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Konrad Adler and Christian Grisse

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Real exchange rates and fundamentals: robustness across alternative model specifications*

Konrad Adler
Toulouse School of Economics

Christian Grisse
Swiss National Bank

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Abstract

This paper explores the robustness of behavioural equilibrium exchange rate (BEER) models, focusing on a panel specification with Swiss franc real bilateral rates as dependent variables. We use Bayesian model averaging to illustrate model uncertainty, and employ real exchange rates computed from price level data to explore robustness to the inclusion or exclusion of fixed effects. We find that the estimated coefficients – and therefore also the implied equilibrium values – are sensitive to (1) the combination of explanatory variables included in the model, (2) the set of currencies included in the panel and (3) the inclusion of fixed effects. Increases in government consumption and net foreign assets and improvements in the terms of trade in Switzerland relative to foreign countries are associated with a Swiss franc real appreciation, as predicted by economic theory. By contrast, several macroeconomic variables commonly thought to be linked to real exchange rates are found not to exhibit a robust relationship with Swiss franc real rates. Our findings can help policymakers in understanding the uncertainty associated with estimates of equilibrium exchange rates.

JEL classification: C11, C33, F31, F32, F41
Keywords: Equilibrium exchange rates, model uncertainty, model combination, panel data

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1 Introduction

An important question for policymakers is whether currency movements reflect temporary factors, such as safe-haven effects which are likely to recede once market turbulence subsides; or whether they are driven by movements in fundamental macroeconomic variables, i.e. by an appreciation of the "equilibrium" exchange rate, that are more likely to be permanent. Several alternative approaches have been proposed to estimate equilibrium exchange rates.[1] The problem for policymakers is that these approaches often produce very different results. Furthermore, even within any particular approach to estimating the equilibrium exchange rate the estimates will still depend on a number of modeling assumptions.

This paper studies the robustness of "behavioral equilibrium exchange rate" (BEER) models. In the BEER approach equilibrium real exchange rates are estimated as the real rates consistent with a set of macroeconomic fundamental variables, typically in a panel regression across currencies.[2] Focusing on a panel specification with real bilateral rates as dependent variables, this paper highlights the extent to which coefficient estimates are sensitive to the set of variables included in the model, to the currencies included in the panel, and to the estimation methodology (fixed effects versus pooled estimation). We make three contributions. First, we explore the consequences of model uncertainty, which arises because a large number of fundamentals is identified by the theoretical literature as potential drivers of real exchange rates, but with a limited dataset it is not necessarily optimal to include all these variables (some of which may have little explanatory power for real exchange rates) in the regression. We estimate real exchange rate regressions for all possible combinations of the explanatory variables, and use Bayesian model averaging to weigh the alternative models in a statistically optimal way.[3] We find that increases in government consumption and net foreign assets and improvements in the terms of trade in Switzerland relative to foreign countries are associated with a Swiss franc real appreciation, robustly across model specifications, as predicted by economic theory. In contrast, several macroeconomic variables commonly thought to be linked to real exchange rates do not exhibit a robust relationship with Swiss franc real rates. For example, relative GDP per capita exhibits the expected positive relationship with Swiss franc real exchange rates only in the cross-section, but not over time; in panel regressions with fixed effects the coefficient is often negative. Alternative specifications imply a range of values for the model coefficients; the implied equilibrium rates will therefore depend on the particular combination of variables included in the model.

Second, we explore the implications of alternative currency samples for the estimated coefficients. It is not necessarily optimal to use the largest possible panel to estimate the relationship between real exchange rates and fundamentals: while the parameters can be estimated more pre-

[1] See Driver and Westaway (2004) for a survey.

[2] The BEER approach is also used by the IMF to assess equilibrium exchange rates. See IMF (2012).

[3] Bayesian model averaging was introduced by Sala-i-Martin et al. (2004), and used by Bussière et al. (2010) and Ca'Zorzi et al. (2012) to explore model uncertainty in the context of fundamental drivers of current accounts.

cisely with a larger number of observations, the assumption that coefficients are identical across currencies becomes more problematic with a larger number of currencies. For example, drivers of real exchange rates could differ across developed and emerging market economies; and the real exchange rates of small countries and of financial centers could be driven by special factors. Estimating the model for alternative currency samples we find that the coefficients (and consequently the equilibrium rates) are highly sensitive to the chosen sample.

Our third contribution is to contrast the estimated coefficients in models with and without fixed effects. The use of fixed effects is common practice in the literature and is necessary because real exchange rates are index numbers. However, the inclusion of fixed effects makes the estimated equilibrium rates hard to interpret, especially when the sample is short and real rates are close to their long-run average: with fixed effects the predicted real rates are by construction on average equal to the long-run real rate average. We make use of real exchange rates computed based on price level data from the Eurostat-OECD PPP project to estimate the relationship between Swiss franc bilateral real exchange rates and fundamentals in a panel without fixed effects. We find that the exclusion of fixed effects can have a significant impact on the estimated coefficients. This will then also affect the model-implied equilibrium exchange rates, both in terms of their level and in terms of their evolution over time.

The objective of this paper is not to develop and estimate a structural model of determinants of Swiss franc real exchange rates. Instead, we start from the observation that economic theory has suggested a large number of potential drivers of real exchange rates.[4] Based on these theories, BEER models used in policy analysis need to select those variables that exhibit the most robust relationship with the real exchange rate. We therefore work with a reduced form model and explore the link of a large number of potentially important macroeconomic and financial variables with Swiss franc real exchange rates. The empirical literature has often employed reduced form models in which a long-run, cointegrating relationship between real exchange rates and fundamentals is estimated.[5] In such an exercise, the fundamental variables cannot be interpreted to exhibit a causal effect on the real exchange rate. Nevertheless, this approach can help to determine the extent to which real exchange rates diverge from their historical link with fundamentals. This information can be useful for policymakers.

This paper is related to the large literature on the fundamental determinants of real exchange rates, and to the literature on equilibrium exchange rates. Recent papers have focused particularly on providing empirical evidence for the Balassa-Samuelson effect, which holds that countries with strong growth in the traded goods sector should see their real exchange rates appreciate. Ricci et al. (2013), Gubler and Sax (2011) and Mancini-Griffoli et al. (2014) have used data on productivity growth in the traded and non-traded sectors, suitably defined, to estimate the relationship between

[4]See for example Samuelson (1964), Balassa (1964), Neary (1988), Bergstrand (1991), de Gregorio and Wolf (1994), de Gregorio, Giovannini and Wolf (1994), Ostry (1994), Higgins (1998) and Rose et al. (2009).

[5]See for example Ricci et al. (2013) for a recent example.

real exchange rates and proxies for the Balassa-Samuelson effect, as well as other fundamental variables. Studies of the determinants of Swiss franc real exchange rates include Macini-Griffoli et al. (2014) and Reynard (2009). We follow Mancini-Griffoli et al. (2014) in using bilateral real rates as dependent variables. Our contribution relative to these papers is that we focus on the robustness of estimated coefficients across alternative model specifications, using a larger set of bilateral currency pairs and explanatory variables. A paper that is complementary to ours is Bénassy-Quéré et al. (2009), who also study the robustness of BEER models. They focus on robustness to using alternative measures of productivity differentials as explanatory variables, to alternative samples in the time dimension, and to alternative numeraire currencies for the real exchange rates. In contrast, this paper studies robustness across a much larger set of explanatory variables, across alternative samples in the cross-section (rather than the time dimension), and to estimation with and without fixed effects.

The remainder of this paper is structured as follows. The next section reviews the BEER approach to estimating equilibrium exchange rates, discusses the economic intuition behind alternative fundamental variables that could determine long-run real exchange rates and introduces the data used in this study. Section 3 presents baseline results and explores their robustness to alternative combinations of explanatory variables and currency samples. Section 4 uses real exchange rates based on price-level data to estimate the model without fixed effects. Finally, section 5 concludes.

2 Empirical approach

2.1 The BEER methodology

In the BEER approach, a reduced-form relationship between the real exchange rate and a set of fundamental economic variables is estimated. While most of the literature focuses on effective exchange rates, we follow Mancini-Griffoli et al. (2014) and study bilateral Swiss franc exchange rates.[6] Let $R_{i,t}$ denote the Swiss franc real exchange rate versus country i, defined in terms of Swiss goods per foreign goods (i.e. an increase in $R_{i,t}$ corresponds to a Swiss franc real depreciation). Nominal equilibrium rates are estimated in three steps.

First, real exchange rates are regressed on a set of fundamental variables. Because the sample size in the time dimension is limited, it is impracticable to estimate these regressions for each bilateral rate separately. Instead we employ panel methods. Let $Z_{i,t}$ denote a vector of explanatory variables, with each variable in $Z_{i,t}$ defined as the value in the foreign country relative to Switzerland.[7] If $R_{i,t}$ and $Z_{i,t}$ are both non-stationary and cointegrated we can estimate their long-run,

[6] BEER models explain differences in relative prices across countries and across time using a set of macroeconomic variables. Using effective (trade-weighted) real exchange rates as the dependent variable has the disadvantage that a change in trade weights will affect the effective exchange rate, without an underlying change in relative prices.

[7] More precisely, let $X_{i,t}$ and $X_{CH,t}$ denote, respectively, the values of explanatory variable X in country i and in Switzerland. For variables that are expressed as percentages of GDP (e.g. net foreign assets, government consumption,

cointegrating relationship directly using DOLS (Stock and Watson (1993)):

$$\ln(R_{i,t}) = \alpha_i + \beta Z_{i,t} + \sum_{s=-p}^{+p} \gamma_s \Delta Z_{i,t+s} + \epsilon_{i,t} \tag{1}$$

where α_i is a country-specific constant, the parameter vector β captures the long-run relationship between $R_{i,t}$ and $Z_{i,t}$ and γ_s is a vector of parameters. Due to the limited sample size we set $p = 1$. A positive element in the coefficient vector β implies that an increase in the corresponding explanatory variable in Switzerland relative to the foreign country is associated with a real Swiss franc appreciation. If $R_{i,t}$ and $Z_{i,t}$ are not cointegrated then a regression in levels may be appropriate, i.e. regression (1) with $\gamma_s = 0$. We use alternative panel unit root tests to test for stationarity, and the Westerlund (2007) test as well as unit root tests on the residuals of regression (1) (as suggested by Pedroni (2004)) to test for cointegration. Since such tests are never fully conclusive – in particular given the relatively short length of the panel with annual data – we follow MacDonald and Ricci (2007) and report results for both the DOLS regression (1) and the OLS regression of (1) with $\gamma_s = 0$.

The predicted values from the long-run (cointegrating) relationship are interpreted as equilibrium real exchange rates, denoted by $R^*_{i,t}$:

$$R^*_{i,t} = \exp(\hat{\alpha}_i + \hat{\beta} Z_{i,t}) \tag{2}$$

Finally, the nominal equilibrium rate between Switzerland and country i (in Swiss francs per foreign currency), $E^*_{i,t}$, is computed by multiplying the real equilibrium rate with the consumer price differential:

$$E^*_{i,t} = R^*_{i,t} \frac{P_{CH,t}}{P_{i,t}} \tag{3}$$

Several points are worth noting. First, the estimated equilibrium rates will depend on the set of variables $Z_{i,t}$ included in the estimation. Since economic theory suggests a large number of potentially relevant variables, given the limited sample size there is considerable uncertainty about the "true" model. Second, the inclusion of country fixed effects α_i is necessary because real exchange rates are index numbers. With a short sample in the time dimension the estimated equilibrium real exchange rate could be strongly influenced by the fixed effect, i.e. by past real exchange rate levels. Third, the estimated equilibrium rates will obviously depend on the sample (across time and across countries) used in the estimation. And finally – a point not addressed in this paper – the assumption that parameters are identical across the currencies in the panel may be problematic.

fiscal balance) we include the difference $X_{i,t} - X_{CH,t}$ in $Z_{i,t}$. For other variables we include the log difference $\ln(X_{i,t}) - \ln(X_{CH,t})$.

2.2 Fundamental determinants of real exchange rates

Economic theory suggests a number of fundamental macroeconomic variables as drivers of real exchange rates. In the medium term, factors that affect the demand for traded relative to non-traded goods will have an impact on the real exchange rate: while the supply of non-traded goods is constrained, from the point of view of a small open economy traded goods are supplied elastically at the exogenous world market price. Therefore an increase in the demand for non-traded goods is associated with an increase in the prices of non-traded goods relative to traded goods, and hence with an appreciated the real exchange rate. Variables that capture structural determinants of the demand for traded relative to non-traded goods include the following:[8]

- *PPP-adjusted real GDP per capita.* An increase in domestic relative to foreign wealth is associated with higher demand for domestic non-traded goods, and hence with an appreciation of the real exchange rate.[9] Output per capita is also often interpreted as a broad measure of productivity, accounting for the Balassa-Samuelson effect.

- *Net foreign assets.* Increases in net foreign assets represent increases in wealth and should also be associated with an appreciated real exchange rate. Equivalently, net creditor countries will eventually need to run trade deficits to satisfy their intertemporal budget constraints, which is facilitated by a real appreciation.[10]

- *Terms of trade.* Improvements in the terms of trade similarly represent higher wealth, associated with an appreciated real exchange rate.[11] We use both commodity terms of trade, following Ricci et al. (2013), and terms of trade in goods and services as in Mancini-Griffoli et al. (2014). For advanced economies the second measure is likely to be more relevant; but the advantage of a commodity-based measure is that for many countries it can be considered exogenous with respect to exchange rate movements.[12]

- *Government consumption.* Government spending is often thought to be biased towards non-traded goods. Higher government consumption should therefore be associated with a real

[8] Where available, we include in the list below references to theoretical models suggesting a role for these variables. For some variables no structural model may exist, but economic intuition still suggests that they may be useful proxies for relevant effects. We try to include most variables that have been used in the literature. In particular, follow the IMF (2013) in exploring the role of the government financial balance, the output gap, health spending and credit developments.

[9] See for example Bhagwati (1984) and Bergstrand (1991).

[10] The link between external wealth and the real exchange rate is explored in Lane and Milesi-Ferretti (2002, 2004). Because of valuation effects, net foreign assets are contemporaneously affected by exchange rate movements. We mitigate this endogeneity by lagging net foreign assets by one year, following Ricci et al. (2013).

[11] See for example Neary (1988).

[12] We lag terms of trade in goods and services by one year to mitigate endogeneity with respect to the exchange rate.

appreciation.[13]

- *Government financial balance.* A larger fiscal deficit implies lower saving, higher demand non-traded goods, and hence an appreciated real exchange rate.
- *Demography.* We employ the old-age-dependency ratio (Higgins (1998)), the fertility rate (Rose et al. (2009)) and population growth as measures of demographic developments. Increases in these variables indicate a higher share of economically inactive people in the population, lower saving, higher demand for non-traded goods, and an appreciated real exchange rate.
- *Output gap.* The output gap is included to capture demand shocks. A positive output gap should then be associated with an appreciated real exchange rate.
- *Health spending.* Higher health spending implies increased demand for non-traded goods and an appreciated real exchange rate.
- *Credit.* An expansion of credit above its long-term average could reflect strong domestic demand, associated with a real appreciation.
- *Trade openness.* Following the IMF (2013), we use the ratio of trade to GDP as a proxy for trade liberalization. Countries with liberalized trade are thought to have lower prices for domestically produced traded goods, corresponding to a real depreciation.

A well-known theory of long-run real exchange rates is due to Balassa (1965) and Samuelson (1964). Given prices for traded goods which are fixed on world markets, productivity growth in the traded goods sector is associated with higher wages, which in turn leads to higher prices in the non-traded sector. Consequently, countries with higher productivity growth in the traded than in the non-traded goods sector experience a real appreciation. It is not straightforward to estimate this effect empirically because the productivity differential between traded and non-traded goods is difficult to measure. Typically researchers have employed proxies such as GDP per capita and productivity in the whole economy, with the assumption that wealthier and more productive economies should also experience particularly high productivity growth in the (capital intensive) traded goods sector. Another popular proxy is the ratio between consumer prices and producer prices, used for example in Reynard (2009), with the assumption that producer prices contain a larger share of traded goods than consumer prices. Gubler and Sax (2011), Ricci et al. (2013) and Mancini-Griffoli et al. (2014) use sector-level data to estimate productivity growth in the traded and non-traded goods sectors directly, using some suitable classification of sectors into traded and

[13] See de Gregorio and Wolf (1994), de Gregorio et al. (1994), Ostry (1994), Froot and Rogoff (1995) and Galstyan and Lane (2009).

non-traded. In this note we use productivity growth in the total economy as a proxy for the Balassa-Samuelson effect. This data is available for a larger set of countries, is updated more regularly, and is likely to be measured more precisely than sector-level productivity data. Nevertheless, we note that sector-level productivity is the theoretically superior measure of the Balassa-Samuelson effect.

Finally, we include a few additional variables to control for the effects of monetary policy and financial factors on exchange rates:

- *Real interest rate.* This variable captures the monetary policy stance: higher real interest rates should be associated with a stronger exchange rate.
- *Change in central bank reserves.* Following the IMF (2013), this variable is included as a second measure for the effects of monetary policy on exchange rates. If central banks intervene to weaken their currency, one would expect increases in reserves to be associated with a weaker exchange rate.
- *Realized stock market volatility.* Following the IMF (2013), we use stock market volatility to capture the effect of markets' risk sentiment on exchange rates. The Swiss franc is often considered a "safe haven" currency which appreciates when risk sentiment increases.

These three variables are interacted with capital account openness (measured by the Chinn and Ito (2006) index), which allows for a differential impact (in terms of both sign and magnitude) across currency pairs. With this specification, the impact of real interest rates, changes in reserves and volatility on exchange rates is larger for countries with more open capital accounts.

2.3 Data

We work with two different datasets.[14] In section 3 we use annual data from 1980 to 2011, and Swiss franc bilateral real exchange rates which are computed using CPI data from the OECD.[15] The sample covers 21 industrialized economies, with the country coverage limited by the availability of data on the explanatory variables for the whole sample period. In section 4 we use price-level data from the Eurostat/OECD PPP project to compute real exchange rates. This data is available only for the years 1995-2011. For these years our sample includes 23 countries. We include the euro area economies separately: despite the adoption of the common currency their real exchange rate movements remain fairly heterogeneous, reflecting country-specific price level movements. We exploit this heterogeneity to estimate the relationship between real exchange rates and fundamentals more precisely with a larger dataset.

[14] A list of countries included in the regressions, as well as details on data sources are available in the appendix.

[15] For some countries, data is available for several years prior to 1980. For the regressions we nevertheless focus on data from 1980, to avoid the time period of strong real exchange rate adjustments following the break-up of Bretton Woods. For stationarity tests (Table 1) we use data from 1973 where available.

Figure 1 reports data on Swiss franc real bilateral exchange rates, computed using alternative data sources and methods but normalized to equal 100 in 1995 for comparability.[16] An increase corresponds to a Swiss franc depreciation. The movements of bilateral rates from the two data sources are very similar, although the peak in the Swiss franc real rate versus the pound sterling is estimated to be higher in 2007 based on the Eurostat-OECD price level data. Over the sample from 1980 the Swiss franc has appreciated in real terms against most currencies. The movements since 1995 were dominated by a Swiss franc real depreciation in the years before the crisis and a strong appreciation since the beginning of the global financial crisis.

Figure 2 reports the time paths of the explanatory variables, computed as the value in the foreign country relative to Switzerland, for Germany, Japan, the US, the UK and the average of all 21 countries in the 1980-2011 sample. The clearest trends are observed in net foreign assets, which have grown in Switzerland relative to most other countries, and in GDP per capita and labor productivity, which have risen faster in most foreign countries than in Switzerland (while mostly remaining lower than in Switzerland). The strong movement of the fiscal balance variables at the end of the sample period reflects the deterioration of public finances in many countries at the height of the global financial crisis. The sharp fall in central bank reserves since 2009 is due to the foreign exchange interventions by the Swiss National Bank. The terms of trade have improved in Switzerland relative to most other countries, consistent with the Swiss franc real appreciation since 1973. The increase in volatility – with the variable defined as the product of realized US stock market volatility and capital account openness – reflects the rise in stock market volatility over time, together with increased openness in many countries (relative to Switzerland, which is classified as a very open economy throughout the sample).

A visual inspection of Figures 1 and 2 suggests that many series are non-stationary or at least highly persistent. While relative purchasing power parity (PPP) implies stationary real exchange rates, the effects of movements in the fundamental variables discussed in the previous section may prevent PPP from holding (for example due to the Balassa-Samuelson effect). The output gap is stationary by definition, while the fiscal balance could be expected to be stationary from a theoretical point of view. We use panel unit root tests proposed by Levin, Lin and Chu (2002; LLC test), Im, Pesaran and Shin (2003; IPS test) and Pesaran (2007; CIPS test) to test whether the variables in our panel are non-stationary.[17] The null of non-stationarity is rejected if the autoregressive parameters are sufficiently small in magnitude. For the LLC test, which assumes that the autoregressive parameter is identical across currencies, the alternative hypothesis is that all panels are stationary. For the IPS test, which is less restrictive than LLC because it allows the autore-

[16] The real exchange rates computed using OECD data on CPIs in the bottom panel of Figure 1 are index numbers. In contrast, the levels of the real rates computed using Eurostat/OECD price-level data do have meaning, which is exploited in section 4 to estimate regression (1) without fixed effects. Nevertheless, for the purpose of this chart we normalize all real rates for comparability so that 1995 equals 100.

[17] The LLC and IPS tests were conducted using the built-in Stata command `xtunitroot`. The CIPS test was conducted using the `multipurt` Stata routine written by Markus Eberhardt.

gressive parameter to be heterogeneous across currencies, the alternative hypothesis is that some panels are stationary. The Pesaran (2007) CIPS test also allows for heterogenous autoregressive parameters, and moreover has the advantage in accounting for cross-sectional dependence. The results are reported in Table 1. The three tests agree (not surprisingly) that the fertility rate, fiscal balance, output gap, real interest rate and central bank reserves are stationary. For most other variables, at least one of the tests points to non-stationarity. In particular, the CIPS test provides the clearest evidence that most of the variables in our dataset are non-stationary.

3 Results

3.1 Benchmark specifications

Table 2 reports the estimated coefficients from the cointegrating relationship, corresponding to the estimate of β in regression (1), for alternative specifications of the model. The regressions additionally include country-specific fixed effects and first differences of the explanatory variables which we omit from the table to save space. The number of observations varies across specifications because some variables are not available for all countries and all years. To account for the serial correlation of the errors which is induced by the inclusion of the first differenced variables in (1) we report Newey-West corrected t-statistics in parentheses.[18] As discussed above, economic theory predicts positive coefficients for most variables. For the fiscal balance, trade openness, and central bank reserves we expect a negative coefficient. From Figures 1 and 2 it is clear that the increase in the volatility measure together with the long-term real appreciation of the Swiss franc against many currencies is likely to produce a negative coefficient for this variable.[19]

To test whether the panel cointegration specification is valid Table 2 also reports tests for the null hypothesis that the residuals are non-stationary. For alternative specifications of the model (corresponding to alternative combinations of explanatory variables) reported in columns, the null of non-stationarity can always be rejected at least at the 5 percent level of significance, giving support to the DOLS regression specification.[20] Specification (c), discussed below, represents a weighted average of alternative models. For this specification no unit root tests can be conducted. Figure 3 reports the residuals from specification (a). While residuals for the real exchange rate

[18] We estimate only the cointegrating relationship between the real exchange rate and explanatory variables. This is a long-run equilibrium relationship but cannot necessarily be interpreted as a causal relationship running from the explanatory variables to the exchange rate. For several explanatory variables, such as net foreign assets or the terms of trade, the presence of reverse causation is likely.

[19] We exclude health spending (per capita and as a share of GDP) from the regressions in section 3, because this variable is available only from 1995.

[20] We could not conduct the LLC unit root test because this test requires a balanced panel, whereas we work with unbalanced panels. For specification (b) we also conducted the Westerlund (2007) cointegration test, using the Stata program `xtwest` described in Persyn and Westerlund (2008). Using this test the null of no cointegration cannot be rejected. Using `xtwest` the Westerlund (2007) test could not be conducted for specifications (a) and (d) because they contain too many explanatory variables.

equations versus some countries – for example Austria – have increased over time in a way that could suggest non-stationarity of the residuals, for most countries the residuals appear stationary, although persistent. Because non-stationarity and cointegration tests are not conclusive we report alternative results for regression (1) under the assumption of no cointegration (with $\gamma_s = 0$) in Table 4. The results are consistent across the two specifications in the sense that whenever coefficients are found to be statistically significant at conventional levels of significance, they have the same sign and comparable magnitudes in Tables 2 and 4.

We now turn to discussing the benchmark specifications in columns (a) and (b) of Table 2. Column (a) presents results from a specification that includes all explanatory variables. Many variables are found to exhibit a statistically significant relationship with Swiss franc real exchange rates, and where significant the coefficients mostly have the expected sign. The exceptions are productivity and central bank reserves. We would expect an increase in reserves to be associated with a currency depreciation if the central bank intervenes to weaken the currency; but the results suggests that, on average, higher reserves were correlated with an appreciated exchange rate. The positive coefficient on reserves could be driven by the 2008-2011 episode, when increases in Swiss reserves coincided with a sharp Swiss franc appreciation. This reflects correlation rather than causation: without interventions the appreciation would likely have been stronger. In column (b) we report a specification that is comparable to Mancini-Griffoli et al. (2014). As discussed above, the main difference to their specification is that we use labor productivity in the whole economy as a proxy for the Balassa-Samuelson effect, whereas Mancini-Griffoli et al. (2014) include a measure based on productivity measured at the sector level. All coefficients are highly statistically significant, and with the continued exception of productivity have the expected positive sign. The sign of the productivity coefficient is at odds with the predictions of the Balassa-Samuelson effect: as discussed above, if an increase in Swiss relative to foreign productivity reflects increased Swiss productivity in the traded goods sector, then we would expect a positive coefficient reflecting the Balassa-Samuelson effect.[21]

The within-group R^2 measure shows that even excluding fixed effects, our regressors can explain a reasonable share of real exchange rate variation. For a few exchange rate pairs in the panel the adjusted R^2 are negative for some specifications. This stems not from the adjustment penalizing a large number of included explanatory variables, but mainly reflects the fact that parameters estimated for all currency pairs jointly do not provide a good fit for each individual real exchange rate. Thus, the observation of negative R^2 for some currencies can be viewed as an indication that the assumption underlying the panel model (1) that coefficients are identical across currencies may not be a good description of the data. This assumption is necessary, however, because the sample does not include a sufficient number of observations across time to estimate the parameters with any confidence for individual currencies.

[21]Gubler and Sax (2011) also find evidence for a “reversed” Balassa-Samuelson effect in a fixed-effects panel of OECD countries.

3.2 Robustness to alternative combinations of explanatory variables

This section explores how robust the results reported in the first two columns of Table 2 are to the inclusion of alternative combinations of explanatory variables. As discussed in section 2, economic theory suggests a number of variables which could potentially be linked to real exchange rates, but is mostly silent about which variables should have the largest effects. Therefore the temptation is large to experiment with alternative specifications but only report results from the particular combination of variables that gives the most plausible results. It is not necessarily optimal to simply include all potential explanatory variables in the regression, as in specification (a) in Table 2: while this minimizes the potential for omitted variable bias, the drawback is that given a limited number of observations, the presence of irrelevant variables leads to parameters which are less precisely estimated. In this section we explicitly document how the parameter estimates depend on the combination of variables included in the model. To do this we follow Bussière et al. (2010) and apply Bayesian averaging of classical estimates (BACE), introduced by Sala-i-Martin et al. (2004).

We begin by estimating separate regressions for all possible combinations of our 16 variables, ranging from models where just one or two variables are included to the specification including all nine variables. Figure 4 shows the distribution of the coefficients across models, with red bars denoting estimates that are statistically significant at the 5 percent level. These distributions illustrate how robust the sign and the magnitude of the estimated coefficients are to alternative model specifications. The following conclusions emerge. First, credit, government consumption, net foreign assets, trade openness, the real interest rate and the terms of trade for goods and services have the expected positive coefficients (negative for openness) for all or at least for the great majority of model specifications. This suggests that these variables indeed exhibit the theoretically predicted relationship with the Swiss franc real exchange rate. The coefficient on labor productivity is negative in most specifications. The coefficient for GDP per capita, which was found to have the expected positive sign in specifications (a) and (b) in Table 2, has a negative sign for almost half of the possible model specifications. Similarly, the coefficients for the commodity terms of trade, the fiscal balance, the old age dependency ratio, and to a lesser degree also the output gap and population growth vary considerably across specifications.

Figure 5 reports, for selected variables, how the sign and statistical significance of the estimated coefficient varies with the other variables included in the model. Each sub-chart corresponds to a particular variable; within each sub-chart, the bars correspond to combinations in which the variable on the horizontal axis and the sub-chart variable are jointly included in the model. For most variables no particular pattern would emerge: for example, the coefficient on net foreign assets is positive and mostly statistically significant, independent of the particular variables also included in the model. In the reported charts we focus on those variables whose coefficients are positive and statistically significant in some specifications, and negative and significant in other specifications in Figure 4. There does not appear to be a clear pattern, apart from the observation that the sign and significance of the commodity terms of trade seems to be linked to the presence of the overall terms of trade, and similarly for labor productivity and GDP per capita. This is not too surprising as these variables are strongly correlated.[22]

Following the BACE approach we weigh the alternative models to produce results that incorporate information from the distribution of coefficients across models, giving more weight to combinations of variables which can better explain real exchange rates.[23] Column (c) in Table 2 reports the results, which are in terms of both sign and magnitude of the coefficients broadly in line with the first two specifications.[24] Column (d) reports an alternative specification, where only those variables are included which have the expected sign and are statistically significant across most specifications in Figure 4. Based on this criterion a model specification with six variables is estimated. The coefficients all have the signs predicted by theory, with magnitudes close to those in specification (a).

As explained in the previous section, the predicted value from the BEER regression is often interpreted as equilibrium real exchange rate. We have documented that the estimated coefficients are highly sensitive - in terms of both magnitude and sign - to the particular combination of variables that the researcher chooses to include in the regression. It follows that the model-implied equilibrium exchange rate will also depend on the chosen specification: alternative model specifications can imply very different paths for equilibrium exchange rates.

3.3 Robustness to alternative country samples

In BEER models the coefficients are typically estimated in a panel setting. This implies, however, that the estimated parameters depend on the sample of currencies over which the model is estimated. The results reported in Table 2 are based on a sample of 21 bilateral Swiss franc exchange rates. This section explores how robust these regression results are to alternative country samples. To illustrate this we draw 15 of our 21 countries, for all possible country combinations including 15 countries, and run the regression with all 16 variables.

Figure 6 reports the distribution of coefficients across country samples. For all variables, coefficient estimates vary substantially across samples. Moreover, for some variables there exist samples such that the coefficients are estimated to be positive or negative and statistically significant. Finally, for all variables except the terms of trade (where the endogeneity with respect to real exchange rate movements is most likely to be most problematic) there exist a large number of potential samples for which the coefficients are not statistically significant. These findings illustrate that the estimates are highly dependent on the countries included in the sample. Clearly, the selection of

[22] Figure 11 shows the distributions for the coefficients in the alternative regression under the assumption of no cointegration. They are very similar to the distributions reported in Figure 4.

[23] The weights depend both on the estimated explanatory power of alternative specifications and on our prior expectation of the number of variables included in the model. For the results reported here we set this prior to 4.

[24] We do not report measures of fit in column (c) since the specification reflects a weighted average of alternative models. Also, we do not report the number of observations, which varies marginally across specifications.

countries included in the sample will then also have a significant influence on the model-implied equilibrium rates.

To illustrate how the estimated coefficients depend on the sample of countries Figures 7 and 8 report scatterplots for real exchange rates versus GDP per capita and labor productivity, across countries. We focus on these two explanatory variables because they were previously found not to exhibit the expected robust positive relationship with Swiss franc real exchange rates. Lighter dots mark observations from earlier time periods (towards 1973), while darker dots mark observations from later time periods (towards 2011). We observe that for most countries, the GDP per capita variable is negative, indicating higher wealth in Switzerland than abroad. However, for all countries GDP per capita abroad has increased over time relative to Switzerland. This catch-up effect should, according to economic theory, be associated with a real depreciation of the Swiss franc, i.e. with an increase in the real exchange rate expressed in terms of Swiss per foreign goods. In contrast the charts show, with the exception of Japan, New Zealand and Portugal, a flat or negative relationship: the Swiss franc has appreciated in real terms over time, against most currencies (an exception is the Japanese yen). This is at odds with the positive coefficient on GDP per capita found in Table 2; but recall that the sign of this coefficient varied in Figure 5 depending on the variables included in the model.[25]

As with GDP per capita, productivity is higher in Switzerland for most countries and most time periods, with foreign countries catching up over time (observations are moving to the right on the horizontal axis). However, the Swiss franc has appreciated over time against most currencies, producing a negative relationship between productivity and the Swiss franc real exchange rate (the only exception is the real exchange rate versus Portugal).[26]

4 Exploiting price-level data to estimate BEER models without fixed effects

A fundamental drawback of models in the BEER tradition is the need to include fixed effects. As discussed above, fixed effects are necessary because real exchange rates are index numbers. With fixed effects and a small sample period, however, estimates of equilibrium exchange rates could be strongly influenced by the country-specific constants. This makes the estimated equilibrium rates hard to interpret. With the availability of price level data it becomes possible to compute estimates of the *level* of real exchange rates. This allows one, at least in principle, to estimate regression (1) using pooled estimation (without country-specific constants, i.e. setting $\alpha_i = \alpha$ for all i). However, one still has to make the potentially strong assumption that the explanatory variables included in

[25] Fixed-effects panel regressions with GDP per capita alone produce a negative coefficient; but that coefficient turns positive when labor productivity is included in the regression.

[26] As discussed above, this is not necessarily evidence against the Balassa-Samuelson effect, as productivity in the whole economy may not be a good proxy for the productivity differential between traded and non-traded goods.

the estimation are uncorrelated with other drivers of real exchange rates which are not accounted for in the regressions.

In this section we use Swiss franc bilateral real exchange rates computed from price-level data published by Eurostat and the OECD to estimate equilibrium exchange rates.[27] Using this data the real exchange rates exhibit meaningful cross-sectional variation. All explanatory variables except for labor productivity and the terms of trade (which are both index numbers) also have meaningful levels. When regression (1) is estimated without fixed effects the normalized average level of productivity and the terms of trade will both be captured in the constant α. Thus, these two variables can only contribute to explaining the variation in real exchange rates over time, but not across currencies in a given year. To illustrate the potential influence of cross-sectional correlations on the estimated coefficients Figures 9 and 10 show scatterplots for real exchange rates (computed based on price level data) versus government consumption and net foreign assets, across countries for alternative years. Recall that these two variables were earlier found to be robustly related to Swiss franc equilibrium exchange rates report scatterplots, based on variation across time only. The scatterplots do not reveal any obvious cross-sectional relationships, suggesting that for these two variables the use of pooled versus fixed effects estimation should not have a big impact.

Table 3 reports the results for four alternative specifications. Columns (a) and (b) report results for the model with all 16 variables, with and without fixed effects. Columns (c) and (d) report results for the specification following Mancini et al. (2014), again with and without fixed effects. The differences between the results in Table 3 and those earlier reported in columns (a) and (b) of Table 2 reflect five different factors: (1) a different sample period covering the years 1995-2011 only, (2) a larger country sample that includes 3 additional currency pairs, (3) different real exchange rates computed using price-level data, (4) the inclusion of health spending as an additional variable, and (5) the exclusion of fixed effects (in columns (b) and (d) of Table 3 only).[28]

A striking result compared to Table 2 is that productivity now has the expected positive relationship with the real exchange rate, regardless of whether the model is estimated with or without fixed effects. In Table 2 and Figure 4 net foreign assets was one of the variables that exhibited a robust positive relationship with real exchange rates across specifications. In contrast, net foreign assets mostly do not have the expected positive coefficient in Table 3. The coefficient on GDP per capita is positive and highly statistically significant in the regressions without fixed effects. This is driven by the robust positive correlation between income levels and real exchange rates in the cross-section, reflecting the well established Penn effect. Without fixed effects some explanatory variables, such as the old age dependency ratio and openness, become statistically significant. Pre-

[27] A detailed description of how real exchange rates are constructed based on price-level data can be found in the appendix. This data was used in recent papers by Faber and Stokman (2009), Berka, Devereux and Engel (2012) and Berka and Devereux (2013).

[28] Because of the short sample, starting only in 1995, no tests for non-stationarity of the residuals could be conducted for the specifications in Table 3. Table 5 reports results for estimations with and without fixed effects under the assumption of no cointegration. The results are very similar to those of Table 3.

sumably this is the case because some variables which do not exhibit a lot of variation over time, but do vary across countries, can explain the cross-country variation in the real exchange rates.

Overall the results in Table 3 show that (not surprisingly) the presence of fixed effects can have an impact on the estimated coefficients, as some variables explain the cross-country variation in real exchange rates but not their variation across time. This, in turn, will also influence the implied equilibrium exchange rates. In fact, computing the predicted values of the cointegration relationships across the specifications in Table 3 shows that not only the level of equilibrium values but also their movement over time is affected by the exclusion of fixed effects.

5 Conclusion

A common approach to estimating equilibrium exchange rates is to identify equilibrium rates with the long-run relationship between real exchange rates and fundamental macroeconomic variables. Estimates from such "behavioral equilibrium exchange rate"(BEER) models are frequently used in the policy debate, for example in the regular IMF exchange rate assessments. But how robust are these estimates of equilibrium exchange rates? In this paper we argue that the estimated coefficients, and consequently also the implied equilibrium exchange rates, are sensitive to a number of modeling assumptions. Therefore, it is important to interpret the point estimates of equilibrium exchange rates with care, and to explore how the effects of specific variables depend on the chosen model specification.

This paper makes three contributions. First, we apply Bayesian averaging of classical estimates to account for model uncertainty. Second, we explore the sensitivity of estimated equilibrium rates with respect to the currencies included in the sample. And third, we use real exchange rates based on price-level data to estimate panel models without the inclusion of fixed effects. Because the price level data is only available since 1995 this specification has the drawback of being estimated over a relatively short sample. Nevertheless, estimation of a BEER model without fixed effects fills a hole in the literature, as well as providing potentially more reliable and easier to interpret estimates of equilibrium rates for policymakers.

We conclude by discussing the interpretation of equilibrium exchange rate estimates from BEER models. By definition, such models identify movements in real equilibrium rates with movements in fundamental variables. In a well specified BEER model a large share of the variation of real exchange rates should be explained by the included macroeconomic variables, and consequently the estimated deviation between exchange rates and their equilibrium levels should tend to be small. This is consistent with the idea that for freely floating exchange rates, market forces should ensure that exchange rates remain well anchored in fundamentals. Nevertheless, in panel models there can be persistent deviations of real exchange rates from their estimated equilibrium levels, particularly if the estimated coefficients provide a bad fit for particular currency pairs. In BEER models that include fixed effects – as is typically the case – it is implicitly assumed that each individual real exchange rate is in equilibrium on average across time. This is particularly problematic when the time dimension of the sample is short.

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Appendix: variable definitions and data sources

A Country list

The estimations in section 3 use annual data covering the 1980-2011 sample, for Switzerland and the following 21 countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom, United States. We limit ourselves to these 21 countries to ensure (almost) complete data availability for all our explanatory variables.

The estimations in section 4 use annual data for the years 1995-2011, for Switzerland and the following 23 countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, United Kingdom, United States. Data coverage in this sample is limited by the availability of price-level data from Eurostat/OECD, as well as by data availability for the explanatory variables.

B Variable definitions and data sources

The following data are from the World Bank WDI indicators:

- Credit: domestic credit to the private sector, percent of GDP, deviation from own country mean. For Austria, Belgium, the Netherlands and France, the missing 1998 values were filled with the average of 1997 and 1999.
- Government consumption: general government final consumption expenditure, percent of GDP
- Fertility rate: average number of births per woman
- Old age dependency ratio: ratio of population aged over 65 divided by population between 30 and 65 years old
- Openness: exports and imports of goods and services, percent of GDP
- Population growth: growth rate of the total population
- Reserves: change in total reserves (including gold), percent of GDP, interacted with current account openness
- Health expenditure, percent of GDP
- Health expenditure per capita: PPP, constant 2005 international dollars

- Real interest rate: short term interest rate minus GDP deflator, interacted with current account openness

The following data are from the OECD:

- GDP per capita: PPP constant 2005 international dollars
- Fiscal balance: cyclically adjusted government net lending, percent of potential GDP
- Commodity terms of trade: ratio of the price of commodity exports to the price of commodity imports. Commodity export and import prices are indices, 2005=100
- Output gap, percent of GDP
- Government financial balance, percent of GDP
- Consumer price indices
- Nominal exchange rates

Data from other sources:

- Total factor productivity, total economy, index 2005=100: from the DG ECFIN AMECO database, obtained via Datastream. For Switzerland before 1991 data are extrapolated with labor productivity growth (whole economy), obtained from the OECD. Labor productivity (index, 2005=100) is also used for Korea. For countries and time periods where both labor productivity and total factor productivity are available, the two series are highly correlated.
- Terms of trade in goods and services: from the DG ECFIN AMECO database, obtained via Datastream. Index, 2005=100
- Net foreign assets: from Lane and Milesi-Ferretti (2007).[29]
- Current account openness: Chinn and Ito (2006) index, available at `http://web.pdx.edu/~ito/Chinn-Ito_website.htm`
- Realized volatility: standard deviation of the S&P 500 (Datastream), interacted with current account openness. We use realized volatility rather than the VOX/VIX index as in IMF (2012) because it is available for a longer time period.

[29]We thank Philip Lane for providing us with an update of this dataset up to and including 2011.

C Construction of real exchange rates using price level data

Section 4 makes use of real exchange rates constructed using price-level data from the Eurostat/OECD PPP project.[30] Eurostat collects prices of baskets of different types of goods, with various levels of disaggregation. We chose the highest (GDP-level) aggregation. Let P_i denote the price level in country i in terms of local currency per representative good. Also, let $\bar{P}$ denote the average price level across the average of 15 euro area countries. The database does not provide price data directly, but instead reports purchasing power parities (PPPs) defined as $Q_i = P_i/\bar{P}$ and measured in terms of local currency per euro. Absolute purchasing power parity would require that the nominal exchange rate E_i in terms of local currency per euro satisfies $P_i = E_i\bar{P}$, or equivalently that $Q_i = E_i$. Using this data, we compute the real exchange rate R_i between country i and the euro area-15 countries as $R_i = E_i\bar{P}/P_i = E_i/Q_i$. With this definition an increase in R_i corresponds to a real depreciation for country i. The real exchange rate between Switzerland and country i is then defined as $R_{CH,i} = R_{CH}/R_i$, where an increase again corresponds to a real depreciation of the Swiss franc. Let $R^*_{CH,i}$ denote the estimate of the equilibrium real rate between Switzerland and country i. The equilibrium nominal rate is then computed as $E^*_{CH,i} = R^*_{CH,i}Q_{CH}/Q_i$.

[30] The data is available at `http://epp.eurostat.ec.europa.eu/portal/page/portal/purchasingpowerparities/introduction`

Tables and figures

Table 1: Panel unit root tests

	trend	Levin-Lin-Chu (2002)	Im-Pesaran-Shin (2003)	Pesaran (2007)
GDP per capita	yes	-0.42	-0.77	1.62
commodity terms of trade	no	-1.52*	-1.54*	4.42
credit, % of GDP	yes	4.00	0.27	-0.01
fertility rate	no	-5.63***	-5.02***	-3.10***
fiscal balance, % of GDP	no	-2.44***	-5.17***	-3.97***
government consumption, % of GDP	no	-2.42***	-1.51*	-1.56*
health spending, % of GDP	no	-0.45	1.62	3.56
health spending, per capita	no	-3.78***	-0.94	1.85
productivity	yes	-0.63	0.40	-0.59
net foreign assets, % of GDP	yes	0.89	1.03	1.79
old age dependency ratio	no	-7.21***	-6.53***	-0.25
trade openness	yes	0.59	-0.25	1.50
output gap	no	-4.64***	-9.33***	-4.23***
population growth	no	-2.01**	-2.75***	-0.01
real interest rate	no	-4.36***	-8.55***	-3.04***
realized volatility	yes	2.70	1.43	5.41
reserves, % of GDP	no	-15.65***	-18.26***	-4.80***
terms of trade (goods and services)	no	2.39	3.87	3.94
CPI-based RER	yes	-0.56	-4.49***	-1.01
Price-level-based RER	yes	-2.60***	-1.18	-0.44

Notes: This table reports results from alternative panel unit root tests. The null hypothesis is that the series are stationary. ***,**,* means that the null can be rejected at the 1%, 5% and 10% level of significance. Tests allow for deterministic trends as indicated. Levin-Lin-Chu (2002) test: the lag selection criterion is AIC (up to 3 lags). The Bartlett kernel (Newey-West bandwith) and the demean options are used in Stata. This test requires a balanced panel; some countries (at most one) and years had to be excluded. Im-Pesaran-Shin (2003) test: the lag selection criterion is AIC (up to 3 lags); the demean option was used in Stata. Pesaran (2007) test: 2 lags are included.

Table 2: Regression results, 1980-2011

	(a)	(b)	(c)	(d)
GDP per capita	0.2530*	0.2099**	0.3165***	
	(1.72)	(2.31)	(2.85)	
commodity terms of trade	-0.1150*		-0.0359	
	(-1.76)		(-0.76)	
credit, % of GDP	0.0002		0.0002	0.0006***
	(0.98)		(1.24)	(3.42)
fertility rate	0.0042		0.0054	
	(0.06)		(0.14)	
fiscal balance, % of GDP	0.0030		0.0028	
	(1.31)		(1.57)	
government consumption, % of GDP	0.0169***	0.0150***	0.0178***	0.0165***
	(3.48)	(3.21)	(5.24)	(4.52)
productivity	-0.1704	-0.4341***	-0.2760**	
	(-0.92)	(-3.39)	(-2.10)	
net foreign assets, % of GDP	0.0363**	0.0835***	0.0261	0.0832***
	(2.07)	(4.64)	(1.54)	(4.65)
old age dependency	-0.0002		-0.0007	
	(-0.04)		(-0.28)	
trade openness	-0.0364		-0.0545	-0.1068*
	(-0.58)		(-1.09)	(-1.89)
output gap	-0.0022		-0.0002	
	(-0.62)		(-0.17)	
population growth	0.0256		0.0216	
	(1.39)		(1.56)	
real rate	0.0040***		0.0043***	0.0030*
	(2.59)		(3.82)	(1.96)
realized volatility	-0.0245***		-0.0233***	
	(-4.76)		(-5.85)	
reserves, % of GDP	0.1120*		0.1211**	
	(1.87)		(2.44)	
terms of trade (goods and services)	0.4257***	0.3586***	0.3796***	0.4856***
	(4.90)	(4.33)	(6.91)	(7.88)
Observations	579	609		604
within $\bar{R}^2$	0.69	0.51		0.55
Im-Pesaran-Shin (2003) test	-6.19***	-4.45***		-5.11***
Pesaran (2007) test	-2.13**	-2.18**		-2.11**

Notes: Results from regression (1) for alternative specifications listed in columns. The models include fixed effects and first differenced terms. The dependent variables are CPI-based Swiss franc real bilateral exchange rates. A positive coefficient implies that increases in the explanatory variable in Switzerland relative to the foreign country are associated with a real Swiss franc appreciation. We exclude health spending which is only available from 1995. Column (a) is the baseline specification with all 16 variables. Column (b) includes only those variables that are also included in Mancini et al. (2014). Column (c) reports a weighted average of estimates across alternative models, based on the BACE approach. Column (d) includes only variables found to have a statistically significant coefficient with the expected sign, robustly across model specifications in Figure 4. Newey-West t-statistics are in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. The last two lines report panel unit root test applied to the residuals, with ***, ** and * indicating that the null of non-stationarity can be rejected at the 1%, 5% and 10% level.

Table 3: Regression results, 1995-2011: estimation with and without fixed-effects

	(a)	(b)	(c)	(d)
GDP per capita	-0.0862	1.1143***	1.0338***	0.8431***
	(-0.16)	(5.77)	(4.99)	(14.05)
commodity terms of trade	-0.3279***	0.0319		
	(-2.62)	(0.16)		
credit, % of GDP	0.0006*	0.0012**		
	(1.90)	(2.33)		
fertility rate	0.3788**	0.4219***		
	(2.34)	(3.04)		
fiscal balance, % of GDP	0.0024	-0.0031		
	(0.62)	(-0.52)		
government consumption, % of GDP	0.0141	0.0141**	0.0118*	0.0200***
	(1.20)	(2.39)	(1.80)	(4.34)
health spending, % of GDP	-0.0097	0.0253*		
	(-0.48)	(1.66)		
health spending, per capita	-0.2853	-0.3333**		
	(-1.24)	(-2.22)		
productivity	1.1319*	0.6977	-0.4037	0.1046
	(1.68)	(1.42)	(-1.07)	(0.29)
net foreign assets, % of GDP	-0.0343	-0.0934**	-0.0093	-0.0280
	(-1.18)	(-2.54)	(-0.39)	(-0.76)
old age dependency	0.0011	0.0298***		
	(0.13)	(4.31)		
trade openness	0.1723*	-0.0601		
	(1.96)	(-1.59)		
output gap	0.0024	-0.0013		
	(0.30)	(-0.12)		
population growth	0.0677*	0.0827**		
	(1.78)	(2.01)		
real rate	0.0119***	0.0029		
	(5.01)	(0.95)		
realized volatility	0.0220	-0.0345		
	(1.35)	(-1.48)		
reserves, % of GDP	0.0654	0.5268*		
	(0.50)	(1.71)		
terms of trade (goods and services)	1.0299***	0.8120***	0.2128*	0.5139**
	(4.03)	(4.01)	(1.82)	(2.49)
fixed effects	yes	no	yes	no
Observations	292	292	350	350
within $\bar{R}^2$	0.78		0.57	

Notes: Results from regressions (1) for alternative specifications listed in columns. The models include country fixed effects (columns (a) and (c)), a constant (columns (b) and (c)) and first-differenced terms. The dependent variables are Swiss franc real bilateral exchange rates, based on price-level data. A positive coefficient implies that increases in the variable in Switzerland relative to the foreign country are associated with a real Swiss franc appreciation. The first two columns represent the baseline specification with all 16 variables, with/without fixed effects. The last two columns represent the specification in Mancini et al. (2014), with/without fixed effects. Newey-West t-statistics are in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

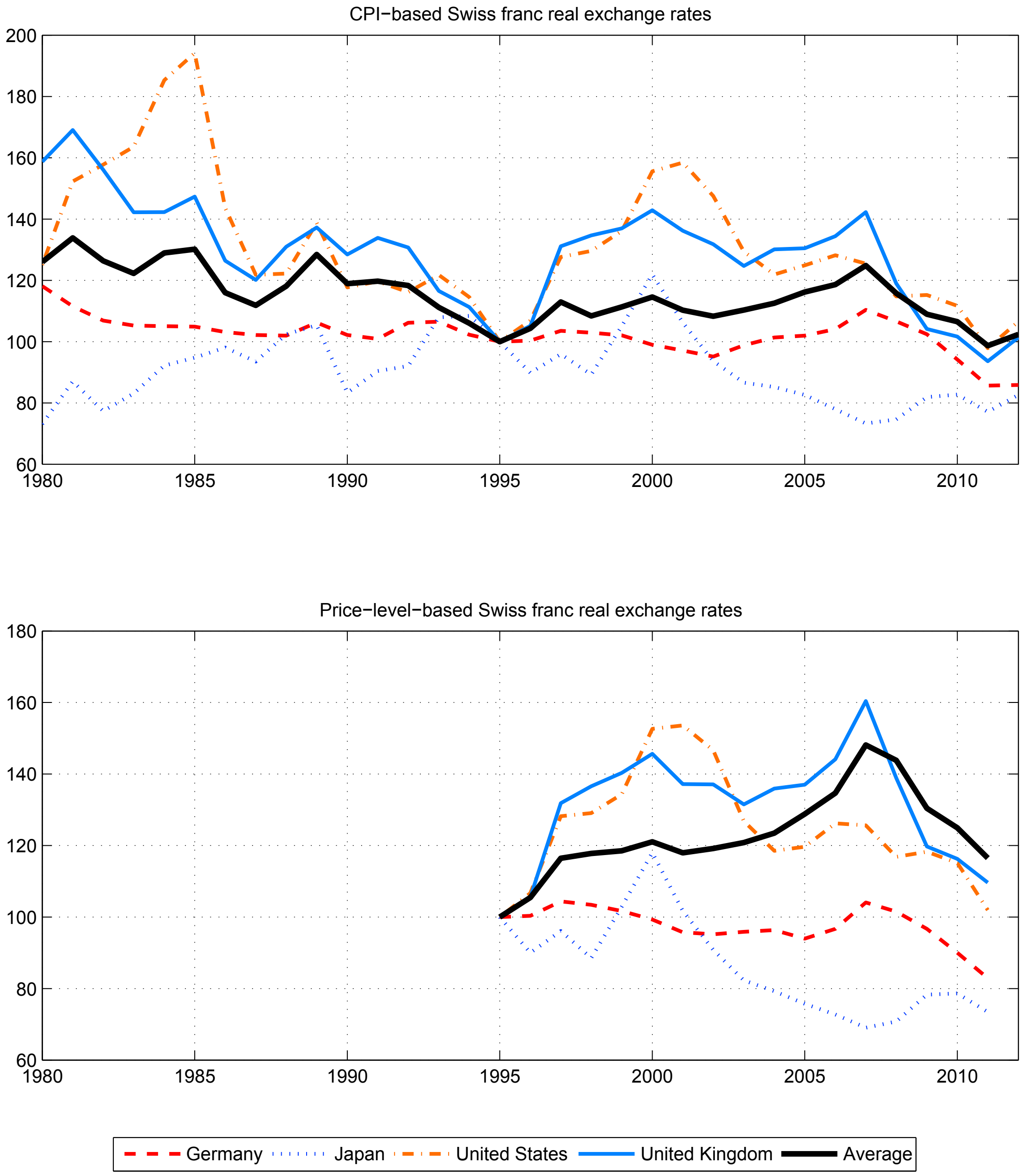

Figure 1: Swiss franc real bilateral exchange rates. The top panel shows real rates computed using consumer price indices. The bottom panel shows real rates computed using price level data from the Eurostat/OECD PPP project. All real rates are expressed in terms of Swiss goods per foreign goods (an increase corresponds to a Swiss franc real depreciation) and are normalized so that 1995 = 100. The real exchange rates shown in the bottom panel are used in section 3. The real rates shown in the top panel, but without the normalization, are used in section 4. The averages are computed across 23 countries for the top panel and across 21 countries in the bottom panel. The list of countries can be found in the appendix.

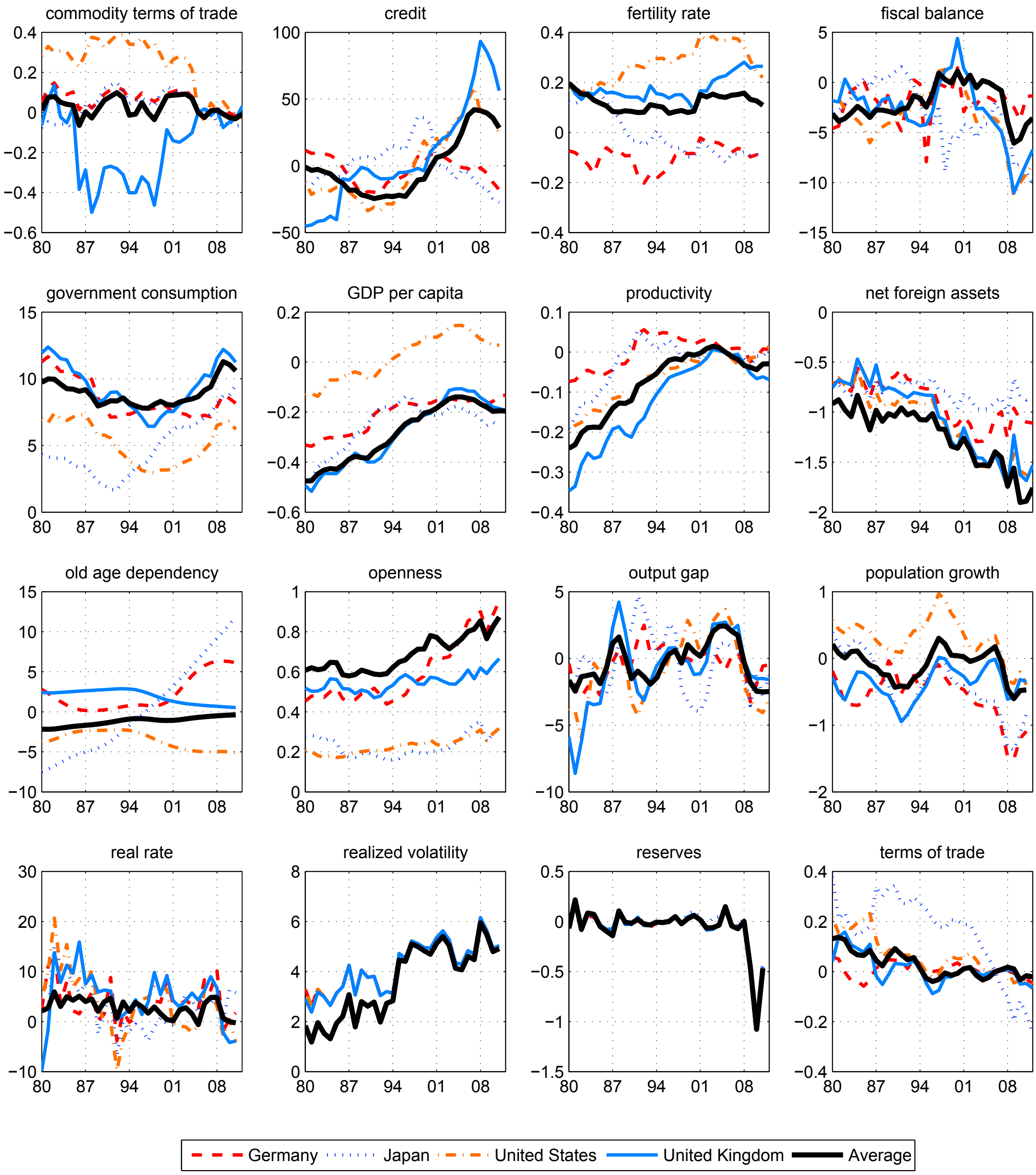

Figure 2: Explanatory variables. For explanatory variables X that are expressed percentages (e.g. net foreign assets, government consumption, fiscal balance, output gap), this chart shows the difference $X_{i,t} - X_{CH,t}$ where $X_{i,t}$ and $X_{CH,t}$ denote, respectively, the values of explanatory variable X in country i and in Switzerland. For other variables the chart reports the log difference $\ln(X_{i,t}) - \ln(X_{CH,t})$.

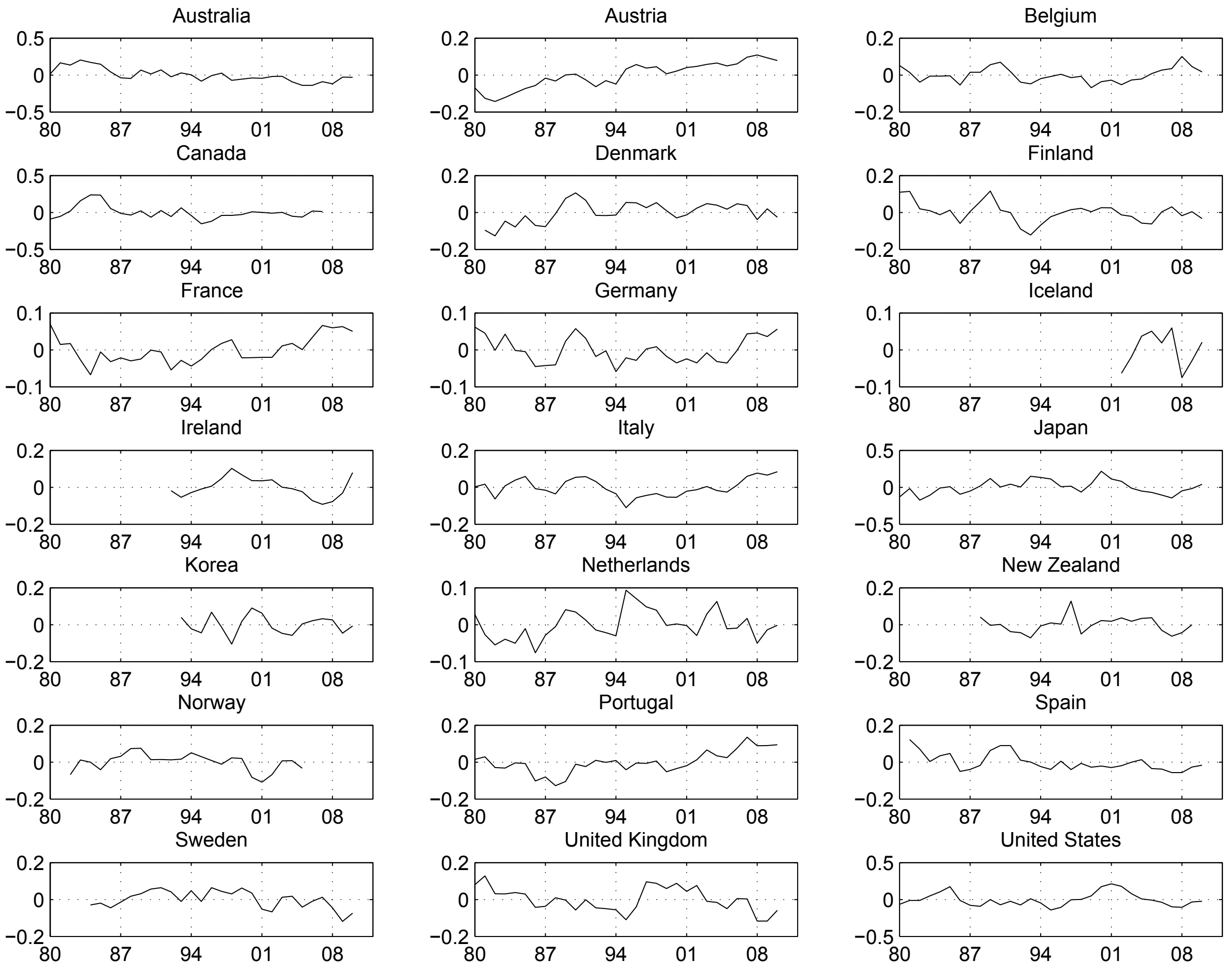

Figure 3: Residuals from specification (a) in Table 2. This specification corresponds to regression (1), 1973-2011, with fixed effects. The dependent variables are CPI-based Swiss franc bilateral real exchange rates.

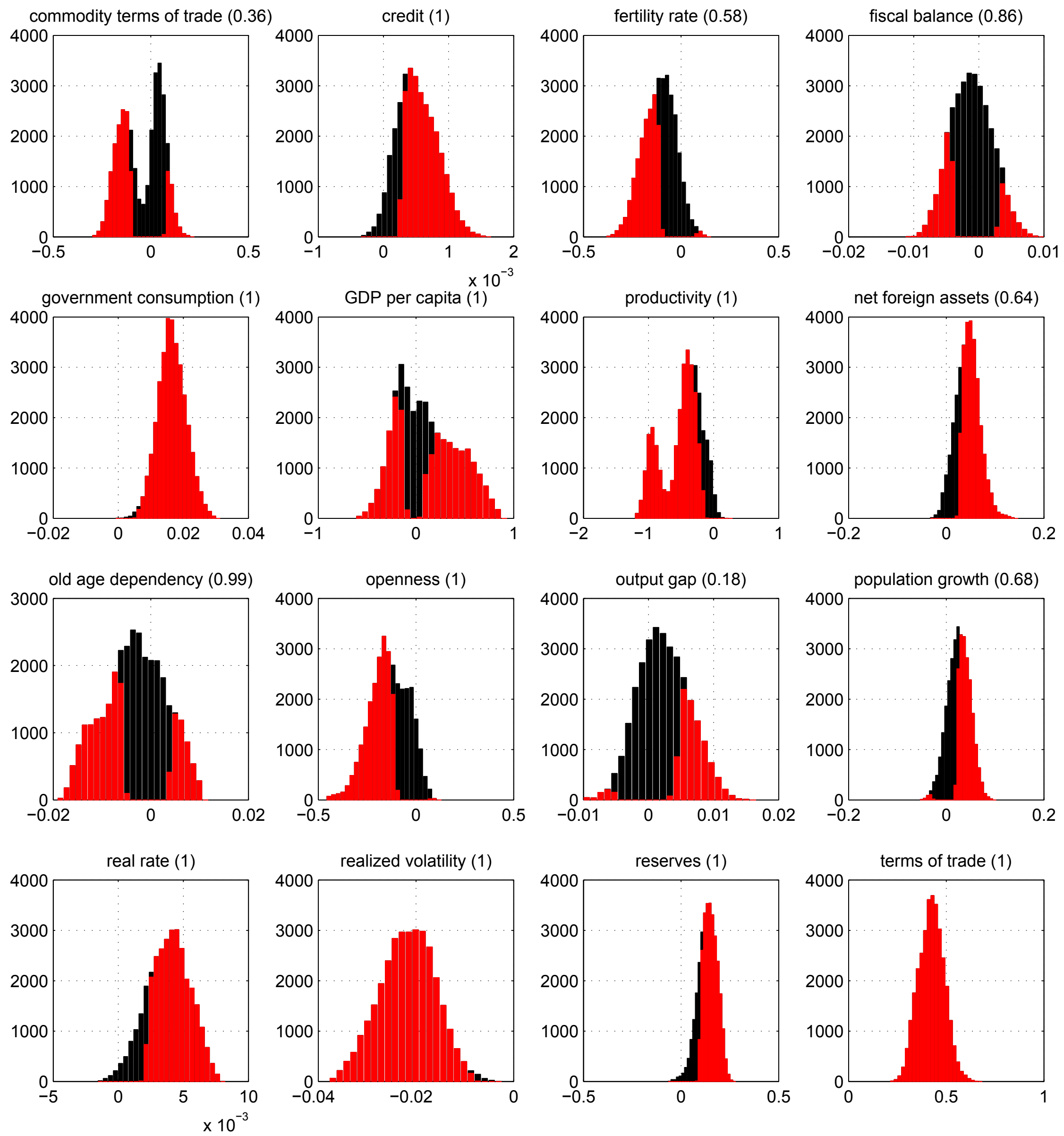

Figure 4: Distribution of coefficients across model specifications. We estimate regression (1) for all possible combinations of our 16 explanatory variables, from models with 1 or 2 variables to the full specification with all 16 variables. This figure plots the distribution of coefficients across all these alternative models. For a given estimate, the proportion of red to black illustrates the share of estimations in which the coefficient is statistically significant at the 5% level. The numbers in parentheses are the model inclusion probabilities according to the BACE approach.

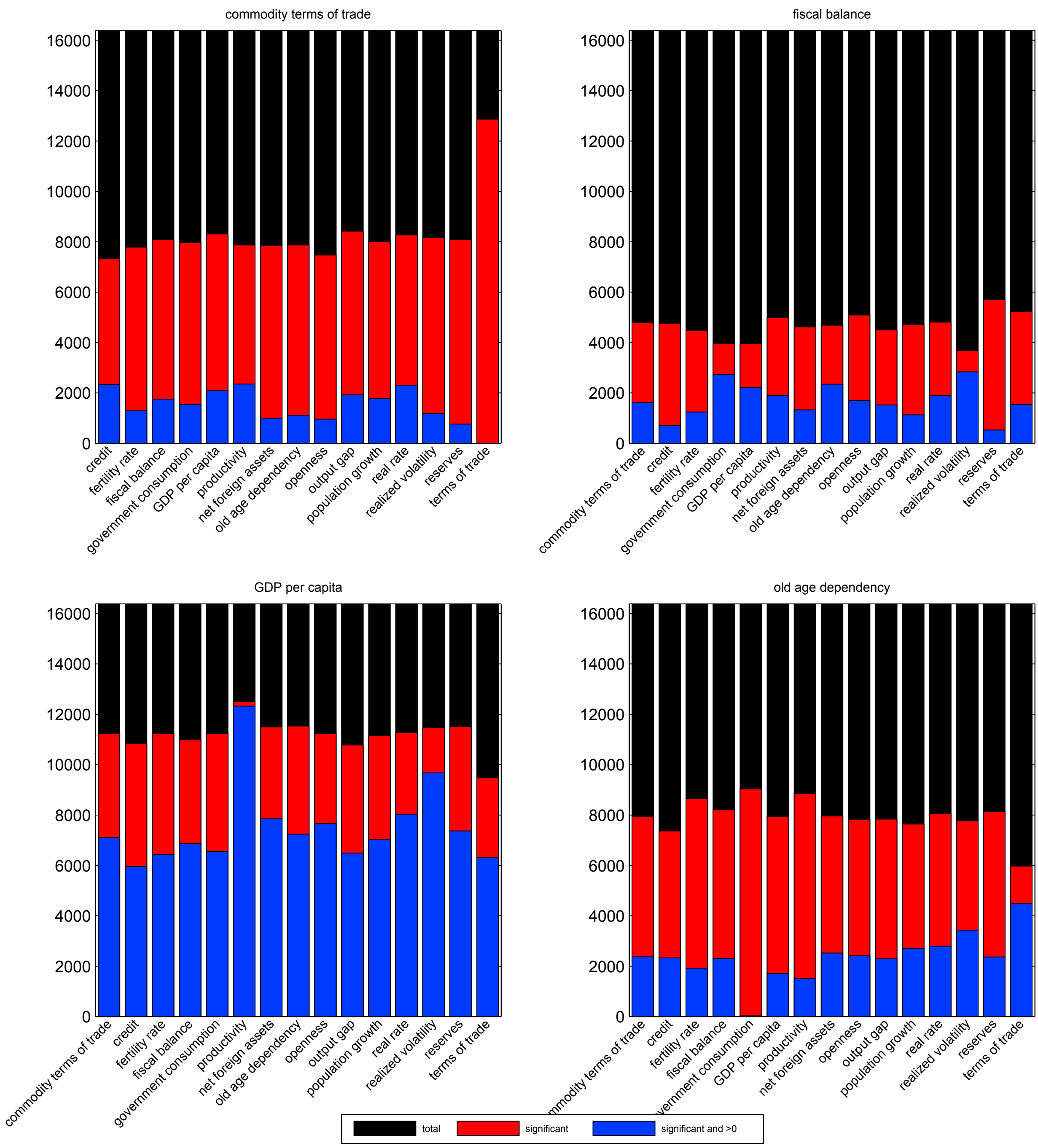

Figure 5: Sign and statistical significance of coefficients across model specifications. We estimate regression (1) for all possible combinations of our 16 explanatory variables, from models with 1 or 2 variables to the full specification with all 16 variables. The subplots illustrate the number of estimates (for the coefficient of the variable given in the title of the plot) that are positive and statistically significant at the 5% level, when the variable listed on the x-axis is also included in the regression.

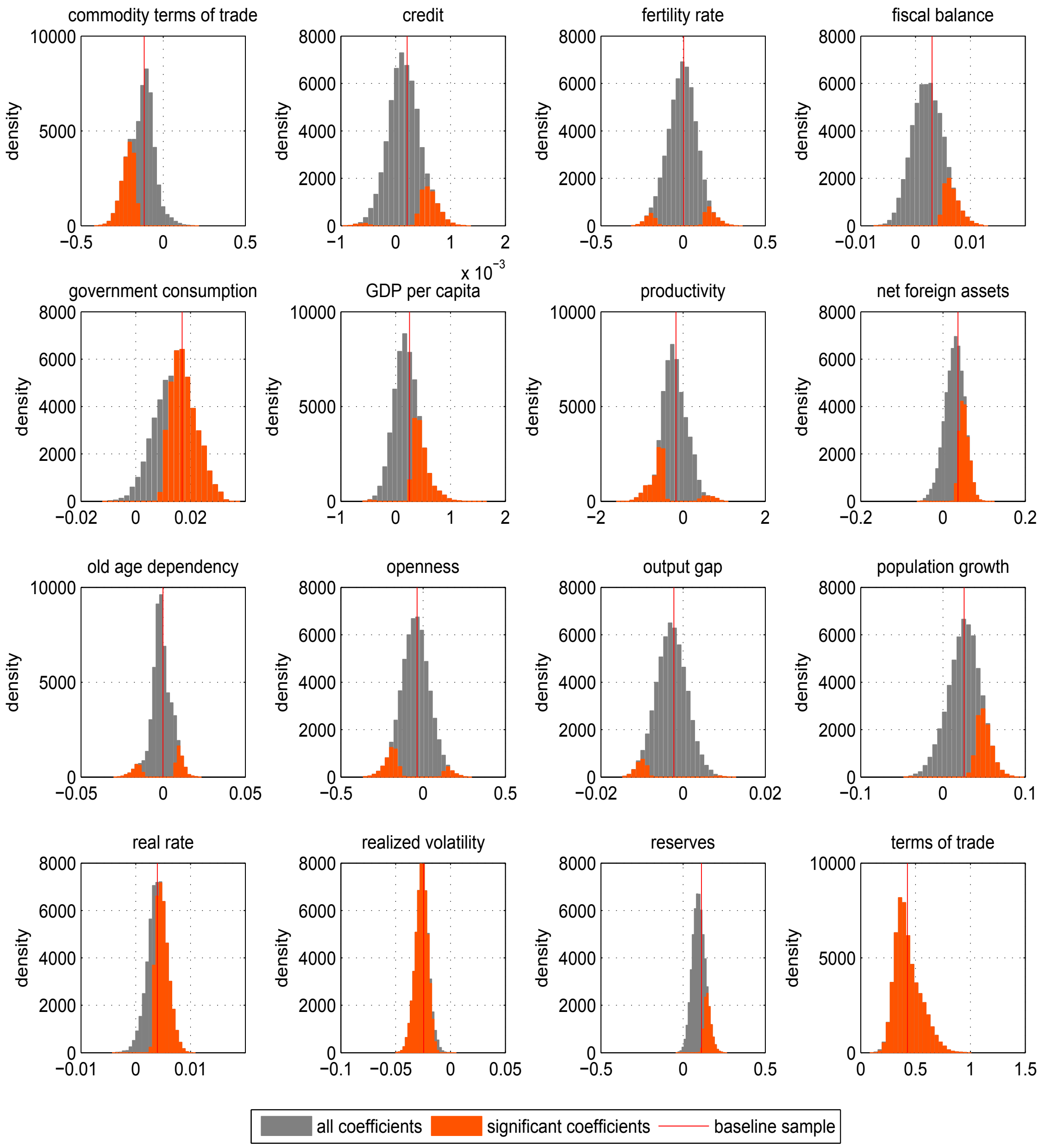

Figure 6: Distribution of coefficients across country samples. We estimate regression (1) for alternative country samples, always including 15 out of the 21 countries in the sample. For a given estimate, the proportion of red to black illustrates the share of estimations in which the coefficient is statistically significant at the 5% level. The red vertical line denotes the baseline estimate from specification (a) in Table 2.

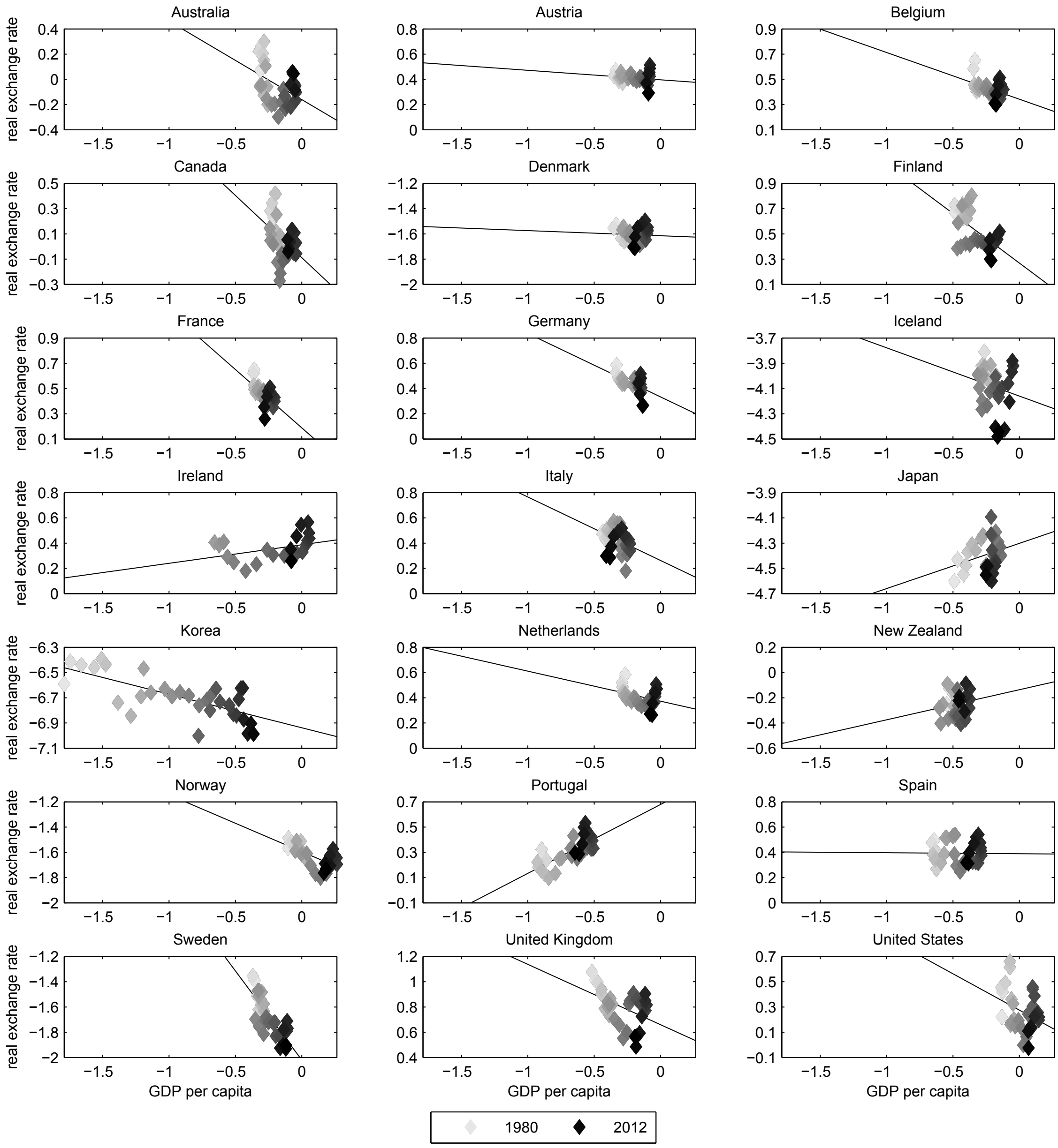

Figure 7: Observations of log bilateral real exchange rates and log relative PPP-adjusted GDP per capita. A decrease in the real exchange rate corresponds to a Swiss franc appreciation. A movement to the right on the x-axis corresponds to a decrease in Swiss GDP per capita relative to the foreign country. Darker dots correspond to observations in later years. Economic theory predicts a positive relationship. While real exchange rates levels are not comparable across countries, changes in real rates are. To make the slopes of the regression lines comparable across countries the y-axis has the same length across subplots.

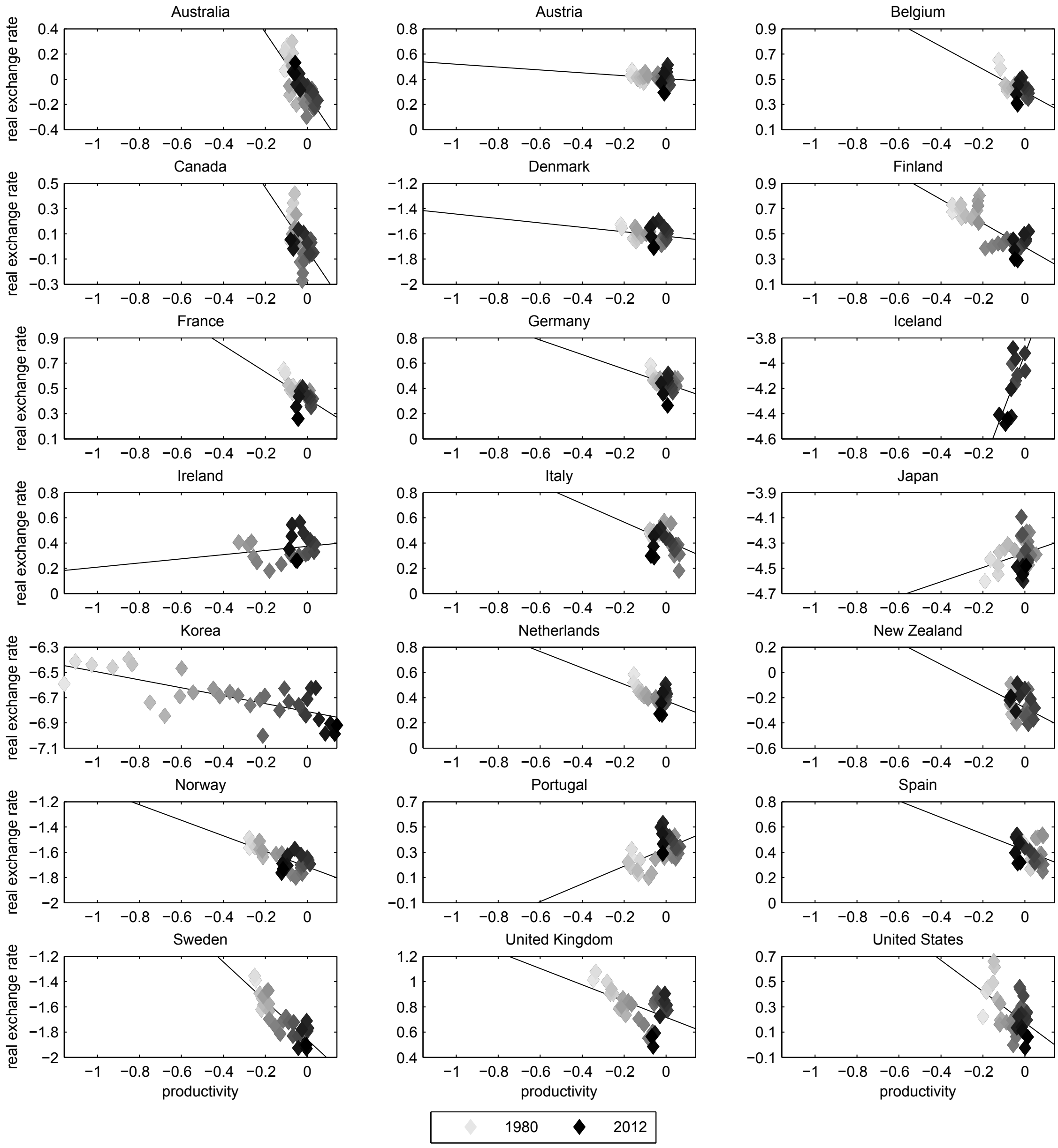

Figure 8: Observations of log bilateral real exchange rates and log relative productivity in the whole economy. A decrease in the real exchange rate corresponds to a Swiss franc appreciation. A movement to the right on the x-axis corresponds to a decrease in Swiss productivity relative to the foreign country. Darker dots correspond to observations in later years. The Balassa-Samuelson effect predicts a positive relationship if higher productivity in the whole economy mainly reflects productivity growth in the traded goods sector. While real exchange rates levels are not comparable across countries, changes in real rates are. To make the slopes of the regression lines comparable across countries the y-axis has the same length across subplots.

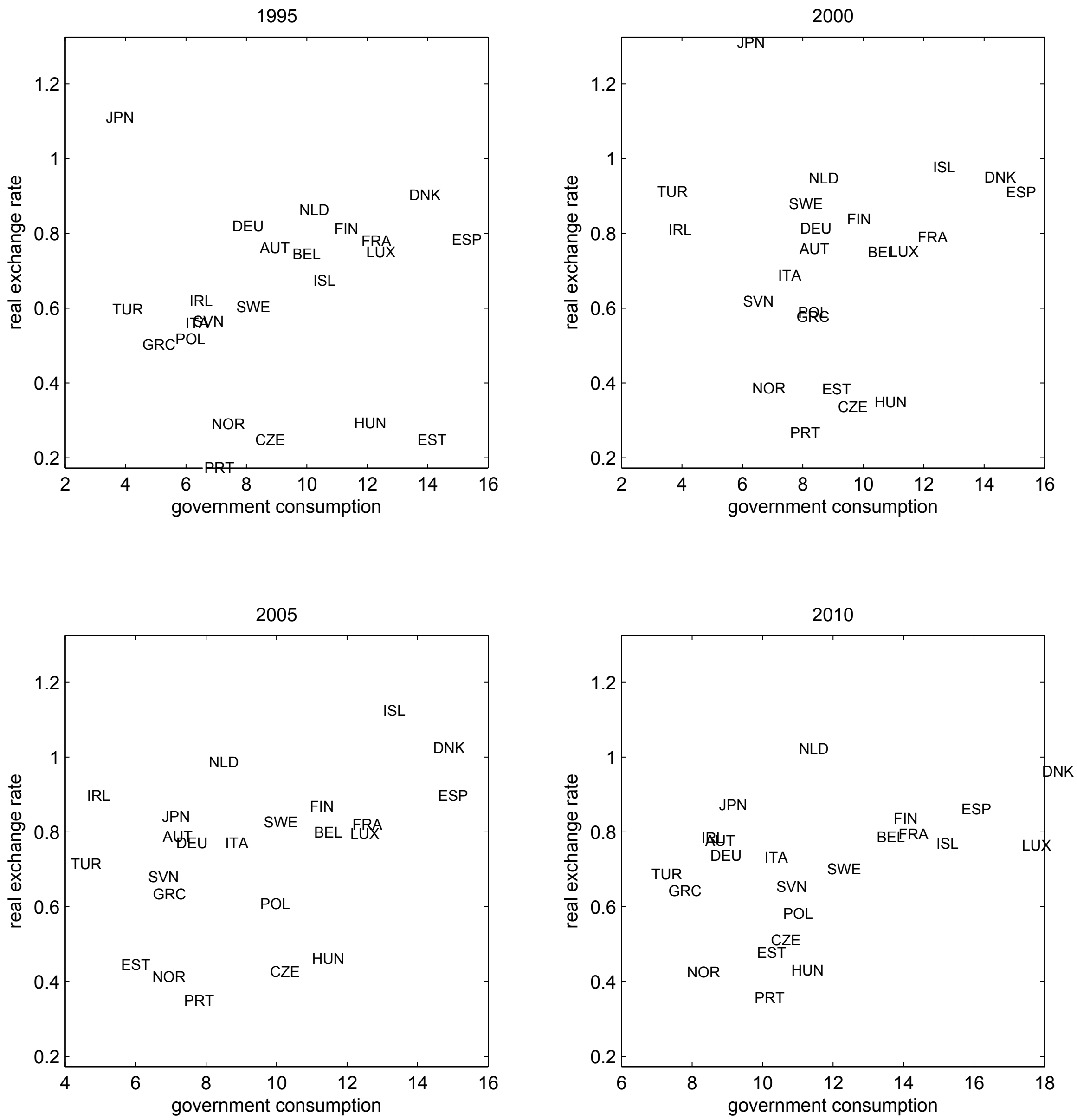

Figure 9: Observations of bilateral real exchange rates and government consumption. A decrease in the real exchange rate corresponds to a Swiss franc appreciation. A movement to the right on the x-axis corresponds to a decrease in Swiss government consumption relative to the foreign country. Real exchange rates are computed based on price level data from the Eurostat-OECD PPP project, so that the level comparison of real rates is meaningful.

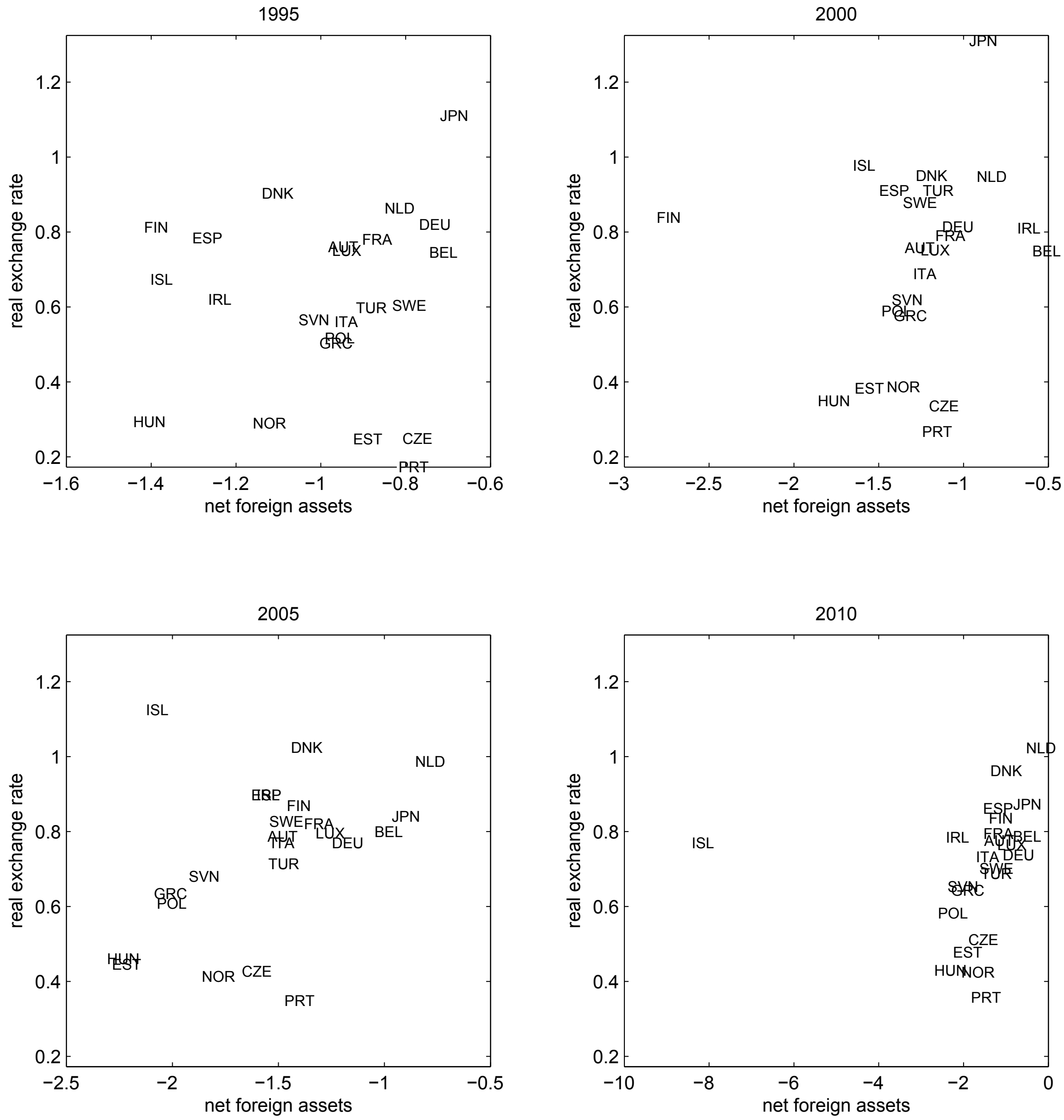

Figure 10: Observations of bilateral real exchange rates and net foreign assets. A decrease in the real exchange rate corresponds to a Swiss franc appreciation. A movement to the right on the x-axis corresponds to a decrease in Swiss net foreign assets relative to the foreign country. Real exchange rates are computed based on price level data from the Eurostat-OECD PPP project, so that the level comparison of real rates is meaningful.

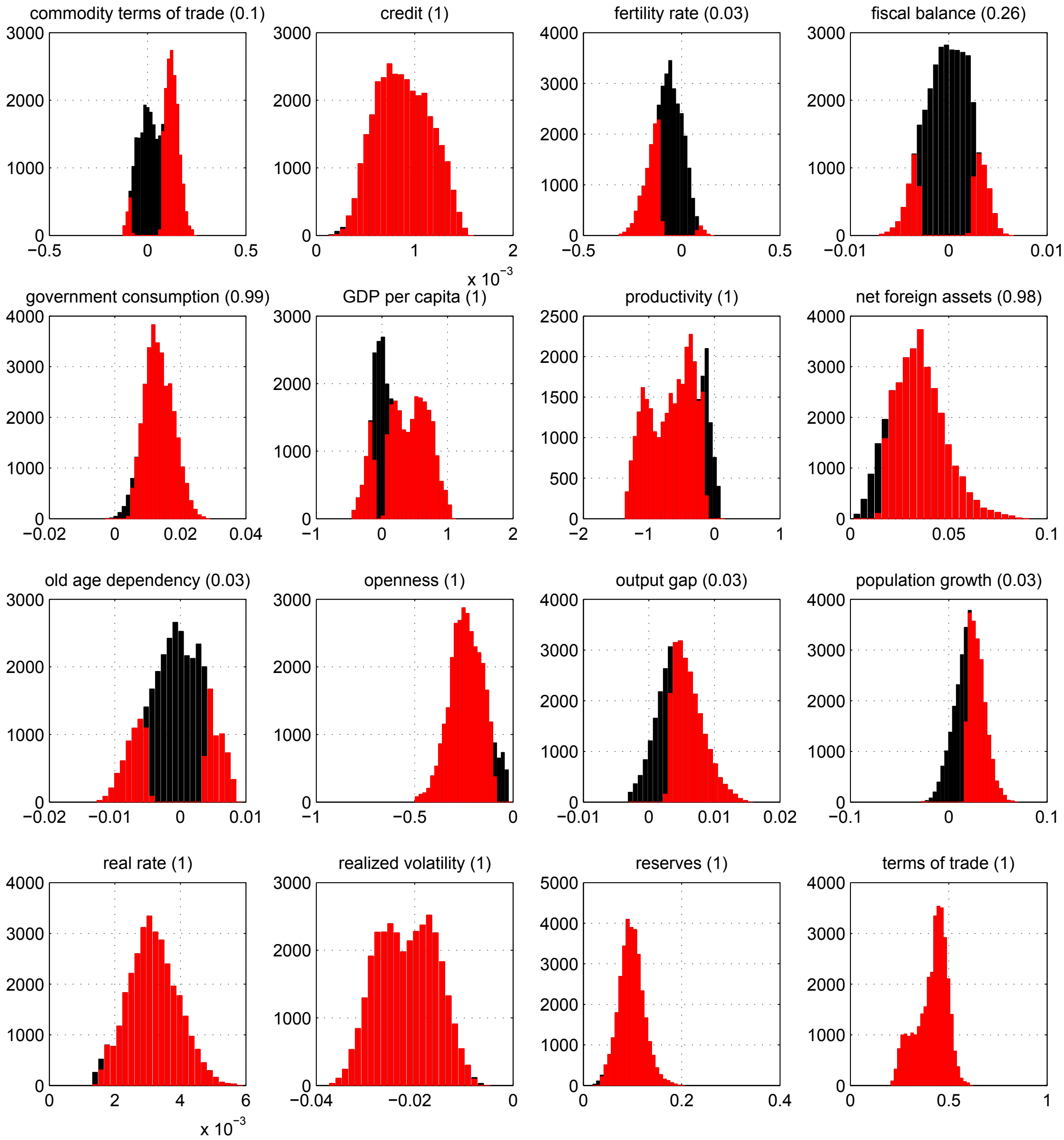

Figure 11: Distribution of coefficients across model specifications. We estimate regression 1 under the assumption of no cointegration ($\gamma_s = 0$) for all possible combinations of our explanatory variables, from models with 1 or 2 variables to the full specification with all variables. This figure plots the distribution of coefficients across all these alternative models. For a given estimate, the proportion of red to black illustrates the share of estimations in which the coefficient is statistically significant at the 5% level. The numbers in parentheses are the model inclusion probabilities according to the BACE approach.

Table 4: Regression results, 1980-2011, no cointegration

	(a)	(b)	(c)	(d)
GDP per capita	0.6879***	0.3865***	0.6699***	
	(6.14)	(4.17)	(8.10)	
commodity terms of trade	0.0553		0.0060	
	(1.13)		(0.29)	
credit, % of GDP	0.0005***		0.0005***	0.0008***
	(2.89)		(4.16)	(5.14)
fertility rate	0.0328		0.0009	
	(0.56)		(0.10)	
fiscal balance, % of GDP	0.0026		0.0008	
	(1.60)		(0.59)	
government consumption, % of GDP	0.0125***	0.0096***	0.0104***	0.0080**
	(2.89)	(2.61)	(3.83)	(2.26)
productivity	-0.6923***	-0.6488***	-0.6648***	
	(-4.60)	(-5.17)	(-6.27)	
net foreign assets, % of GDP	0.0298***	0.0652***	0.0313***	0.0455***
	(3.99)	(7.35)	(3.76)	(5.83)
old age dependency	0.0004		0.0000	
	(0.11)		(0.06)	
trade openness	-0.1945***		-0.1896***	-0.1913***
	(-3.61)		(-4.59)	(-3.66)
output gap	0.0007		0.0000	
	(0.30)		(0.06)	
population growth	0.0006		0.0001	
	(0.05)		(0.06)	
real rate	0.0038***		0.0035***	0.0025**
	(3.62)		(4.67)	(2.07)
realized volatility	-0.0243***		-0.0225***	
	(-5.49)		(-7.04)	
reserves, % of GDP	0.0759***		0.0871***	
	(4.00)		(4.75)	
terms of trade (goods and services)	0.2845***	0.3525***	0.3021***	0.4456***
	(4.32)	(5.15)	(6.98)	(8.39)
Observations	614	634		632

Notes: Results from regression (1) under the assumption of no cointegration ($\gamma_s = 0$) for alternative specifications listed in columns. The models include country fixed effects. The dependent variables are CPI-based Swiss franc real bilateral exchange rates. A positive coefficient implies that increases in the explanatory variable in Switzerland relative to the foreign country are associated with a real Swiss franc appreciation. We exclude health spending from the regressions because this variable is only available from 1995. Column (a) is the baseline specification with all variables. Column (b) includes only those variables that are also included in Mancini et al. (2014). Column (c) reports a weighted average of model estimates across alternative models, based on the BACE approach. Column (d) includes only variables found to have a statistically significant coefficient with the expected sign, robustly across model specifications in Figure 11. Newey-West t-statistics are in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

Table 5: Regression results, 1995-2011, no cointegration: estimation with and without fixed-effects

	(a)	(b)	(c)	(d)
GDP per capita	1.1477***	1.0965***	1.1963***	0.8588***
	(4.22)	(8.74)	(8.47)	(18.06)
commodity terms of trade	-0.0585	0.0298		
	(-0.84)	(0.29)		
credit, % of GDP	0.0006***	0.0012***		
	(3.45)	(3.83)		
fertility rate	-0.0167	0.3765***		
	(-0.14)	(2.88)		
fiscal balance, % of GDP	0.0019	0.0028		
	(0.99)	(0.94)		
government consumption, % of GDP	0.0068	0.0095**	0.0090**	0.0209***
	(1.47)	(2.36)	(2.13)	(4.77)
health spending, % of GDP	0.0039	0.0319**		
	(0.32)	(2.30)		
health spending, per capita	-0.1608	-0.4035***		
	(-1.46)	(-4.03)		
productivity	-0.6649**	0.0675	-0.3180	0.4890
	(-1.99)	(0.19)	(-1.11)	(1.39)
net foreign assets, % of GDP	0.0088	-0.0188*	0.0167	-0.0120
	(0.95)	(-1.87)	(1.21)	(-0.66)
old age dependency	-0.0036	0.0213***		
	(-0.66)	(4.43)		
trade openness	-0.0123	-0.1362***		
	(-0.22)	(-4.64)		
output gap	0.0051	-0.0026		
	(1.18)	(-0.48)		
population growth	0.0278	0.0377*		
	(1.41)	(1.71)		
real rate	0.0038***	0.0021		
	(2.80)	(1.25)		
realized volatility	0.0266***	0.0062		
	(3.22)	(0.41)		
reserves, % of GDP	0.0149	0.0454		
	(0.68)	(1.18)		
terms of trade (goods and services)	0.3299**	0.6029***	0.3202***	0.5072***
	(2.01)	(3.63)	(3.25)	(2.84)
fixed effects	yes	no	yes	no
Observations	361	361	385	385
within $\bar{R}^2$	0.56		0.53	

Notes: Results from regression (1) under the assumption of no cointegration ($\gamma_s = 0$) for alternative specifications listed in columns. The models include country fixed effects (columns (a) and (c)), a constant (columns (b) and (c)) and first-differenced terms. The dependent variables are Swiss franc real bilateral exchange rates, based on price-level data. A positive coefficient implies that increases in the variable in Switzerland relative to the foreign country are associated with a real Swiss franc appreciation. The first two columns represent the baseline specification with all 16 variables, with/without fixed effects. The last two columns represent the specification in Mancini et al. (2014), with/without fixed effects. Newey-West t-statistics are in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

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