}$ and $m_{it}^{*}$ are the log of money supply at home and abroad, and $y_{it}$ and $y_{it}^{*}$ are the log of aggregate output at home and abroad. As in Sarno and Sojli (2009), we consider two values for $\gamma$: 1 and 0.5. For money supply we use monthly data on M1, seasonally adjusted, from the OECD. Our proxy for monthly aggregate output is industrial production, seasonally adjusted, from the OECD.

In addition, we also estimate the discount factor using the fundamental from the Taylor rule model in Engel and West (2005):

$$f_{it}^{TR} = \left(p_{it} - p_{it}^{*}\right) + \left(i_{it} - i_{it}^{*}\right), \tag{5}$$

where $f_{it}^{TR}$ is the Taylor rule fundamental of country $i$ in month $t$, $p$ and $p_{it}^{*}$ are the log of the consumer price index (CPI) at home and abroad, and $i_{it}$ and $i_{it}^{*}$ are the log of one plus the interest rate at home and abroad. We use OECD data for the CPI and the short-term interest rate. However, for some countries OECD data was missing, and replaced by similar series from Datastream or IFS: see Appendix A for the full list of countries and data sources.

### 3.2. Econometric methods

Our objective is to estimate the discount factor $b$ in the exchange rate model (1). We pool the data and apply panel estimation techniques to increase efficiency. We first apply the group panel cointegration tests of Pedroni (1999) to test if the spot rate, the fundamental and the expected exchange rate (consensus forecast) have a cointegration relationship. We then estimate a panel error correction model (ECM) to estimate $b$ in the long-run equilibrium relation (1), while simultaneously estimating the parameters of the short-run dynamics and the adjustment speed:

$$\Delta s_{i,t} = \delta_{0,i} + \delta_{1,i}\Delta f_{i,t-1} + \delta_{2,i}\Delta s_{i,t-1}^{E} + \alpha_i\left(s_{i,t-1} - (1-b_i)f_{i,t-1} - b_i s_{i,t-1}^{E}\right) + v_{i,t}, \tag{6}$$

where $s_{i,t}^{E} = E_t[s_{i,t+K}]$ denotes the consensus $K$-month ahead forecast of the log exchange rate of country $i$ at time $t$, $b_i$ is the discount factor for the expected exchange rate in the cointegration equation, and the parameter $\alpha_i$ ($<0$) is the error-correcting adjustment speed. The parameters $\delta_{1,i}$ and $\delta_{2,i}$ are the coefficients of the lagged changes in the fundamental $f$ and the expected exchange rate $s^E$, while $\delta_{0,i}$ is a country-specific constant and $v_{i,t}$ is the error term.

For estimating the ECM, we apply three methods: the fixed effect (FE) estimator, the pooled mean-group (PMG) estimator of Pesaran et al. (1999), and the mean-group (MG) estimator of Pesaran and Smith (1995). The FE method allows only the intercepts to differ between the countries, while the PMG estimator assumes a common co-integrating vector but allows the short-run parameters, variances and adjustments speeds to vary (Blackburne and Frank, 2007). Finally, the MG estimator averages the coefficients over separate time-series regressions for all countries. We apply the Hausman test to select between the MG, PMG and FE estimators. As a robustness check, in Section 4.2 we also estimate an alternative parsimonious model specification: a mixed model with random slopes, allowing unobserved variation in discount factors between countries.

## 4. Results

First, panel unit root tests of Breitung (2000) and Hadri (2000) confirm that the spot rate, the fundamentals and the consensus forecast are not stationary. Table 1 shows results of Pedroni (1999) panel cointegration tests to verify if these three series have a cointegration relationship. The tests all support the alternative hypothesis of a cointegration relation, as the three test statistics follow a standard normal distribution with a tail critical value of −1.645. In addition, a robustness check with the Fisher-Johansen panel cointegration test also confirms that there is one cointegration relationship. In sum, there is strong evidence that the spot rate, the fundamental and the consensus forecast jointly follow a long-term equilibrium relationship.

**Table 1**
Panel cointegration and ECM specification tests.

| | (1) | (2) | (3) |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| | | *Traditional fundamental, $\gamma = 1$* | |
| *Panel cointegration tests* | | | |
| Group rho | −116.1 | −77.76 | −35.06 |
| Group $t$ | −60.32 | −43.37 | −24.53 |
| Group ADF | −23.17 | −15.15 | −9.74 |
| *ECM specification tests* | | | |
| Hausman MG vs PMG, $p$-value | 0.846 | 0.572 | 0.120 |
| Hausman MG vs FE, $p$-value | 0.945 | 0.911 | 0.934 |
| | | *Traditional fundamental, $\gamma = 0.5$* | |
| *Panel cointegration tests* | | | |
| Group rho | −116.0 | −75.60 | −31.99 |
| Group $t$ | −60.15 | −42.38 | −23.09 |
| Group ADF | −23.11 | −13.92 | −9.61 |
| *ECM specification tests* | | | |
| Hausman MG vs PMG, $p$-value | 0.679 | 0.426 | 0.144 |
| Hausman MG vs FE, $p$-value | 0.947 | 0.925 | 0.941 |
| | | *Taylor rule fundamental* | |
| *Panel cointegration tests* | | | |
| Group rho | −116.9 | −75.25 | −30.39 |
| Group $t$ | −60.00 | −41.75 | −21.96 |
| Group ADF | −22.36 | −10.33 | −8.18 |
| *ECM specification tests* | | | |
| Hausman MG vs PMG, $p$-value | 0.585 | 0.888 | 0.939 |
| Hausman MG vs FE, $p$-value | 0.931 | 0.911 | 0.877 |
| Observations | 5175 | 5175 | 5175 |
| Number of countries | 25 | 25 | 25 |

Notes: The table reports the results of Pedroni (1999) panel cointegration tests, followed by Hausman tests for the specification of the panel error correction model (ECM) in Equation (6). Group rho, Group $t$ and Group ADF are panel cointegration test statistics of Pedroni (1999) to test if the spot rate, the fundamental and the expected exchange rate (consensus forecast) have a cointegration relationship. Under the null hypothesis of "no cointegration relation" the three test statistics follow a standard normal distribution, with a 5% critical value of −1.645. The ECM specification tests show $p$-values for two Hausman tests. The first Hausman test compares the pooled mean-group (PMG) estimator of Pesaran et al. (1999) to the mean-group (MG) estimator of Pesaran and Smith (1995). The null hypothesis is that the ECM coefficient $b$ is constant across countries, and in that case the PMG estimator is more efficient. The second Hausman tests compares the fixed effect (FE) estimator to the mean-group (MG) estimator. The null hypothesis is that the ECM coefficients $b$, $\alpha$, $\delta_1$ and $\delta_2$ are constant across countries, and in that case the FE estimator is more efficient. The panel data consists of 5175 monthly observations on the spot exchange rate, the traditional fundamental, the Taylor rule fundamental and the consensus exchange rate forecast for 25 countries. See the Appendix for the country list. The upper panel of the table shows results using the traditional fundamental with coefficient value $\gamma = 1$ in Equation (4), while the middle panel shows results when using $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5).

As explained in Section 3, we estimate the ECM in (6) with three panel estimation methods that make different assumptions about variation between countries in the model coefficients: the fixed effect (FE) estimator, the pooled mean-group (PMG) estimator of Pesaran et al. (1999), and the mean-group (MG) estimator of Pesaran and Smith (1995). The Hausman test results displayed in Table 1 cannot reject the null hypothesis of constant coefficients across countries, indicating that the pooled FE estimator is most efficient. For our main results in Table 2 we therefore report the FE estimates of the discount factor $b$.

Table 2 shows the ECM estimation results for the discount factor $b$, separately for the 3-month, 6-month and 12-month consensus forecast horizon in column (1), (2) and (3). Further, the upper panel of Table 2 shows results using the traditional fundamental values with coefficient value $\gamma = 1$ in Equation (4), while the middle panel shows results for $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5). The results in Table 2 confirm that the discount factor is close to one. For example, with a forecast horizon of 3 months and for $\gamma = 1$, the estimated discount factor $b$ is 0.990. The null hypothesis "$b = 1$" can be rejected with p-value $< 0.01$, with the significance indicated by the "+"-signs in the table. As expected, the discount factors become slightly lower as the forecast horizon becomes longer in column (2) and (3), for 6 and 12 months: $b = 0.986$, and $b = 0.982$. Further, the error correction parameter $\alpha$ is always significantly negative, implying mean-reversion to the long-term equilibrium relation between the spot exchange rate, the fundamental and the expected exchange rate.

The lower panel of Table 2 shows the results for the Taylor rule fundamental: $b = 0.985$, 0.978 and 0.967 for 3, 6 and 12 months, respectively. Again, the discount rate is close to unity, although slightly lower compared to the traditional fundamental. Further, the discount rate is lower at longer forecast horizons, as the model implies. Overall, the results in Table 2 confirm for a panel 25 currencies in the period 2001–2018 that the discount factor is close to one, supporting the feeble link between exchange rates and fundamentals in the asset pricing model suggested by Engel and West (2005) and Engel et al. (2007).

**Table 2**
Panel ECM estimation results.

| | (1) | (2) | (3) |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| | *Traditional fundamental, $\gamma = 1$* | | |
| *Cointegration equation* | | | |
| Discount factor $b$ | $0.990^{+++}$ | $0.986^{+++}$ | $0.982^{++}$ |
| *Short-term equation* | | | |
| Error correction speed $\alpha$ | −0.638*** | −0.344*** | −0.181*** |
| $\delta_1$ for $\Delta f_{i,t-1}$ | 0.003 | 0.001 | −0.001 |
| $\delta_2$ for $\Delta s^E_{i,t-1}$ | 0.266*** | 0.441*** | 0.544*** |
| | *Traditional fundamental, $\gamma = 0.5$* | | |
| *Cointegration equation* | | | |
| Discount factor $b$ | $0.990^{+++}$ | $0.987^{+++}$ | $0.984^{+}$ |
| *Short-term equation* | | | |
| Error correction speed $\alpha$ | −0.631*** | −0.338*** | −0.182*** |
| $\delta_1$ for $\Delta f_{i,t-1}$ | 0.015** | 0.014* | 0.013* |
| $\delta_2$ for $\Delta s^E_{i,t-1}$ | 0.273*** | 0.445*** | 0.541*** |
| | *Taylor rule fundamental* | | |
| *Cointegration equation* | | | |
| Discount factor $b$ | $0.985^{+++}$ | $0.978^{++}$ | $0.967^{++}$ |
| *Short-term equation* | | | |
| Error correction speed $\alpha$ | −0.621*** | −0.334*** | −0.180*** |
| $\delta_1$ for $\Delta f_{i,t-1}$ | 0.015 | 0.070** | 0.083** |
| $\delta_2$ for $\Delta s^E_{i,t-1}$ | 0.285*** | 0.450*** | 0.545*** |
| Observations | 5158 | 5158 | 5158 |
| Number of countries | 25 | 25 | 25 |

Notes: The table reports estimated coefficients for the panel error correction model (ECM) in Equation (6), using a fixed effect estimator where the ECM coefficients $b$, $\alpha$, $\delta_1$ and $\delta_2$ are constant across countries. The discount factor $b$ is the weight on the expected exchange rate $s^E_{i,t-1}$ in the cointegration equation, while the weight on the fundamental $f_{i,t-1}$ is $(1-b)$. In column (1) the forecast horizon of the expected (consensus) exchange rate is 3 months, while in column (2) and (3) the forecast horizons are 6 and 12 months. The upper panel shows results using the traditional fundamental values calculated with coefficient value $\gamma = 1$ in Equation (4), while the middle panel shows results when using $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5). The panel data consists of 5175 monthly observations on the spot exchange rate, the traditional fundamental, the Taylor rule fundamental and the consensus exchange rate forecast for 25 countries. See the Appendix for the country list.
$^{+,++,+++}$ Denote $p < 0.1$, 0.05, 0.01 for testing the null hypothesis that the discount factor $b$ is 1.
*,**,*** Denote $p < 0.1$, 0.05, 0.01 for testing the null hypothesis that the coefficient is 0.

### *4.1. Discount factor in developing economies*

In the literature the discount factor so far has only been estimated for advanced economies, while our panel also contains developing economies. In this section we examine whether there is a difference in discount factors between developing and advanced economies. For that purpose, we include an interaction term between a dummy for developing economies and the consensus forecast $s^E_{i,t-1}$ in the cointegration relation of the ECM model. We use the list of advanced economies from the IMF World Economic Outlook (2019) to identify the 12 advanced and 13 developing economies in our sample: see Appendix A.

Table 3 displays the estimation results, which show that the discount factor $b$ in developing countries is significantly lower than in advanced economies. The difference in discount factors is −0.01, −0.03 and −0.05 for the traditional fundamental when using 3, 6 and 12 months forecasts respectively. The gap becomes larger as the forecast horizon for the expected exchange rate increases. A possible theoretical explanation for this finding is that developing countries tend to have higher levels of inflation and nominal interest rates, which leads to a lower interest semi-elasticity of money demand in the general-equilibrium monetary models of Obstfeld and Rogoff (2003) and Benchimol and Qureshi (2020). In the money income model (Engel and West, 2005) a lower interest semi-elasticity of money demand implies a lower discount factor.

The lower panel shows similar findings for the Taylor rule fundamental. In Taylor rule models, the discount factor is generally determined by the strength of the central banks' response to the exchange rate. In Engel and West (2005), the central bank raises interest rates when the domestic currency depreciates relative to its PPP target. In Huber and Kaufmann (2020), the central bank lowers interest rates when the domestic currency appreciates in real terms. The stronger the response by the central bank, the lower the discount rate. Therefore, an additional explanation for a lower discount factor in developing countries may be that central banks in developing countries respond more strongly to exchange rate fluctuations.

The ECM estimation results in Table 3 also indicate that the discount factor in advanced economies is close to 1 at all horizons, such that the null hypothesis "$b = 1$" cannot be rejected at the 5% level. Either $b$ is less than one as the model prescribes, but so close to one that we do not have sufficient power to reject "$b = 1$", or the model simply does not hold. Either way, a practical implication is that in

**Table 3**
Discount factors in developing and advanced economies.

| | (1) | (2) | (3) |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| | | *Traditional fundamental, $\gamma = 1$* | |
| Discount factor $b$ | | | |
| Developing economies | $0.986^{+++}$ | $0.976^{+++}$ | $0.964^{+++}$ |
| Advanced economies | $0.996^{+}$ | 1.002 | 1.011 |
| Diff. in discount factor | −0.010*** | −0.026*** | −0.047*** |
| ($t$-statistic) | (-4.40) | (-4.34) | (-3.76) |
| | | *Traditional fundamental, $\gamma = 0.5$* | |
| Discount factor $b$ | | | |
| Developing economies | $0.985^{+++}$ | $0.976^{+++}$ | $0.965^{+++}$ |
| Advanced economies | 0.997 | 1.005 | 1.015 |
| Diff. in discount factor | −0.012*** | −0.029*** | −0.050*** |
| ($t$-statistic) | (-4.29) | (-3.98) | (-3.62) |
| | | *Taylor rule fundamental* | |
| Discount factor $b$ | | | |
| Developing economies | $0.980^{+++}$ | $0.963^{+++}$ | $0.969^{+++}$ |
| Advanced economies | 0.994 | 1.007 | 1.006 |
| Diff. in discount factor | −0.014* | −0.043*** | −0.037*** |
| ($t$-statistic) | (-1.82) | (-3.06) | (-4.52) |
| Observations | 5158 | 5158 | 5158 |
| Number of countries | 25 | 25 | 25 |

Notes: The table reports estimated coefficients for the panel error correction model (ECM) in Equation (6), extended with an interaction term between a dummy for developing economies and the consensus forecast $s^E_{i,t-1}$ in the cointegration equation. The coefficient of this interaction term is reported under "Diff. in discount factor", and is used to test the null hypothesis that the discount factor $b$ is equal in developing and advanced economies. We use the list of advanced economies from the IMF (2019) to define the 12 advanced and 13 developing economies in our sample: see the Appendix. The discount factor $b$ is the weight on the expected exchange rate $s^E_{i,t-1}$ in the cointegration equation. In column (1) the forecast horizon of the expected (consensus) exchange rate is 3 months, while in column (2) and (3) the forecast horizons are 6 and 12 months. The upper panel of the table shows results using the traditional fundamental values calculated with coefficient value $\gamma = 1$ in Equation (4), while the middle panel shows results when using $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5). The panel data consists of 5175 monthly observations on the spot exchange rate, the traditional fundamental, the Taylor rule fundamental and the consensus FX forecast for 25 countries.
$^{+,++,+++}$ Denote $p < 0.1, 0.05, 0.01$ for testing the null hypothesis that the discount factor $b$ is 1.
*,**,*** Denote $p < 0.1, 0.05, 0.01$ for testing the null hypothesis that the difference in $b$ is 0, comparing between developing and advanced economies.

advanced economies forecasting exchange rates with the traditional fundamental and the Taylor rule fundamental will be especially hard, even if the asset pricing model does in fact hold.

### 4.2. *Robustness check: mixed model with heterogeneity in discount factors*

As a robustness check, we estimate the discount factor with an alternative estimation approach: a mixed model that allows for unobserved heterogeneity in discount factors between countries, and a random effect to capture country-specific errors. We start by rewriting the exchange rate model (1) in the following form:

$$s_t - f_t = b(E_t s_{t+1} - f_t) \tag{7}$$

Next, with our panel dataset we estimate the equation above as a mixed model, including a country-specific random slope $v_i^b$ for the discount factor $b$, and a country-specific error term $u_i$:

$$s_{i,t} - f_{i,t} = \left(b + v_i^b\right)\left(s^E_{i,t} - f_{i,t}\right) + u_i + \varepsilon_{i,t} \tag{8}$$

The random slope $v_i^b$ allows for unobserved random variation in discount factors between countries, around the overall mean discount factor $b$. Further, the random effect $u_i$ captures country-specific errors in the model, independent from the generic error term $\varepsilon_{i,t}$. Before estimating model (8) above, panel cointegration tests confirmed that $(s_{i,t} - f_{i,t})$ and $(s^E_{i,t} - f_{i,t})$ indeed have a long-term equilibrium relation.

Table 4 shows the estimation results for the mixed model (8), when also including a dummy- interaction term that allows to test for differences in discount factors between advanced and developing economies. The results show that the discount factor is close to one, discount factors in developing economies are significantly lower than in advanced economies, and further the gap increases as the

**Table 4**
Mixed model estimation results.

| | (1) | (2) | (3) |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| | | *Traditional fundamental,* $\gamma = 1$ | |
| Discount factor $b$ | | | |
| Developing economies | $0.984^{+++}$ | $0.966^{+++}$ | $0.941^{+++}$ |
| Advanced economies | $0.995^{+}$ | 1.003 | 1.014 |
| Diff. in discount factor | −0.011*** | −0.037*** | −0.073*** |
| ($t$-statistic) | (-2.97) | (-4.44) | (-4.58) |
| Stdev. random slope $v_i^b$ | 0.008 | 0.019 | 0.038 |
| Stdev. random effect $u_i$ | 0.050 | 0.121 | 0.213 |
| Stdev. error term $\varepsilon_{i,t}$ | 0.013 | 0.022 | 0.034 |
| | | *Traditional fundamental,* $\gamma = 0.5$ | |
| Discount factor $b$ | | | |
| Developing economies | $0.986^{+++}$ | $0.970^{+++}$ | $0.947^{+++}$ |
| Advanced economies | 0.996 | 1.004 | 1.015 |
| Diff. in discount factor | −0.010** | −0.034*** | −0.068*** |
| ($t$-statistic) | (-2.53) | (-3.57) | (-3.70) |
| Stdev. random slope $v_i^b$ | 0.009 | 0.022 | 0.044 |
| Stdev. random effect $u_i$ | 0.045 | 0.111 | 0.203 |
| Stdev. error term $\varepsilon_{i,t}$ | 0.013 | 0.022 | 0.033 |
| | | *Taylor rule fundamental* | |
| Discount factor $b$ | | | |
| Developing economies | $0.984^{+++}$ | $0.968^{+++}$ | $0.940^{+++}$ |
| Advanced economies | 0.990 | 0.995 | 0.997 |
| Diff. in discount factor | −0.007 | −0.027* | −0.057** |
| ($t$-statistic) | (-0.86) | (-1.68) | (-2.03) |
| Stdev. random slope $v_i^b$ | 0.018 | 0.038 | 0.068 |
| Stdev. random effect $u_i$ | 0.050 | 0.140 | 0.284 |
| Stdev. error term $\varepsilon_{i,t}$ | 0.013 | 0.022 | 0.034 |
| Observations | 5175 | 5175 | 5175 |
| Number of countries | 25 | 25 | 25 |

Notes: The table reports estimated coefficients for the mixed model with random effects in Equation (8), extended with an interaction term between a dummy for developing economies and the right-hand-side variable $(s_{i,t}^E - f_{i,t})$. The coefficient of this interaction term is reported under "Diff. in discount factor", and is used to test the null hypothesis that the discount factor $b$ is equal in developing and advanced economies. We use the list of advanced economies from the IMF (2019) to define the 12 advanced and 13 developing economies in our sample: see Appendix A. The discount factor $b$ is the weight on the expected exchange rate $s_{i,t-1}^E$ in the cointegration equation. In column (1) the forecast horizon of the expected (consensus) exchange rate is 3 months, while in column (2) and (3) the forecast horizons are 6 and 12 months. The upper panel shows results using the traditional fundamental values calculated with $\gamma = 1$ in Equation (4), while the middle panel shows results for $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5). The standard deviations of the random slope $v_i^b$, the random effect $u_i$ and the error term $\varepsilon_{i,t}$ in the mixed model are also shown. The panel data consists of 5175 monthly observations on the spot exchange rate, the traditional fundamental, the Taylor rule fundamental and the consensus FX forecast for 25 countries.
$^{+,++,+++}$ Denote $p < 0.1, 0.05, 0.01$ for testing that the null hypothesis that the discount factor $b$ is 1.
*,**,*** Denote $p < 0.1, 0.05, 0.01$ for testing that the null hypothesis that the difference in $b$ is 0, comparing between developing and advanced economies.

forecast horizon for the expected exchange rate becomes longer. In sum, the panel fixed effects estimator (FE) in Table 3 and the mixed model estimation approach in Table 4 lead to the similar results, and the same conclusions about the value of the discount factor.

### 4.3. *Robustness check: separating countries based on the World Uncertainty Index*

As a further robustness check, we have also divided the 25 countries into two groups with relatively high and low levels of economic and political uncertainty in the period 2001–2018, based on the World Uncertainty Index (WUI) data of Ahir et al. (2018).[1] In general asset pricing models discount factors represent the weights put on expected future fundamentals. As a consequence, we expect that the discount factor is lower in the group of countries with high uncertainty about the future values of the fundamentals. The results, shown in Appendix B Table B1, are similar to those shown in Tables 3 and 4: the discount factor is close to one, the discount factor in countries

[1] The classifications of the countries based on high/low uncertainty and based on developing/advanced are related, but not perfectly: the correlation between the dummies is $r = 0.36$ ($p = 0.073$).

with high uncertainty is significantly lower compared to economies with low uncertainty, and this gap increases at longer forecast horizons. This provides an alternative explanation for the finding in Tables 3 and 4 that discount factors are lower in developing countries, as Ahir et al. (2018) show that the level of economic and political uncertainty is on average higher in developing countries than in advanced economies.

## 5. Conclusions

Engel and West (2005) and Engel et al. (2007) show that when the discount factor in the asset pricing model of the exchange rate is close to one, fundamental-based forecasts perform poorly even if the model holds. Empirical evidence on the value of the discount factor so far has been limited to a small number of major currencies (Sarno and Sojli, 2009; Balke et al., 2013). In this paper, we estimated the discount factor for a large cross-section of 25 currencies, in the period from 2001 to 2018, using efficient panel estimation techniques.

We find that the mean discount factor is close to one, with pooled estimates ranging from 0.967 to 0.990. The discount factor increases as the forecast horizon for the expected exchange rate becomes shorter. Further, the discount factor is significantly lower in developing economies, compared to advanced economies. This implies that exchange rate forecasting is more likely to be successful in developing economies and at longer forecast horizons (Mark, 1995). However, the evidence also suggests that making good fundamental-based forecasts will be hard in any case, as even the lowest discount factor in our results is still close to one: namely, 0.940, for a 12-month forecast horizon in developing economies.

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## Declaration of competing interest

None.

## Appendix A. Dataset

### *A.1. Country List and Data Sources*

The table below shows the countries and national currencies (versus the US dollar) in the dataset. Further, the third column indicates whether the economy is classified *Advanced* or *Developing*, based on the IMF World Economic Outlook (2019). The last four columns show the data sources for monthly observations on money supply (M1), industrial production, the consumer price index (CPI), and the interest rate. Interest rates are short-term rates from the OECD, or if not available, the interbank rate from OECD. If OECD interest rate data was missing for a country, the money market rate from the IMF was used.

**Table A1**
List of Countries, Currencies and Data Sources

| Country | Currency | IMF Class. | M1 | Ind. Prod. | CPI | Interest |
|---|---|---|---|---|---|---|
| Australia | Australian Dollar | Advanced | OECD | DS | DS | OECD |
| Brazil | Brazilian Real | Developing | OECD | OECD | OECD | OECD |
| Canada | Canadian Dollar | Advanced | OECD | OECD | OECD | OECD |
| Chile | Chilean Peso | Developing | OECD | OECD | OECD | OECD |
| Colombia | Colombian Peso | Developing | OECD | OECD | OECD | OECD |
| Czech Rep. | Czech Koruna | Advanced | OECD | OECD | OECD | OECD |
| Denmark | Danish Krone | Advanced | OECD | OECD | OECD | IFS |
| Euro area | Euro | Advanced | OECD | OECD | OECD | OECD |
| Hong Kong | Hong Kong Dollar | Advanced | DS | DS | IFS | IFS |
| Hungary | Hungarian Forint | Developing | OECD | OECD | OECD | OECD |
| India | Indonesian Rupiah | Developing | OECD | OECD | OECD | OECD |
| Indonesia | Indian Rupee | Developing | OECD | OECD | OECD | OECD |
| Japan | Japanese Yen | Advanced | OECD | OECD | OECD | OECD |
| South Korea | Korean Won | Advanced | OECD | OECD | OECD | OECD |
| Mexico | Mexican Peso | Developing | OECD | OECD | OECD | OECD |
| Norway | Norwegian Krone | Advanced | OECD | OECD | OECD | OECD |
| Philippines | Philippine Peso | Developing | DS | IFS | IFS | IFS |
| Poland | Polish Zloty | Developing | OECD | OECD | OECD | OECD |
| Russia | Russian Rouble | Developing | OECD | OECD | OECD | OECD |
| Singapore | Singapore Dollar | Advanced | DS | IFS | IFS | IFS |
| South Africa | South Afr. Rand | Developing | OECD | OECD | OECD | OECD |
| Sweden | Swedish Krona | Advanced | OECD | OECD | OECD | OECD |
| Thailand | Thai Baht | Developing | DS | DS | IFS | IFS |
| Turkey | Turkish Lira | Developing | OECD | OECD | OECD | OECD |
| UK | British Pound | Advanced | OECD | OECD | OECD | OECD |

Notes: The source abbreviations are: DS for Datastream, IFS denotes the IMF International Financial Statistics database, and OECD stands for data from the Organization for Economic Cooperation and Development.

## Appendix B. Results for High and Low Economic Uncertainty Countries

The table below shows estimation results for the panel error correction model (ECM) in Equation (6), extended with an interaction term between a dummy for high economic uncertainty and the consensus forecast in the cointegration equation, similar to Table 3 in the main text. The 25 countries in the sample were divided into two groups with relatively high and low levels of economic and political uncertainty in the period 2001–2018, based on the World Uncertainty Index (WUI) data of Ahir et al. (2018).

**Table B1**
Discount Factors in High and Low Economic Uncertainty Countries

| | (1) | (2) | (3) |
|---|---|---|---|
| | 3 months | 6 months | 12 months |
| | | *Traditional fundamental,* $\gamma = 1$ | |
| Discount factor $b$ | | | |
| High uncertainty countries | $0.985^{+++}$ | $0.978^{+++}$ | $0.971^{+++}$ |
| Low uncertainty countries | $0.995^{++}$ | 0.996 | 0.996 |
| Diff. in discount factor | −0.010*** | −0.018*** | −0.025** |
| ($t$-statistic) | (-4.22) | (-2.85) | (-2.00) |
| | | *Traditional fundamental,* $\gamma = 0.5$ | |
| Discount factor $b$ | | | |
| High uncertainty countries | $0.985^{+++}$ | $0.977^{+++}$ | $0.971^{+++}$ |
| Low uncertainty countries | 0.997 | 0.999 | 1.000 |
| Diff. in discount factor | −0.012*** | −0.021*** | −0.029** |
| ($t$-statistic) | (-5.31) | (-3.16) | (-2.19) |
| | | *Taylor rule fundamental* | |
| Discount factor $b$ | | | |
| High uncertainty countries | $0.977^{+++}$ | $0.965^{+++}$ | $0.953^{+++}$ |
| Low uncertainty countries | 0.998 | 1.003 | 0.994 |
| Diff. in discount factor | −0.020*** | −0.038*** | −0.041* |
| ($t$-statistic) | (-3.18) | (-2.80) | (-1.71) |
| Observations | 5158 | 5158 | 5158 |
| Number of countries | 25 | 25 | 25 |

Notes: The table reports estimated coefficients for the panel error correction model (ECM) in Equation (6), extended with an interaction term between a dummy for high economic uncertainty and the consensus forecast $s^E_{i,t-1}$ in the cointegration equation. We divided the 25 countries into two groups with relatively high and low levels of economic and political uncertainty in the period 2001–2018, based on the World Uncertainty Index (WUI) data of Ahir et al. (2018). The coefficient of this interaction term is reported under "Diff. in discount factor", and is used to test the null hypothesis that the discount factor $b$ is equal in high and low economic uncertainty countries. The discount factor $b$ is the weight on the expected exchange rate $s^E_{i,t-1}$ in the cointegration equation. In column (1) the forecast horizon of the expected (consensus) exchange rate is 3 months, while in column (2) and (3) the forecast horizons are 6 and 12 months. The upper panel of the table shows results using the traditional fundamental values with coefficient $\gamma = 1$ in Equation (4), while the middle shows results for $\gamma = 0.5$ and the lower panel shows results for the Taylor rule fundamental in Equation (5). The panel data consists of 5175 monthly observations on the spot exchange rate, the traditional fundamental, the Taylor rule fundamental and the consensus FX forecast for 25 countries.
$^{+}$,$^{++}$,$^{+++}$ Denote $p < 0.1$, 0.05, 0.01 for testing the null hypothesis that the discount factor $b$ is 1.
*,**,*** Denote $p < 0.1$, 0.05, 0.01 for testing the null hypothesis that the difference in $b$ is 0, comparing between countries with high and low economic uncertainty.

## References

Ahir, H., Bloom, N., Furceri, D., 2018. The World Uncertainty Index. Working paper. Stanford University.
Balke, N.S., Ma, J., Wohar, M.E., 2013. The contribution of economic fundamentals to movements in exchange rates. J. Int. Econ. 90 (1), 1–16.
Benchimol, J., Qureshi, I., 2020. Time-varying money demand and real balance effects. Econ. Modell. 87, 197–211.
Blackburne III, E.F., Frank, M.W., 2007. Estimation of nonstationary heterogeneous panels. STATA J. 7 (2), 197–208.
Breitung, J., 2000. The local power of some unit root tests for panel data. In: Baltagi, B. (Ed.), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels* (*Advances In Econometrics*, vol. 15, pp. 161–178.

Cheung, Y.W., Chinn, M.D., Pascual, A.G., 2005. Empirical exchange rate models of the nineties: are any fit to survive? J. Int. Money Finance 24 (7), 1150–1175.
Engel, C., West, K.D., 2005. Exchange rates and fundamentals. J. Polit. Econ. 113 (3), 485–517.
Engel, C., Mark, N.C., West, K.D., 2007. Exchange rate models are not as bad as you think. NBER Macroecon. Annu. 22, 381–473, 2007.
Hadri, K., 2000. Testing for stationarity in heterogeneous panel data. Econom. J. 3 (2), 148–161.
Huber, F., Kaufmann, D., 2020. Trend fundamentals and exchange rate dynamics. Economica 87 (348), 1016–1036.
IMF, October 2019. World Economic Outlook.
Ince, O., Molodtsova, T., 2017. Rationality and forecasting accuracy of exchange rate expectations: evidence from survey-based forecasts. J. Int. Financ. Mark. Inst. Money 47, 131–151.
Mark, N.C., 1995. Exchange rates and fundamentals: evidence on long-horizon predictability. Am. Econ. Rev. 85 (1), 201–218.
Meese, R.A., Rogoff, K., 1983. Empirical exchange rate models of the seventies: do they fit out of sample? J. Int. Econ. 14 (1–2), 3–24.
Neely, C.J., Sarno, L., 2002. How well do monetary fundamentals forecast exchange rates? Fed. Reserv. Bank St. Louis Rev. 84 (5), 51–74.
Obstfeld, M., Rogoff, K., 2003. Risk and exchange rates. In: Helpman, E., Sadka, E. (Eds.), Economic Policy in the International Economy: Essays in Honor of Assaf Razin, pp. 74–120.
Pedroni, P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxf. Bull. Econ. Stat. 61 (S1), 653–670.
Pesaran, M.H., Smith, R., 1995. Estimating long-run relationships from dynamic heterogeneous panels. J. Econom. 68 (1), 79–113.
Pesaran, M.H., Shin, Y., Smith, R.P., 1999. Pooled mean group estimation of dynamic heterogeneous panels. J. Am. Stat. Assoc. 94 (446), 621–634.
Rossi, B., 2013. Exchange rate predictability. J. Econ. Lit. 51 (4), 1063–1119.
Sarno, L., 2005. Towards a solution to the puzzles in exchange rate economics: where do we stand? Can. J. Econ. 38 (3), 673–708.
Sarno, L., Sojli, E., 2009. The feeble link between exchange rates and fundamentals: can we blame the discount factor? J. Money Credit Bank. 41 (2-3), 437–442.