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Deviations in real exchange rate levels in the OECD countries and their structural determinants*

Martin Berka and Daan Steenkamp†

Abstract

We study the validity of an augmented Balassa-Samuelson theory in a panel of real exchange rate levels across 17 OECD countries between 1970 and 2012 using a unique panel of levels of total factor productivity (TFP) across sectors. We find that real exchange rates can be explained by relative sectoral TFP levels both across countries and over time in the direction predicted by Balassa-Samuelson hypothesis. We also show that drivers of labour wedges such as structural labour market differences are important in explaining real exchange rate levels. Nevertheless, large average conditional deviations in real exchange rate levels remain across countries in our sample.

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Non-technical summary

The most commonly used theoretical framework describing why prices in some countries are higher than in others (i.e. explaining deviations from purchasing power parity) is the Balassa-Samuelson model. The Balassa-Samuelson model implies that stronger tradable sector productivity growth should tend to cause a country's real exchange rate to appreciate. This paper develops measures of productivity and real exchange rate levels across industries and countries to allow the Balassa-Samuelson hypothesis to be tested.

We show that the model finds empirical support in 17 OECD economies: there is a link between real exchanges and sectoral productivity levels both across countries and over time. We then show theoretically and empirically that relaxing the model's assumptions about wage determination and the role of labour market differences across sectors and countries helps improve the performance of the model. However, there remains large unexplained deviations in real exchange rates across countries that the model cannot account for.

1 Introduction

Most papers that investigate the link between real exchange rates and productivity focus on the time variation (using index data) but neglect the cross-sectional dimension. Furthermore, these studies tend to use labour productivity to proxy productivity, despite its well-known limitations.[1] The underlying theoretical framework of the Balassa-Samuelson model (Balassa 1964 and Samuelson 1964) is based on more exogeneous total factor productivity (TFP). The relative traded TFP should appreciate real exchange rate, while the relative nontraded TFP should depreciate it. But the evidence mostly rejects the Balassa-Samuelson hypothesis in time series domain except in cointegration studies.[2] While there is a slightly stronger evidence in the cross sectional studies, particularly when comparing rich and poor economies, these studies are not based on TFP measures of productivity.[3] An exception is Berka et al. (2018), who construct measures of sectoral levels of TFP and real exchange rates, and find support for a Balassa-Samuelson relationship for 9 eurozone economies between 1995 and 2009, after controlling for differences labour wedges. We expand their work by constructing a unique panel of levels of sectoral TFPs, real exchange rates, as well as unit labour costs and measures of institutional differences in labour market for 17 OECD economies with floating exchange rates vis-à-vis the US, between 1970 and 2012. Theoretically, we augment their model for the possibility of firm-side sectoral labour wedges as in Galí et al. (2007) and Karabarbounis (2014), and show that these imply a possible additional metric of institutional labour market differences. We construct these measures and show they significantly improve the fit of the augmented Balassa-Samuleson model.

As far as we are aware, ours is the first paper to find robust evidence in support of an augmented Balassa-Samuelson model among floating-exchange-rate developed countries. But a part of our contribution also lies in the extent of our robustness checks. By using all available vintages of data to construct different vintages of price and productivity measures, we show how these can influence the results of our baseline regressions. We use different

[1] Labour productivity confounds the effects of the total factor productivity with the intensities of capital-to-labour ratios, intermediate input intensities, and differences in industrial structure.

[2] See, for example Chinn and Johnson (1996), Tica and Družić (2006), Lee and Tang (2007), Lothian and Taylor (2008), Ricci et al. (2013), Gubler and Sax (2011a), or Chong et al. (2012).

[3] See De Gregorio et al. (1994) or Canzoneri et al. (1999). Examples of studies that focus on a cross-sectional dimension include Rogoff (1996) and Bergin et al. (2006).

weighting schemes, different coefficient assumptions, and alternative relative price measures. This helps to make sense of the sometimes contradictory findings in the literature on the Balassa-Samuelson hypothesis, which seem to reflect the use of different measures of the underlying concepts, different vintages of data, and different samples. We also show that our results are robust to the inclusion of alternative control variables, such as terms of trade or real interest rate differentials, and the use of lower-frequency data.

There remain, however, large unexplained deviations in real exchange rates across countries that the model cannot account for.

The rest of the paper is organized as follows. The next section describes the construction of our datasets. Section 3 outlines the predictions of a basic model. Section 4 outlines the empirical methodology and section 5 the results and various robustness checks. Section 6 concludes.

2 Description of the data

As far as we are aware, ours is the first study to jointly consider the panel of levels of real exchange rates and levels of sectoral TFP in a group of advanced economies with floating nominal exchange rates. We construct a panel dataset of levels of sectoral TFP, real exchange rates, unit labour costs, terms of trade, and indicators of structural labour market differences for 17 OECD countries, all vis-à-vis the US.[4] The unbalanced annual panel covers the period of 1970 to 2012, with the length of data varying from a minimum of 13 years to a maximum of 42 years (see Table 10 in the Appendix). We present results for both a recent balanced sample and a full unbalanced panel. Appendix B provides detailed descriptions of the approaches used to construct the dataset and Tables 1 to 3 report the descriptive statistics of the main variables used for all countries in the unbalanced panel.

The construction of the panel of sectoral TFP estimates is described in detail in Steenkamp (2015); we only outline our approach here. Drawing on different sources of industry data requires matching of industry classifications. Using concordances, we construct a panel of annual estimates of TFP and real exchange rates by combining cross-sectional TFP and PPP levels for

[4] The countries are: Australia, Austria, Belgium, Czech Republic, Denmark, Spain, Finland, France, Germany, Hungary, Ireland, Italy, Japan, the Netherlands, New Zealand, Sweden, and the United Kingdom. Eight of these countries were amongst the founding members of the eurozone in 1999.

given benchmark years to indices of industry productivity and prices, in line with Berka et al. (2018). Industry TFP levels are constructed based on the Groningen Growth and Development Centre (GGDC) Productivity Level database (1997 benchmark year), and are expressed relative to the US.[5] The construction of the panel of TFP levels in logarithms is as follows: $a_{i,j,t} = \log\left(\frac{TFPlevel_{i,j} \times TFPindex_{i,j,t}}{TFPindex_{i,US,t}}\right)$ where $TFPlevel$ is the relative level of TFP of country i relative to US in sector j, in 1997, and $TFPindex$ are the time-series indices of sectoral TFP, normalized to = 1 in 1997. We aggregate $a_{i,j,t}$ across 11 industries into traded and non-traded aggregates ($a_{i,T,t}$ and $a_{i,N,t}$ respectively) using constant 1997 gross value added (GVA) country-specific weights and a standard industrial classification as in Berka et al. (2018).

Figure 1 plots the levels of traded and non-traded TFP for each country compared to the US. In the unbalanced panel, the level of TFP in traded sector is the highest in the Netherlands and Ireland, and the lowest in Eastern Europe. TFP in non-traded sector is also the highest in the Netherlands, followed by New Zealand, while it is the lowest Japan, the Czech Republic and Hungary.[6] We observe that most countries see downward long-term trends relative to the US in both sectors. Figures 4 to 6 compare our estimates of TFP levels to labour productivity level estimates from Mano and Castillo (2015), with all series expressed relative to the US.[7] For many countries, the relative levels and trends correspond closely with those in relative labour productivity. But there are exceptions: in Austria, Denmark, Hungary, and New Zealand, TFP is lower than labour productivity in traded sector. On the contrary, the Netherlands sees a higher TFP than labour productivity level in the traded sector. Tradable TFP generally shows larger volatility than labour productivity. While many countries only see minor changes in their non-tradable labour productivity when compared with the US, we observe a

[5] Since New Zealand is not included in the GGDC database, we instead use data from Steenkamp (2015). These are constructed using Mason (2013)'s 2009 year benchmark comparisons between New Zealand and Australia. Because Australia is in the GGDC database, it can be used to express New Zealand figures relative to the US.

[6] New Zealand's high ranking for non-tradables reflects the inclusion of real estate, renting and business services because of differing treatment of owner-occupied dwellings in New Zealand compared with the other countries in the sample (discussed in Steenkamp 2015).

[7] Note that there are some comparability issues between the New Zealand estimates and those for other countries, which relate to the PPPs used to compare the value of outputs. For all countries except New Zealand these estimates are based on data in 2005 PPPs for USD, while for New Zealand the estimates are based on data in 2005 current USD (see discussion in Mano and Castillo 2015).

decline in non-tradable TFP in Belgium, Japan, Spain and Italy. The ratio of tradable to non-tradable TFP relative to the US is most notably higher than that based on the labour productivity in Japan, Belgium, and France, and lower in New Zealand and Denmark. The highest growth rates of the relative TFP (traded to nontraded sectors) are in Japan, Sweden, Italy and the Czech Republic, and lowest in Ireland, Australia, Germany and the Netherlands.[8] The correlation between labour productivity and TFP measures is positive: over 0.8 for tradables, around 0.2 for non-tradables and 0.5 for cross-country sectoral productivity differentials over the benchmark sample.

Tables 1, 2, and 3 report stylized facts of our sample variables. For most countries, gaps in traded TFP vis-a-vis the US tend to exceed those for nontraded TFP. Traded TFP also tends to be more volatile than nontraded TFP.

Our panel of real exchange rate levels is constructed using bilateral nominal exchange rates and relative price levels. Logarithm of the level of the bilateral real exchange rate of country i relative to the US is defined as $q_{i,t} \equiv NER_{i:US,t} + p_{i,t} - p_{US,t}$, where NER is the log of the USD price of one unit of domestic currency, so that an increase represents an appreciation. $p_{i,t}$ and $p_{US,t}$ denote logs of aggregate consumer price levels in country i and the US, respectively, and are obtained from the International Comparison Program (ICP) aggregate consumer price PPPs. We construct tradable and non-tradable price levels using the ICP price parities and goods and services CPI series as proxies for tradables and non-tradables price time series.[9]

[8] Bertinelli et al. (2016) produce labour productivity growth rates for tradable and non-tradables for a selected group of OECD economies using EU KLEMS for a balanced panel of 1970-2007. Their estimates suggest that relative labour productivity grew the fastest in Ireland, Finland and Spain, and slowest in Germany, Australia and Denmark.

[9] Most papers in the literature focus exclusively on value added deflators as price proxies when constructing the price of traded to nontraded goods (e.g., Drozd and Nosal 2010, Mihaljek and Klau 2008, Mihaljek and Klau 2004, Engel 1999) or measure the real exchange rate as an index without a meaningful cross-sectional dimension (e.g., Bordo et al. 2014, Chong et al. 2012, Gubler and Sax 2011b, Ricci et al. 2013). Papers that use value-added-based relative prices tend to find a positive relationship between relative sectoral prices and real exchange rates (see Steenkamp 2013 or Drozd and Nosal 2010). We note that such value-added-based price indexes likely bias results towards the acceptance of the Balassa-Samuelson hypothesis because, in our sample, the time series correlation between sectoral TFP measures and value added-based price indices is higher than for consumer price-based indices (Figure 16 in the Appendix). We also construct producer-price indexes and observe that they produce different sectoral inflation rates on average, especially for tradable prices (see Steenkamp 2013 and Figure 15 in the Appendix).

Tables 1, 2, and 3 show that the east European countries in our sample have the lowest level of the real exchange rate, while Denmark, Sweden and Finland the highest. The east European countries have seen the most appreciation of their q, while Sweden and Belgium depreciated the most relative to the US. Hungary and Japan see the highest q volatilty, and the UK the lowest.

We also consider other variables that influence real exchange rates through their impact on relative sectoral prices or the terms of trade. We construct relative Unit Labour Cost levels (ULC) from the OECD data, expressed as the average unit labour cost in country i relative to the unit labour cost in the US after converting them into the same currency. To remove the mechanical influence of nominal exchange rates on ULC, we further construct relative unit cost measure that is orthogonal to the NER for each country by regressing ULC on a constant and NER and collecting the residuals. These orthogonalised relative unit labour costs ($OULC$) are calculated by summing said residual with the average ULC in each country.[10] Table 1 reports that the lowest relative unit labour costs on average are found in the Czech Republic, Hungary, and New Zealand, while the highest are in the United Kingdom (see also Figure 2). Hungary, Czech Republic, Ireland and New Zealand have the fastest-growing ULC over the sample, while Austria sees the fastest decline (Table 3).

We measure terms of trade ($TOT_{i,t}$) as the difference between export and import price levels from Feenstra et al. (2015), who constructs them as export and import PPPs divided by the nominal exchange rate, relative to the US. As with the other variables, they are expressed in logarithms. Over the unbalanced sample, Czech Republic, Hungary, New Zealand and Sweden have the most favourable terms of trade compared to the US, while Australia has the least favourable terms of trade.

Finally, we construct bilateral long-run real interest rate differentials relative to the US ($RIRDIFF_{i,t}$) using the 10-year government bond yields obtained from Bloomberg. Relative interest rate levels are expressed as the home country rate less the US rate, adjusted by relative CPI inflation rates. Over the full sample, real interest rates are the highest in New Zealand and Finland, and the lowest in Hungary and Japan.

[10] Specifically, since the residuals are mean-zero in every country by construction, we add to them the average ULC so as to preserve the correct average level difference between country i and the USA. This prevents the introduction of bias into our fixed effects estimations later on. We note that none of our results hinge on the use of either measure of the unit labour costs.

2.1 Institutional labour market differences

We argue that relaxing the Balassa-Samuelson model's assumption of perfectly competitive labour markets helps explain real exchange rates, and develop this idea in the model in Section 3. On the empirical side, we construct a panel of variables capturing the institutional labour market differences across countries in our sample. We use several indicators from the Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (ICTWSS) dataset (see Visser 2013). These institutional variables capture labour market aspects that are both relevant to wage determination while being largely orthogonal to productivity. Many of these characteristics of wage bargaining have evolved over longer periods of history which makes them exogenous at the medium-run frequencies we consider. Specifically, we choose summary variables that best capture the institutional differences in wage-setting (described in greater detail in Appendix sub-section B.6). As has been appreciated since at least Leontief (1946), indicators of union density or co-ordination in wage-setting influence bargaining power of employees and consequently the flexibility of real wages. Indicators of employment protection, on the other hand, reflect the labour market's ability to adjust to changes in labour demand. Unemployment replacement rates affect the willingness of people to transition from unemployment into the workforce and therefore also stickiness in the labour market. While our model does not capture these channels separately, there is a large literature that studies labour market imperfections, albeit not when it comes to real exchange rates.

As far as we are aware, this is the first study which considers the importance of labour market institutions on real exchange rates using an detailed measures of institutional labour market indicators. However, indicators from the ICTWSS database have been used in related macroeconomic literature. For example, Bertinelli et al. (2016) build a general equilibrium model of an open economy with a two-sector search-and-matching component for the labour market. In their model, wages differ between the traded and non-traded sectors. Empirically, they find that wages in non-traded sector relative to traded sector decline following a relative TFP shock (expressed as traded to non-traded). This effect is stronger in countries with more regulated labour market, as measured by a variety of indicators in the ICTWSS database in their paper. Gnocchi et al. (2015) find that these indicators are related to cyclical movements in real wages, labour productivity and unemployment in OECD economies. Without attributing causality, Egert (2016) finds that anti-competitive regulations are correlated with the total factor productivity measures, both in cross section and in time series across a panel of OECD countries, particularly in countries with highly regulated labour market institutions. Among others, we include two of the variables used by Egert (2016): the strength of the employment protection laws and the unemployment benefit replacement ratio.

We specifically consider the following labour market institutional indicators. $CONC_{i,t}$ is the summary measure of concentration of unions at aggregate and sectoral levels. $AUTH_{i,t}$ is the summary measure of formal authority of unions regarding wage setting at aggregate and sectoral levels. $CENT_{i,t}$ is the measure of the centralisation of wage bargaining measured by weighting national and sectoral concentration of unions by level of importance[11]. $UD_{i,t}$ is the union density rate. Additionally, we consider other sources for measures of labour market institutions. We include the unemployment replacement rate $RR_{i,t}$ from Gnocchi et al. (2015), defined as the ratio of disposable income when unemployed to expected disposable income. We measure the strictness of employment protection on individual contracts with $EPR_{i,t}$ and protection on temporary contracts with $EPT_{i,t}$, both obtained from the OECD. We create a summary measure $Lab4avg_i$ which is the arithmetic average of unadjusted values of UD, $AUTH$, $CONC$ and $AdjCov$, and additionally a principal component $LABPC$, extracted from 53 labour market indicators included in the ICTWSS. Each of our labour market indicators is expressed as a log difference to the level in country i minus the level in the USA, so that a higher value of each of these indicators implies a relatively more rigid labour market compared to the USA.

We argue that our preferred labour market measure, $CONC$ matters in the transmission of relative price changes domestically. Figure 11 in the Appendix shows that countries with more tightly regulated labour markets tend to experience larger changes in both relative wages and relative prices domestically, independently of developments in $OULC$.

2.2 Developments in relative prices and sectoral productivity

The Balassa-Samuelson hypothesis predicts that there will be a positive relationship between sectoral productivity differentials and the real exchange rate. Figure 7 plots average levels of real exchange rates and relative TFPs, as

[11] $CENT$ is a broader measure than $CONC$ because it also incorporates internal and external demarcations between union confederations. The exact definitions of these variables are available in the Appendix.

well as the average growth rates. In both cases, the two variables are positively correlated in the unbalanced panel: countries with a higher relative TFP on average tend to have a higher q; countries with a higher average growth rate of relative TFP tend to have a higher average rate of q appreciation. Real exchange rates appreciate the most in Japan, Australia and Eastern Europe, and the least in France. Relative traded to non-traded TFP grew the most in Japan and the least in Denmark. The time series correlation between relative TFPs ($a_T - a_N$) and q is relatively low at only 0.34, while the correlation between $OLUC$ and q levels is higher at 0.65. The third and fourth panels of Figure 7 plot data for a balanced panel from 1990 to 2017. They show that while the cross-sectional correlation between relative TFP and q is similar to the unbalanced panel, the time series correlation is much weaker. There are many countries where the unconditional correlation is negative. In both samples, the ratio of traded to non-traded TFP levels has been the highest in Ireland, Belgium, and Japan, and the lowest in New Zealand and Hungary. The correlation between $a_T - a_N$ and q is 0.61 in cross-section.

Over the full sample, relative unit labour costs grew the most in Hungary, the Czech Republic, and Ireland and the fell most in Austria and France (see Figure 2 or 3). In cross section, unconditional correlation between $OULC$ and q is 0.29 in the unbalanced panel.

3 Real Exchange Rates in a Theoretical Model

Berka et al. (2018) build a two-sector, two-country DSGE model with a distribution sector and an imperfect elasticity of substitution in tradables. In their model, sectoral productivity and an aggregate labour wedge shocks cause movements in real exchange rate. In addition to the Balassa-Samuelson effect, relative labour wedges cause the real exchange rate to appreciate in their model. Because the labour wedge is on the household side, it also generates a positive correlation between prices and wages because it shifts the labour supply. We offer a simple extension of their model by amending it for the possibility of a labour wedge that varies by sector on the firm side. A sector-specific labour wedge could reflect several factors, such as sectoral variations in the union power. Historically, collective wage bargaining has been performed at the levels of industries. Also, unionization rates tend to vary by sector within countries, and these variations can be fairly dramatic at times (see OECD 1994 or OECD 1997). Figure 8 shows the unionization rates for the US traded and non-traded sectors as an example.

While we study the importance of unionization and other institutional aspects of the labour markets for real exchange rates explicitly in the empirical section, in our model we assume that unions cause wage markups that vary across sectors and countries. While the welfare consequences of fixed labour contracts were first pointed out by Leontief (1946), our current macroeconomic understanding of the roles unions play is largely based on the insider-outsider model. Lindbeck and Snower (1985) introduce the insider-outsider approach which vests some bargaining power to the employees ('insiders'), and discuss their implication for wage setting. Sollow (1985) adds a focus on skills and the longer-term relevance of the overall labour pool. In the first fully developed microeconomic treatment of the union's insider-outsider interaction, Lindbeck and Snower (1988) let the union insiders adopt a form of 'harassment' towards the non-union outsiders. In equilibrium, this allows insiders to charge a wage which is a markup on the outside wage. This is exactly the assumption we adopt in our model. While we do not model insiders and outsiders explicitly, we assume that the outsiders' wages equal marginal product of labour in that industry. Union wages are then a markup on this marginal product. Such insider-outsider approach has since been adopted chiefly to study employment (see for example, Blanchard and Summers 1986 and Lindbeck and Snower 2001), especially in Europe.

While the effects of labour unions on real exchange rates have been appreciated since Giovannini (1990), only a few models propose a concrete mechanism. de Gregorio et al. (1994) present a small open economy model with labour unions in non-traded sector to study the relative price of non-traded to traded goods in Europe. In their model, the unions minimize a loss function $(L - \bar{L})^2 + \sigma(w - \bar{w})^2$ where $\bar{L}$ and $\bar{w}$ are unions' targets for employment and real wage. In equilibrium, real exchange rates appreciate in real wage targets set by the unions.[12] Berka et al. (2018) show that when the labour wedge does not differ by sector, its effect on the real exchange rate is indistinguishable from a wedge that is modelled as parametric shifter of the disutility of labour. We assume that the wage markup is as in Galí et al. (2007) and Karabarbounis (2014): $\mu_{j,t} = (w_t - p_{j,t}) - MPL_{j,t},\ j \in \{T, N\}$, and similarly in the foreign country. The rest of the model is identical to the flexible-price version of Berka et al. (2018) and is explained in the Appendix. Here, we focus on the solution of the linearized version of the model around a symmetric steady state when there is no home bias. Let q be the real exchange rate measured as the relative price of the home to foreign consumption basket, χ^R the relative (always home relative to foreign) disutility of labour, a_T^R the relative productivity in the traded sector, a_N^R the relative productivity of the non-traded sector, μ_N^R the relative markup in the non-traded sector and $\mu_N^R - \mu_T^R$ the relative markup in the non-traded sector relative to traded sector. Then, real exchange rate q can be expressed as:

$$q = \alpha_\chi \chi^R + \alpha_T a_T^R + \alpha_N a_N^R + \alpha_{\mu_N} \mu_N^R + \alpha_{\mu_N - \mu_T}(\mu_N^R - \mu_T^R) \tag{1}$$

where

$$\begin{aligned}
\alpha_\chi = \alpha_{\mu_N} &= \frac{\sigma(1-\gamma\kappa)}{B} \\
\alpha_{a_T} &= \frac{\sigma(1-\gamma\kappa)}{B}\gamma\kappa\psi(\kappa\lambda + \phi(1-\kappa) - 1) \\
\alpha_{a_N} &= -\frac{\sigma(1-\gamma\kappa)}{B}[1 + \psi(1 + \gamma\kappa(\kappa\lambda + \phi(1-\kappa) - 1))] \\
\alpha_{\mu_N - \mu_T} &= \frac{\sigma(1-\gamma\kappa)}{B}\gamma\kappa\psi(\kappa\lambda + \phi(1-\kappa))
\end{aligned}$$

[12] An alternative model structure that would result in real wage markups can be akin to Ahn et al. (2017). Under the assumption that sectoral labour unions aggregate household labor supply in each sector, and that labour inputs have an elasticity of substitution that varies by sector (e.g. if supplying jobs to different occupations in a non-traded sector requires skills that are not as directly substitutable as those in a traded sector), union wages can be written as a sector-specific markup on the marginal costs:

$$\tilde{Y_t^T} = A_t^T L_t^T, \text{ where } L_t^T = \left(\int_0^1 (L_{it}^T)^{\frac{\zeta^T - 1}{\zeta^T}} di\right)^{\frac{\zeta^T}{\zeta^T - 1}}$$

$$\tilde{W_t^T} = \frac{\zeta^T}{\zeta^T - 1} MC_t^T$$

and similarly for non-traded sector. This gives rise to an industry-level wage that is a sector-specific markup on the marginal product of labour. We adopt this by assuming a sector-specific markup.

and

$$B = \sigma + \psi\left(1 + \kappa\left[\sigma(\psi - \theta) + \gamma^2\kappa(1 - 2\sigma\theta) + \gamma(\sigma(\phi + 2\theta + \kappa(\lambda - \phi - \psi + \theta)) - 2)\right]\right)$$

In a standard calibration[13] coefficients in (1) are: $\alpha_{\chi} = \alpha_{\mu_N} = 0.22,\ \alpha_{a_T} = 0.26,\ \alpha_{a_N} = -0.71,\ \alpha_{(\mu_N - \mu_T)} = 0.33$.

Our model solution preserves the Balassa-Sameulson prediction that traded productivity typically appreciates q (though this sign can change for low values of the elasticity of substitution between Home and Foreign traded goods λ) as shown by Benigno and Thoenissen (2003), while allowing for the additional channels of relative disutility of labour, relative wage markup in non-traded sector, and a relative inter-sectoral wage markup. The effect of the relative non-traded wage markup on q is observationally indistinguishable from the effect due to the disutility of labour, while the relative sectoral markup (of non-traded relative to traded sector) acts to further appreciate the real exchange rate. Because non-traded sectors have historically had higher unionization rates than traded sectors (see Figure 8), we expect this relative-relative markup to be positive in the data, on average.

We use the approach outlined in Berka et al. (2018) to show how we can move from the solution above, which uses unobservable disutility of labour, to the observable unit labour costs. In a special case of our model with no distribution sector nor home bias, and when output is linear in labour, we can show that $q = (1-\gamma)(\tau + a_T^R - a_N^R + \mu_N^R - \mu_T^R)$ where τ is the endogeneous terms of trade. Defining unit labour costs as nominal wage divided by real output and expressing the wage difference using first order conditions in the traded sector ($w - w^* - s = \tau + a_T^R - \mu_T^R$), we can express *relative* unit labour costs as $rulc = \tau + (1-\gamma)a_T^R - (1-\gamma)a_N^R - \mu_T^R$. This allows us to write the real exchange rate in this special case as:

$$q = (1-\gamma)rulc + \gamma(1-\gamma)a_T^R - \gamma(1-\gamma)a_N^R + (1-\gamma)\mu_N^R \qquad (2)$$

In this simplified version of the model, the disutility of labour will enter through unit labour costs. This is also true in the general form of the model, but it cannot be shown in a closed-form solution. In the empirical section which follows, we argue that the institutional differences that result in more rigid labour markets coincide with higher markups and therefore place additional appreciation pressure on real exchange rates beyond the direct effect of the unit labour costs.

[13] Specifically, when $\sigma = 2$, $\kappa = 0.6$ (so that the distribution sector accounts for 40% of retail tradable goods in equilibrium), $\theta = 0.7$, $\gamma = \omega = 0.5$, $\psi = 1$, $\phi = 0.25$ and $\lambda = 8$. We discuss these choices in the Appendix.

4 Empirical Methodology

We estimate the empirical form of (2) using pooled OLS:

$$q_{i,t} = \alpha + \beta a_{T,i,t} + \gamma a_{N,i,t} + \delta oulc_{i,t} + \omega x_{i,t} + \epsilon_{i,t} \tag{3}$$

where $q_{i,t}$ is the logarithm real exchange rate of country i in year t, $a_{T,i,t}$ and $a_{N,i,t}$ are similarly log-differences in traded and nontraded productivity, respectively, $oulc_{i,t}$ is the relative (orthogonalised) unit labour cost of country i, and $x_{i,t}$ is a vector of variables describing institutional characteristics of country's individual labour markets. All variables are bilateral, expressed relative to the US. We also estimate equation (3) with fixed and random effects, both of which chiefly use the time-series variation to estimate slope coefficients:

$$q_{i,t} = \alpha + \beta a_{T,i,t} + \gamma a_{N,i,t} + \delta oulc_{i,t} + \omega x_{i,t} + \eta_i + \epsilon_{i,t} \tag{4}$$

where η_i are cross-sectional country effects. The fixed effect regressions allow for different intercepts which are assumed to be fixed over the sample. The random effects estimation assumes that intercepts can vary across countries, but that intercepts are assumed to be random variables.

Finally, we include results from a cross-sectional regression which uses time-series average values for each country i from a balanced panel:

$$q_i = \alpha + \beta a_{T,i} + \gamma a_{N,i} + \delta oulc_i + \omega x_i + \epsilon_i \tag{5}$$

5 Empirical results

The benchmark results of our estimation of the relationship between relative TFP and real exchange rates (equations 3 and 4) are summarised in Table 4.[14] We begin by allowing traded and nontraded TFP to influence q with different magnitudes, and then proceed by sequentially relaxing additional assumptions: first by adding unit labour costs, and then indicators of labour market institutions as separate determinants of q levels in our panel.

[14] Panel unit root tests do not suggest that these variables are non-stationary over the benchmark sample, and they do not reject the null of no cointegration for our default specification.

In the pool regressions, both a_T and a_N are significant with the expected signs.[15] For traded and nontraded TFP, the elasticity is 0.8 and -0.2 per cent, approximately: a 1 percent improvement in relative traded TFP relative relative to the US appreciates a country's q by around 0.8 percent, while a 1 percent improvement in relative nontraded TFP depreciates q by 0.2 percent. Wald tests reject the null hypothesis that relative traded and nontraded TFP have identical coefficients of opposite signs. In fixed effects regressions for the Balassa-Samuelson model, TFP variables do not have the expected signs. This lack of significant TFP-q comovement in time-series is a common result in the literature, especially for the OECD countries.[16] Random effects regressions broadly mimic the results of fixed-effects, with very similar sizes of the coefficient estimates.[17] In cross-sectional regressions, a_T is highly significant but a_N is not.

We add $OULC$ to our basic model and find it is highly significant in all specifications (columns 6 to 9).[18] This is in line with the predictions of our model, in which relative ULC capture the labour wedge that arises from the differences in the disutility of labour, as seen in equation (2). At the same time, the significance of the nontraded productivity measures declines across specifications, but remains significant at 10% in the fixed- and random-effect regressions. Our results suggests that the unit labour costs are particularly important in explaining the time-series movements of q that are unrelated to TFP, especially in the traded sector. This finding does not depend on adding a measure of institutional rigidity of the labour markets such as $CONC$ (Columns 10 to 13). Since $CONC$ rises in the concentration of the union membership at all levels, our estimates suggest that a more unionized labour markets tend to be associated with more appreciated real exchange rates,

[15] Standard errors for the benchmark panel results are based on period weights, but results are not overly sensitive to the method used to adjust standard errors for heteroskedasticity or serial correlation. Likewise, when using Newey-West standard errors for cross-section, results are qualitatively unchanged.

[16] The literature finds more empirical support for the Balassa-Samuelson hypothesis in cross-section than in the time-series. This suggests that lowering the frequency of our observations could result in more significant regression results. We have constructed 5-year non-overlapping averages of all our variables, but find that our baseline results are unchanged apart from a lack of significance of nontraded TFP in the pooled regression and a lack of significance of $CONC$ across specifications. We conclude that our main results are not driven by higher-frequency movements in the data.

[17] For the benchmark sample, Haussman tests indicate a preference for fixed effects over random effects regression.

[18] We note again that the results are not driven mechanically by the NER variation because this has been removed from the relative ULC measures in process of constructing $OULC$. But even when NER is added to our regressions, $OULC$ stays highly significant.

consistent with our introduction of markups in the model. Likelihood ratio tests indicate that the addition of $CONC$ enhances the fit of the model in pool, fixed effects and random effects regressions. In our regressions, estimates of the constant are the unmodelled constant conditional differences between countries. [19]

To summarise, our results indicate that levels of real exchange rates in high-income OECD countries accord with an augmented Balassa-Samuelson theory after we explicitly consider the levels of sectoral TFP and q. Our results also show that labour market differences orthogonal to productivity are a significant additional driver of real exchange rates both in cross-section and over time, and that their inclusion slightly helps to elicit the Balassa-Sameulson relationship in time-series. Neveretheless, statistically the key additional variable is the $OULC$.

5.1 Conditional real exchange rate deviations

Our finding that Balassa-Samuelson model in its basic and augmented forms can explain real exchange levels both across countries and over time overturns most of the existing empirical results for OECD economies with floating exchange rates. But a question that remains is how much of the real exchange rate deviations are not explained by the TFP and the institutional labour market considerations. To shed light on this issue that is closely related to the idea of misalignment of real exchange rates, we collect the estimates of the fixed effects for all countries from our baseline regression, and use them to construct the average unexplained real exchange rate levels. Table 5 in the Appendix reports these conditional mean values of q by country, together with their unconditional means.

Despite our model's ability to significantly explain a large share of q variation in the data, unexplained q deviations remain for some countries. Average q levels are almost fully explained by the fundamentals of the augmented

[19] A standard Balassa-Samuelson hypothesis, for example as expressed in a general-equilibrium treatment of a small open economy in Obstfeld and Rogoff (1996) eliminates demand factors as drivers of real exchange rates. Consequently, under the null of the Balassa-Samuelson hypothesis, unmodelled factors may include structural factors that affect the perceived riskiness of investment, labour and product market regulatory differences that are orthogonal to TFP, labour market imperfections, and other supply-side factors. It is also possible, but more challenging, to model demand-side factors as permanent drivers of q changes without assuming that preferences are non-homothetic, or that government consumption is concentrated in nontraded sector (for example, Bhagwati (1984), Bergstrand (1991), and others).

Balassa-Samuelson model: in Finland, Germany, and Japan, TFP differences and differences in labour markets account for nearly all of the q deviations. But the conditional q deviations can remain large. In the data, q levels in Hungary and the Czech Republic are on average 89% and 81% below that of the USA, respectively. Conditioning on the structural drivers of our augmented Balassa-Samuelson model lowers, but does not close, these gaps: the unexplained level of conditional q is 60% and 49% below the US for these two countries. In UK and Spain, fundamentals also help to explain some of the unconditional deviations of q from parity.

But there are a number of countries where we observe q become more 'misaligned' after conditioning on their economic fundamentals. Most notably, in New Zealand the mean q is -18% relative to the US, but conditioning on fundamentals raises it to +15%. If we take our regressions as structural, this implies that although the average q is below the US level in the data, New Zealand's fundamentals are so much lower than those in the US that the q is actually 15% above where it should be.[20] Other countries where conditioning on their economic fundamentals results in a larger unexplained conditional q deviations are Australia (2% to 21%), the Netherlands (-4% to +13%), Italy (-3% to +10%) and Denmark (31% to 44%), and to a lesser extent Belgium, France and Austria.

On average, the mean absolute q across all countries does not change before and after we condition on the levels of their economic fundamentals vis-à-vis the US.

Both the basic and augmented models 'over-explain' average q deviations, but the augmented model (one that includes $OULC$ and $CONC$) is better. The standard deviation of the conditional residual q deviations across countries is smaller in the augmented than in the basic model or in the unconditional data (0.26, 0.33, and 0.34, respectively). The average absolute deviation across countries also drops from 0.25 in the basic to 0.21 in the augmented model (same as in the unconditional data). In this sense, both versions of the model 'over-explain' the role of the fundamentals for 15 out of 17 countries, but the augmented model less so. Our results suggest that the model misses an important time-invariant determinants of real exchange rate levels.

[20] This reflects New Zealand's traded TFP being well below the US levels, while the non-traded TFP on average being slightly higher than that in the US. Likewise, New Zealand's unit labour costs are the fifth lowest in our sample, while $CONC$ is third highest relative to the U.S.

5.2 Robustness

5.2.1 Testing relative sectoral TFP

Most papers test a basic Balassa-Samuelson specification assuming that only relative sectoral TFP matters for q. Table 6 shows that relative traded-to-nontraded TFP $a_T - a_N$ is highly significant in pool and cross-section, but is only significant in fixed- and random effects models when controlling for unit labour costs and labour market differences.[21] Additional robustness tests are provided in Appendix D, which gives a summary of the impacts by varying the sample, data definitions and the aggregation approaches used.

Table 12 shows that there is a robust positive relationship between relative sectoral TFP and real exchange rates in OECD economies across samples, datasets and specifications. Moreover, in both pool and cross-section, Balassa-Samuelson prediction is not conditional on controlling for the differences in labour market institutions. However, omission of structural labour market differences causes the standard model estimates to be biased upwards in pool and cross-section regressions (see also Table 12 in the Appendix).[22]

5.2.2 Alternative measures of labour market institutions

Several labour market indicators are highly significant in explaining q, suggesting that different types of labour market institutions may contribute to differences in real exchange rates that are orthogonal to productivity. Table 7 provides a summary of coefficient estimates across different labour market institutional variables. Many are significant when added to the benchmark model in a pooled regression. However, the only variables that are significant in both fixed- and random effect specifications are $CONC$, EPT, RR, the average of four indicators ($LAB4avg$) and the first principal component of all the indicators ($LABPC$). None of the indicators are significant in the cross-section, however. Contrary to expectation, EPR and EPT indicators have negative coefficients, although these turn positive if $OULC$ is dropped from the model.

[21] Inclusion of country slope dummies does not alters the estimated impact of TFP on q, on average: we cannot reject the assumption of a common slope.

[22] Table 12 also identifies that Balassa-Samuelson hypothesis is rejected when the non-tradables sector category excludes real estate, renting and business services industries, and when the manufacturing industry alone is used to represent the tradables sector (both for the unbalanced panel).

5.2.3 Inclusion of terms of trade differentials

As Benigno and Thoenissen (2003) and Fitzgerald (2003) show, when countries produce different tradable goods, q in the model is part-driven by an endogenous terms-of-trade effect which runs counter to the Balassa-Samuelson effect. The net effect then depends on the elasticity of substitution between home and foreign tradables. Our model incorporates this possibility. Table 8 shows that adding relative terms of trade to the benchmark model preserves the highly significant coefficient estimates in all specifications except two of the cross-sectional regressions. The only difference is that, in the cross-sectional regression, traded productivity is no longer significant after the addition of TOT.

5.2.4 Inclusion of long-run interest rate differentials

There are theories that, unlike Balassa-Samuelson, argue that aggregate demand considerations can influence real exchange rates (for an overview, see Froot and Rogoff 1995). Bergstrand (1991) shows that with nonhomothetic preferences, increases in demand appreciate q. Gregorio et al. (1994), Chinn and Johnson (1996) and others suppose that concentration of government expenditures in nontraded sector gives a channel for the aggregate demand to influence the real exchange rate. To study the extent to which demand considerations may influence our results, we add long-run real interest rate differentials ($RIRDIFF$) into our regressions. A decrease in real interest rates at home, *ceteris paribus*, may increase demand and hence appreciate the real exchange rate. Table 9 shows that the inclusion of an interest rate differential does not change our baseline results. In the pool regression, there is a negligible change in coefficient sizes and no change in their significance, while the $RIRDIFF$ has a positive and significant sign. Qualitatively, these results carry through in the fixed- and random-effect regressions, and are in line with the findings in Berka et al. 2018). We conclude that our standard coefficient estimates remain unaffected by the addition of this demand-side variable.

6 Conclusion

We evaluate an augmented Balassa-Samuelson hypothesis using a newly constructed panel dataset of levels of sectoral TFP, as well as a panel of real exchange rate levels for 17 OECD countries between 1970 and 2012. We find that the Balassa-Samuelson mechanism is present, especially after we control for differences in labour market institutions and unit labour costs. We augment the model in Berka et al. (2018) for sectoral differences in firms' markups, as in Galí et al. (2007) and Karabarbounis (2014), and show that it implies the need to add measures of institutional labour market differences and unit labour costs to the empirical framework used to test the Balassa-Samuelson hypothesis.

We confirm that the standard model does not always explain relative price differences and their changes over time. However, the addition of labour market institutional differences and unit labour costs improves the fit of a Balassa-Samuelson model. This is in line with the findings in Berka et al. (2018), but their study only included the eurozone member states. We conclude by noting that there remain large unexplained deviations in real exchange rates across countries after conditioning for structural determinants of real exchange rates. In a number of countries, these conditional deviations are even larger than the unconditional real exchange rate deviations.

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A Appendix

Table 1: Summary statistics: average levels (Unbalanced panel)

Country	Sample	$\overline{a_T}$	$\overline{a_N}$	$\overline{a_T - a_N}$	$\overline{q}$	$\overline{oulc}$	$\overline{conc}$	$\overline{tot}$	$\overline{rirdiff}$
AUS	1983-2010	-0.06	-0.09	0.02	0.03	-0.35	0.21	0.00	1.03
AUT	1990-2009	-0.48	-0.21	-0.27	0.06	-0.05	0.60	0.08	0.60
BEL	1995-2010	0.02	-0.18	0.20	0.05	-0.10	-0.03	0.10	0.44
CZE	1995-2007	-0.71	-0.43	-0.27	-0.81	-0.53	0.25	0.11	0.30
DNK	1990-2007	-0.28	-0.03	-0.25	0.31	-0.16	-0.03	0.07	1.22
ESP	1980-2009	-0.26	-0.15	-0.11	-0.18	-0.23	-0.33	0.09	0.08
FIN	1975-2010	-0.16	-0.17	0.01	0.25	-0.01	-0.18	0.10	1.64
FRA	1980-2009	-0.14	-0.23	0.10	0.07	-0.06	-0.96	0.06	0.50
GER	1991-2009	-0.07	-0.17	0.10	0.01	-0.02	0.34	0.05	0.41
HUN	1995-2007	-0.72	-0.26	-0.45	-0.89	-0.32	-0.64	0.13	-1.53
IRE	1988-2007	0.15	-0.06	0.21	0.11	-0.28	0.56	0.08	0.35
ITA	1972-2009	-0.14	0.01	-0.15	-0.05	-0.20	-0.39	0.05	-0.29
JPN	1973-2009	-0.34	-0.53	0.19	0.14	-0.16	-0.28	0.05	-1.08
NLD	1988-2009	0.18	0.14	0.04	0.07	-0.16	0.05	0.03	0.54
NZL	1996-2010	-0.36	0.10	-0.46	-0.15	-0.41	0.35	0.10	1.61
SWE	1993-2010	-0.13	0.00	-0.14	0.26	-0.01	-0.06	0.10	1.46
UK	1972-2009	-0.13	-0.23	0.10	0.18	0.03	0.34	0.04	0.07

Each variable x is in logarithmic form (except real interest rates which are in levels), expressed as a bilateral difference of country i value minus the US value. A $\overline{x}$ represents a time-series average. a_T is the traded TFP, a_N is the non-traded TFP, q is the real exchange rate, $oulc$ is the orthogonalised bilateral unit labour cost difference, $CONC$ is a measure of the centralization of wage bargaining, expressed as the log difference relative to the US, TOT is export over import price *levels* expressed relative to the US, $RIRDIFF$ is real long run interest rate differentials to the US.

Table 2: Summary statistics: time-series volatility (Unbalanced panel)

Country	Sample	$s(a_T)$	$s(a_N)$	$s(a_T\text{-}a_N)$	$s(q)$	$s(oulc)$	$s(conc)$	$s(tot)$	$s(rirdiff)$
AUS	1983-2010	0.13	0.03	0.15	0.14	0.24	0.16	0.07	1.71
AUT	1990-2009	0.06	0.02	0.05	0.13	0.27	0.22	0.03	0.65
BEL	1995-2010	0.08	0.05	0.04	0.15	0.14	0.25	0.03	0.59
CZE	1995-2007	0.08	0.06	0.06	0.19	0.28	0.14	0.04	1.35
DNK	1990-2007	0.12	0.03	0.10	0.12	0.13	0.17	0.03	1.56
ESP	1980-2009	0.14	0.10	0.05	0.19	0.45	0.21	0.07	2.34
FIN	1975-2010	0.16	0.08	0.10	0.16	0.26	0.21	0.06	1.69
FRA	1980-2009	0.06	0.03	0.07	0.15	0.19	0.19	0.05	1.67
GER	1991-2009	0.06	0.03	0.06	0.13	0.24	0.24	0.03	0.80
HUN	1995-2007	0.05	0.02	0.05	0.20	0.43	0.21	0.04	2.74
IRE	1988-2007	0.08	0.07	0.10	0.13	0.29	0.18	0.05	2.05
ITA	1972-2009	0.14	0.11	0.13	0.14	0.32	0.18	0.05	2.67
JPN	1973-2009	0.13	0.08	0.16	0.20	0.33	0.20	0.11	2.48
NLD	1988-2009	0.11	0.03	0.12	0.12	0.17	0.25	0.03	1.29
NZL	1996-2010	0.05	0.02	0.05	0.19	0.37	0.35	0.04	0.97
SWE	1993-2010	0.11	0.03	0.09	0.13	0.17	0.20	0.04	1.26
UK	1972-2009	0.06	0.05	0.09	0.11	0.32	0.20	0.08	2.30

$s(x)$ represents a the time-series standard deviation of variable x in country i (which has been expressed as a bilateral difference of country i value minus the US value).

Table 3: Summary statistics: average growth rates (Unbalanced panel)

Country	Sample	$g(a_T)$	$g(a_N)$	$g(a_T$-$a_N)$	$g(q)$	$g(oulc)$
AUS	1983-2010	-1.18	0.06	-1.24	0.87	1.41
AUT	1990-2009	0.24	0.30	-0.06	0.17	-1.34
BEL	1995-2010	-1.38	-1.14	-0.25	-0.69	-0.43
CZE	1995-2007	0.30	-0.71	1.02	3.84	6.85
DNK	1990-2007	-1.90	-0.07	-1.83	0.06	0.02
ESP	1980-2009	-1.10	-0.85	-0.25	0.17	0.76
FIN	1975-2010	1.17	0.55	0.62	-0.34	-0.11
FRA	1980-2009	-0.46	0.18	-0.64	-0.50	-0.61
GER	1991-2009	-2.04	-0.33	-1.71	0.37	1.98
HUN	1995-2007	1.02	0.53	0.48	3.50	7.04
IRE	1988-2007	0.22	1.24	-1.01	0.80	2.83
ITA	1972-2009	0.00	-1.15	1.17	0.43	1.54
JPN	1973-2009	0.48	-1.20	1.70	1.11	0.02
NLD	1988-2009	-0.83	0.27	-1.10	0.36	0.78
NZL	1996-2010	-1.07	-0.31	-0.77	0.20	2.22
SWE	1993-2010	1.99	0.42	1.57	-0.69	-0.16
UK	1972-2009	0.28	-0.49	0.77	0.09	1.58

$g(x)$ represents the compound average annual growth rate of variable x, in %. Each variable x in country i has been expressed as a bilateral difference of country i value minus the US value. a_T is the Traded TFP, a_N is the non-traded TFP, q is the real exchange rate, *oulc* is the orthogonalised bilateral unit labour cost difference.

Figure 1: TFP levels (relative to US, log)

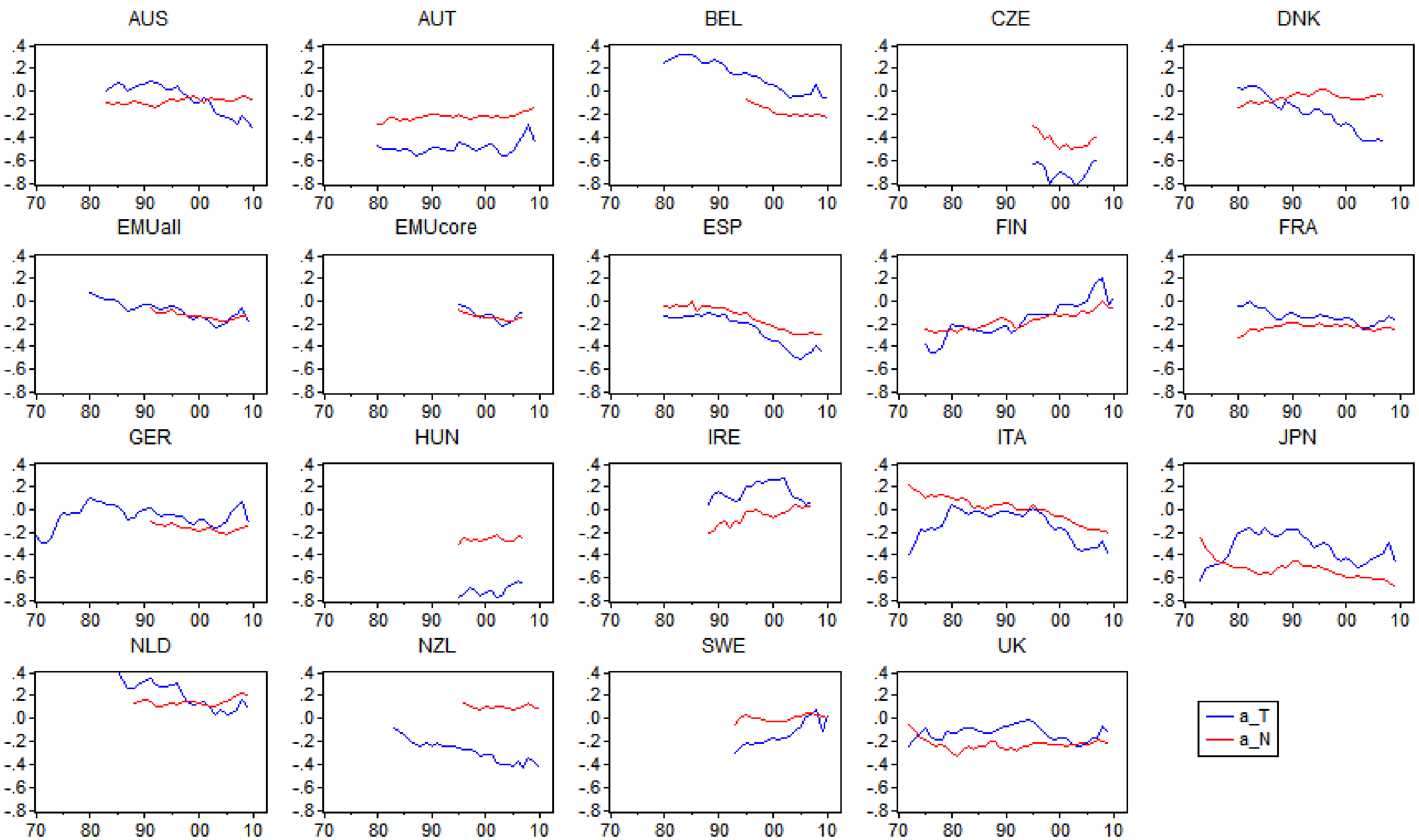


Figure 2: Levels of orthogonalized ULC ($OULC$) and ULC (relative to US, log)

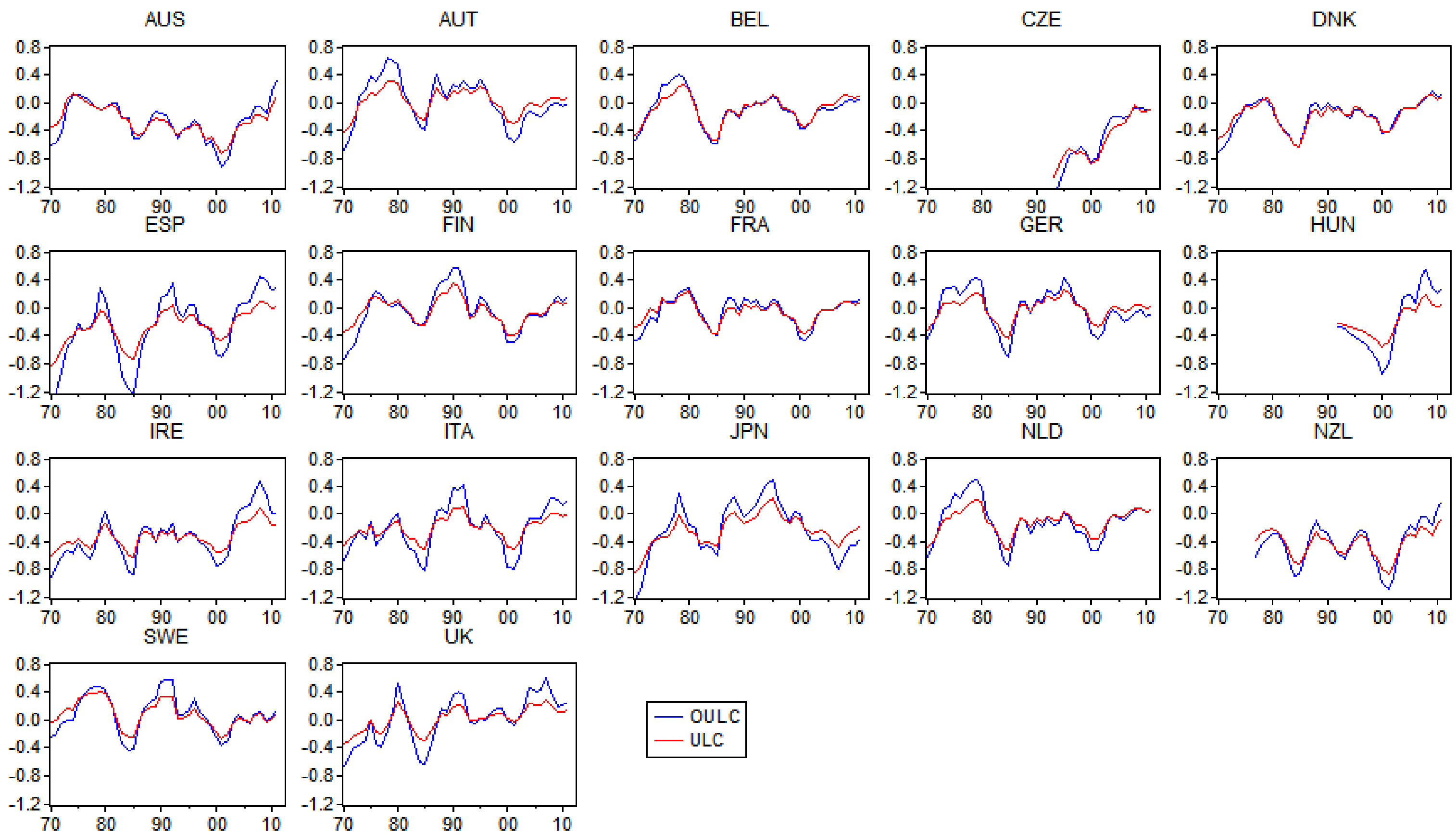


Figure 3: Levels of real exchange rates, orthogonalized ULCs and terms of trade (relative to US, logs)

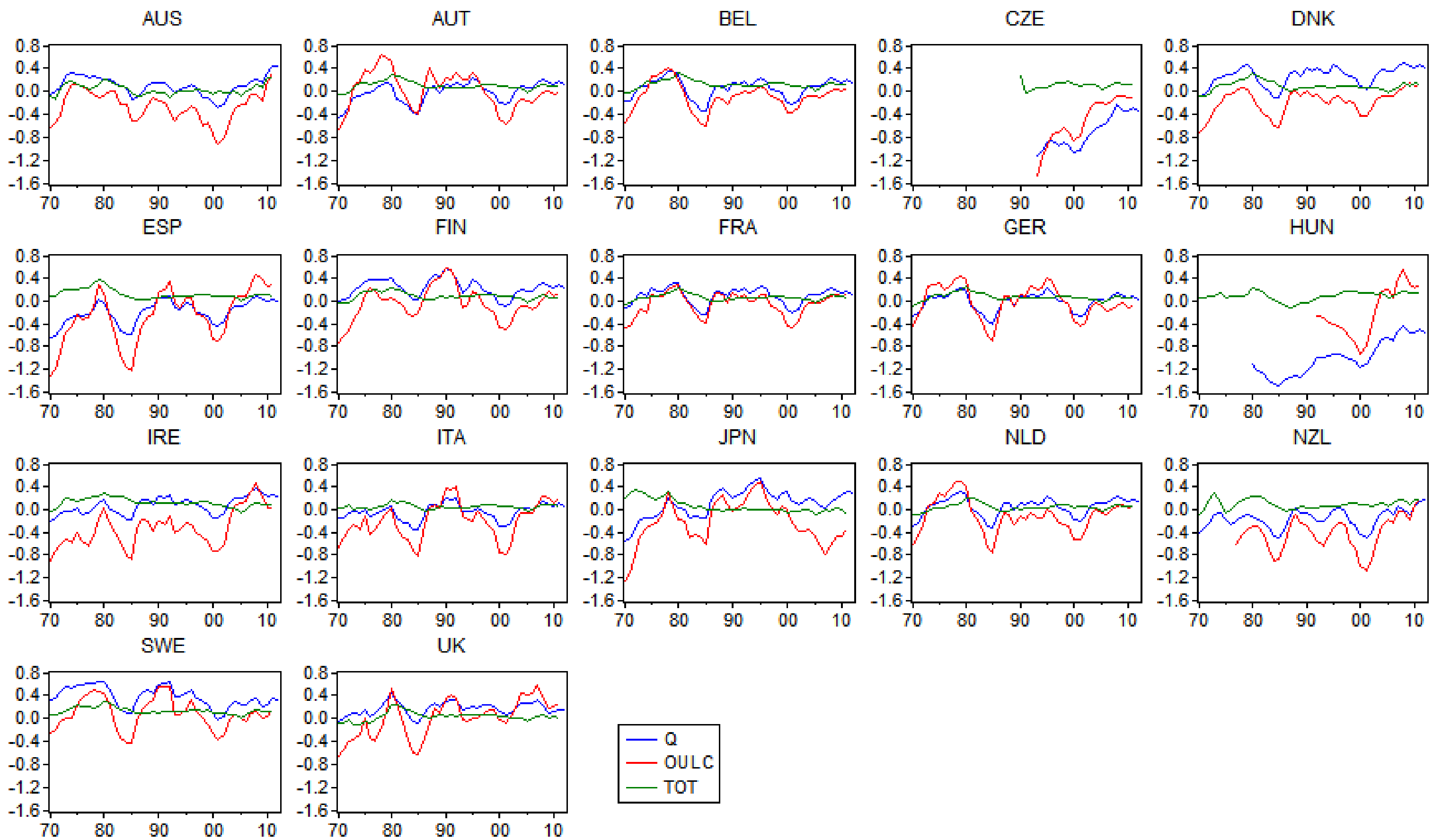
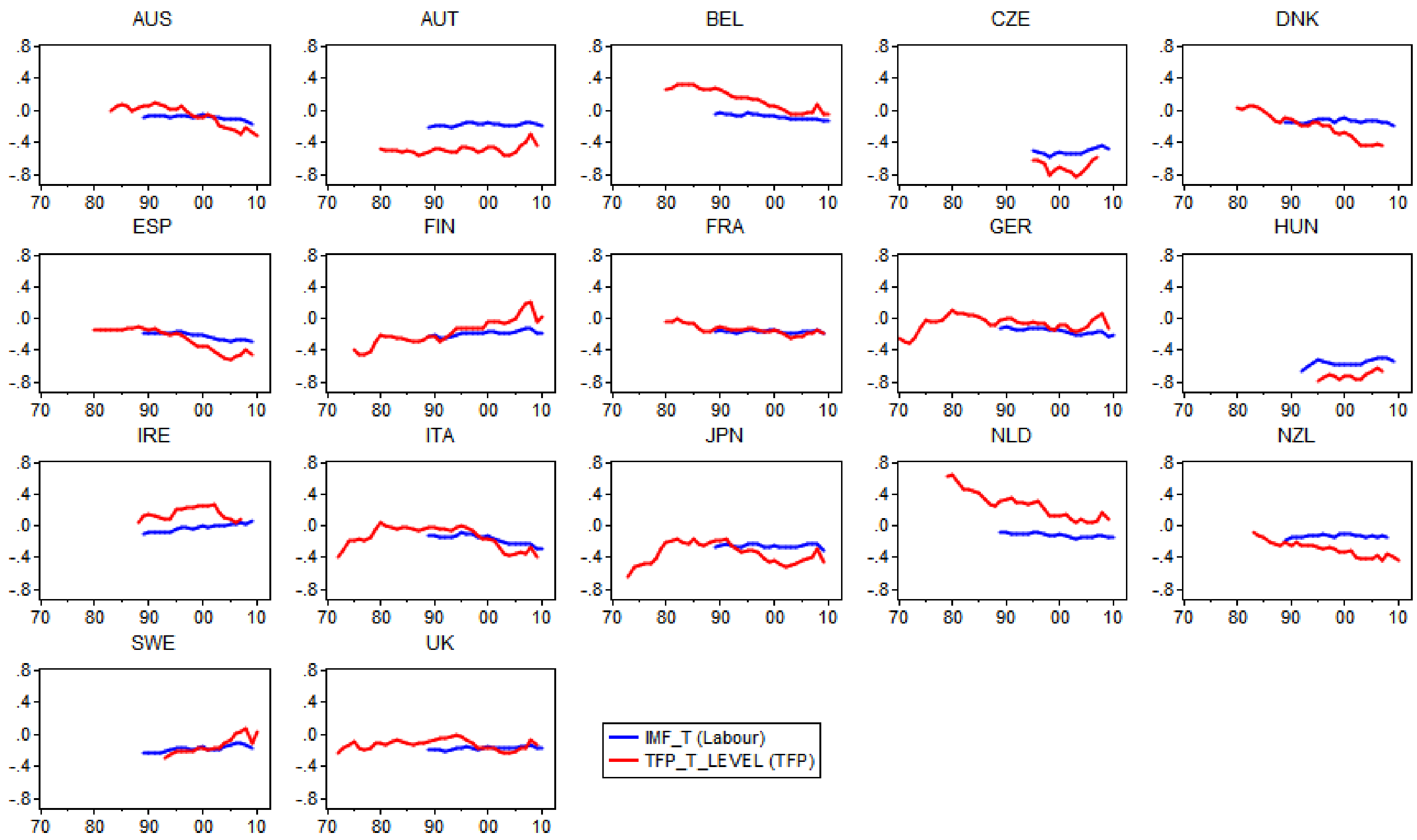
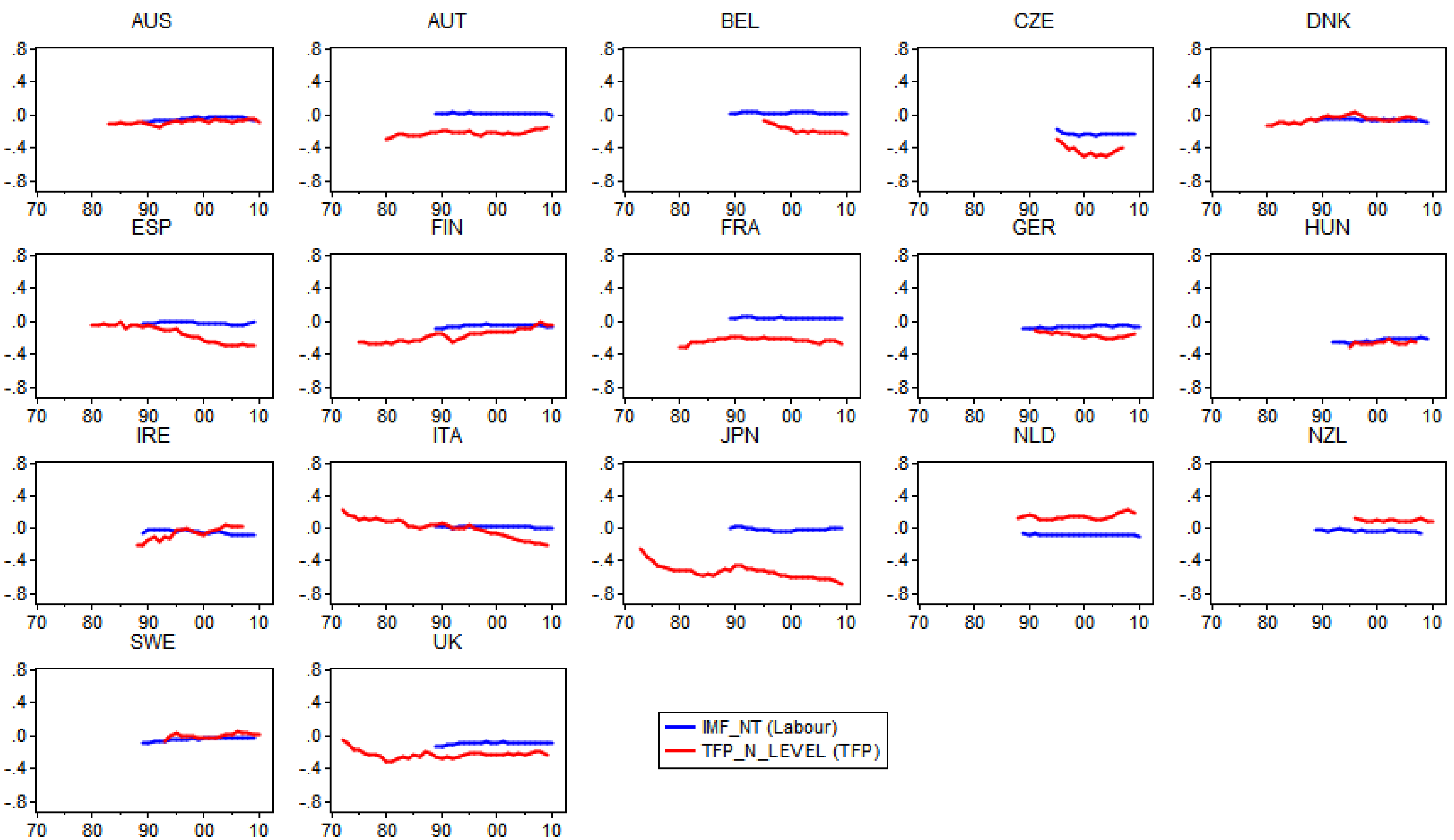


Figure 4: Labour productivity vs TFP (Tradable levels, relative to US)



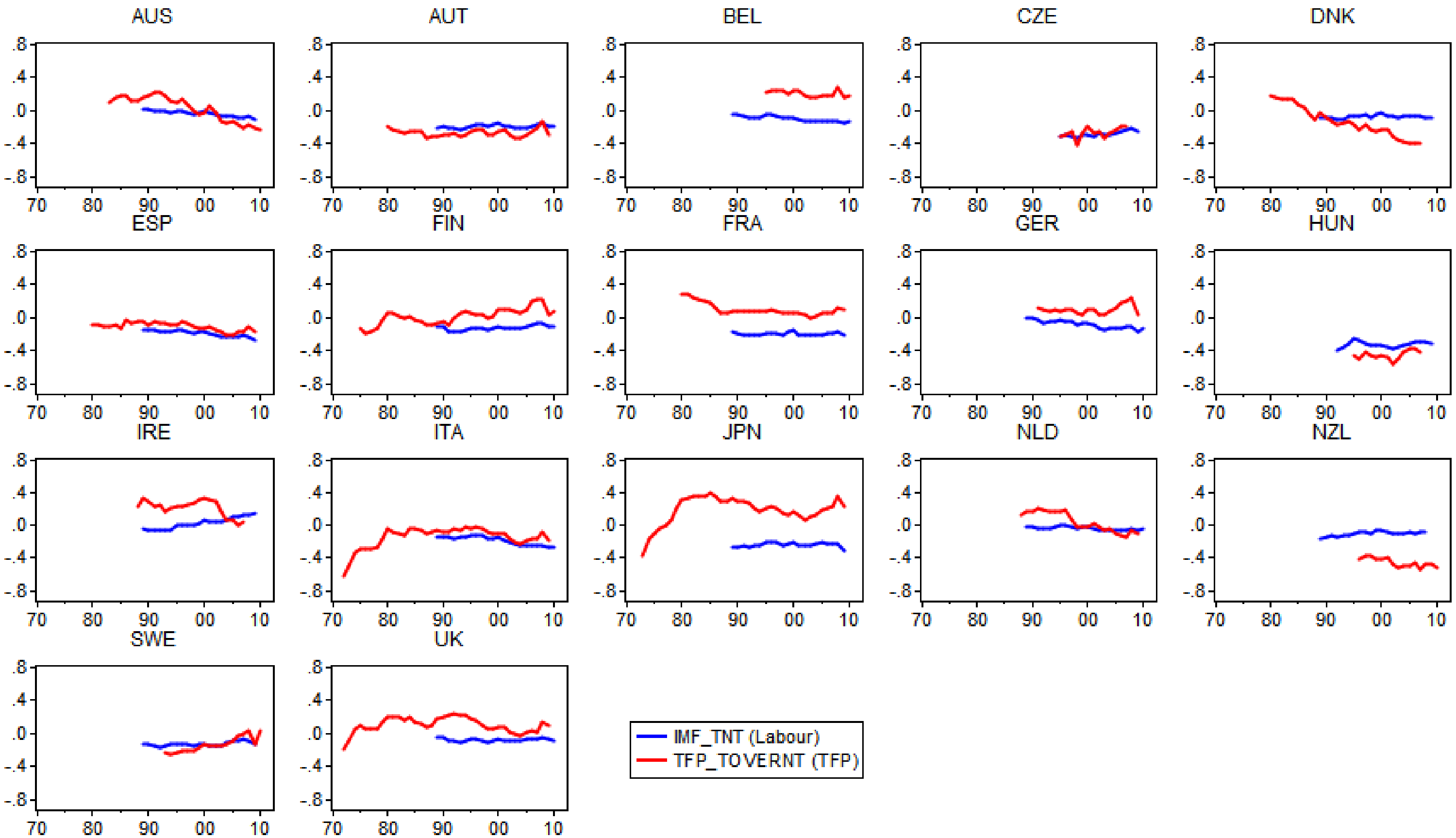
Source: Mano and Castillo (2015) and author's calculations

Figure 5: Labour productivity vs TFP (Non-Tradable levels, relative to US)



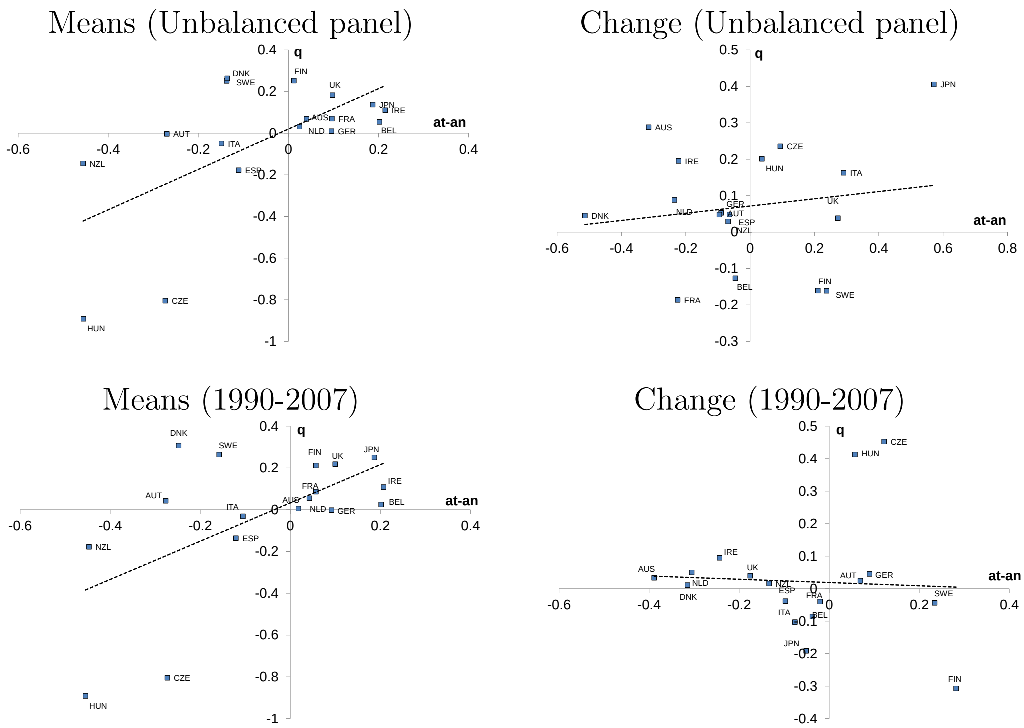
Source: Mano and Castillo (2015) and author's calculations

Figure 6: Labour productivity vs TFP (Tradable-to-non-tradable levels, relative to US)



Source: Mano and Castillo (2015) and author's calculations

Figure 7: Real exchange rate and cross-country productivity ratios



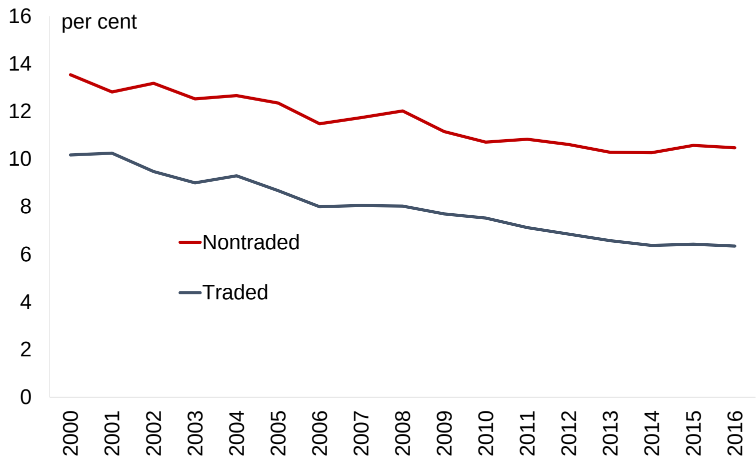
Note: All variables specified in log deviations from US levels. q is the bilateral real exchange rate in levels against the US based on aggregate CPI, a_T and a_N traded and non-traded TFP levels relative to the US. See Table 10 for country samples in the unbalanced panel.

Table 4: q - TFP regressions (1990-2007)

	Basic model				Berka et al (2018) model				Augmented model			
	Pool	**FE**	**RE**	**XS**	**Pool**	**FE**	**RE**	**XS**	**Pool**	**FE**	**RE**	**XS**
a_T	0.78***	−0.03	0.10	0.99***	0.62***	0.17***	0.19***	0.64**	0.62***	0.19***	0.20***	0.62*
s.e.	0.08	0.11	0.1	0.3	0.06	0.04	0.04	0.29	0.06	0.04	0.04	0.3
a_N	−0.23**	0.67***	0.50**	-0.28	−0.07	−0.17*	−0.15*	-0.1	−0.09	−0.17*	−0.16*	-0.08
s.e.	0.12	0.23	0.2	0.46	0.09	0.09	0.09	0.42	0.09	0.09	0.08	0.42
OULC					0.59***	0.50***	0.50***	0.85**	0.60***	0.50***	0.50***	0.88**
s.e.					0.04	0.01	0.01	0.33	0.04	0.01	0.01	0.35
CONC									0.06**	0.06***	0.06***	0.08
s.e.									0.03	0.02	0.02	0.14
$Wald: \beta = -\gamma$	R***	R***	R***	R*	R***	N	N	R**	R***	N	N	R*
LR	R***	R***	R***	R**	R***	R***	R***	N	-	-	-	-
observations	281	281	281	17	281	281	281	17	281	281	281	17

Dependant variable: q is log real exchange rate using aggregate CPI expressed as country i relative to the US. a_i is the log of TFP level of traded relative to non-traded sector in country i ($a_{T,i,t} - a_{N,i,t}$) relative to the US. $a_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors using sectoral outputs as weights. $a_{N,i,t}$ is a TFP aggregation of non-traded sectors. $OULC_{it}$ is orthogonalized relative unit labour costs calculated as are the residuals of a relative ULC regression on nominal exchange rate (expressed at the correct average level). x proxied using $CONC$, defined as the centralization of wage bargaining (weighting of sectoral and aggregate), specified as up for a more centralised labour market. 'Pool' is a pooled regression with all countries and periods sharing the same estimate of a constant and a slope. 'FE' is a fixed effect regression with countries as cross-sections. 'RE' is a random effects panel with countries as cross sections. 'XS' is a regression which uses the time-average value for each country and runs a cross sectional regression. Standard errors are in parentheses. The estimate of the constant is not reported. 'R' denotes rejection of the null and 'N' non-rejection. A * denotes a 10%, ** 5% and *** 1% significance. The Wald test is based on equation (5). The null for the likelihood ratio (LR) test is that the coefficient of the additional regressor (i.e. $OULC$ or $CONC$) is zero.

Figure 8: Traded and Non-Traded average unionization rates in the US



Source: BLS `https://www.bls.gov/webapps/legacy/cpslutab3.htm`

Table 5: Average unexplained real exchange rate levels

	Basic model	**Augmented model**	**Unconditional** q
AUS	0.06	0.21	0.02
AUT	0.17	0.10	0.02
BEL	0.14	0.06	-0.06
CZE	-0.54	-0.49	-0.81
DNK	0.32	0.44	0.31
ESP	-0.02	-0.03	-0.14
FIN	0.31	0.24	0.21
FRA	0.23	0.17	0.09
GER	0.11	-0.02	0.00
HUN	-0.74	-0.60	-0.89
IRE	0.14	0.18	0.11
ITA	0.00	0.10	-0.03
JPN	0.61	0.29	0.25
NLD	-0.03	0.13	-0.04
NZL	-0.25	0.15	-0.18
SWE	0.26	0.31	0.26
UK	0.37	0.09	0.22
Average (absolute)	0.25	0.21	0.21

The figure reports total fixed effect estimates from the benchmark specification in Table 4 for the sample 1990-2007. Each number represents the sum of the constant and the fixed effect estimates for a given country.

Table 6: Robustness to use of relative TFP measure (1990-2007)

	Pool		**FE**		**RE**		**XS**	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
$a_T - a_N$	0.73***	0.57***	0.01	0.20***	0.12	0.20***	0.92**	0.54
s.e.	0.08	0.06	0.11	0.04	0.10	0.04	0.33	0.34
OULC		0.60***		0.50***		0.50***		0.89**
s.e.		0.04		0.01		0.01		0.39
CONC		0.09**		0.06***		0.06***		0.13
s.e.		0.03		0.02		0.02		0.15
observations	281	281	281	281	281	281	17	17

Dependant variable: q is log real exchange rate using aggregate CPI expressed as country i relative to the US. a_i is the log of TFP level of traded relative to non-traded sector in country i ($a_{T,i,t} - a_{N,i,t}$) relative to the US. $OULC_{it}$ is orthogonalized relative unit labour costs calculated as are the residuals of a relative ULC regression on nominal exchange rate (expressed at the correct average level). x proxied using $CONC$, defined as the centralization of wage bargaining (weighting of sectoral and aggregate), specified as up for a more centralised labour market. The estimate of the constant is not reported.

Table 7: Coefficient estimates of selected labour indicators in the benchmark specification (1990-2007)

	CONC	**AUTH**	**CENT**	**UD**	**EPR**	**EPT**	**RR**	**labavg4**	**labpc**
Pool	0.06**	0.06**	0.07***	0.11***	-0.15***	-0.01	0.03*	0.058**	0.07**
FE	0.06***	-0.05	0.01	0.00	-0.06	-0.03**	0.04**	0.06***	0.08***
RE	0.06***	-0.03	0.01	0.02	-0.07*	-0.03**	0.04***	0.06***	0.08***
XS	0.08	0.02	0.07	0.10	-0.17	0.00	0.07	0.08	-0.03

A * denotes a 10%, ** 5% and *** 1% significance when one labour market indicator is added to the benchmark specification from Table 4. 'Pool' is a pooled regression with all countries and periods sharing the same estimate of a constant and a slope. 'FE' is a fixed effect regression with countries as cross-sections. 'RE' is a random effects panel with countries as cross sections. 'XS' is a regression which uses the time-average value for each country and runs a cross sectional regression. Standard errors are in parentheses.

Table 8: Robustness of q-TFP regressions to adding terms of trade

	Pool			FE			RE			XS		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
$a_T - a_N$	0.52***			0.22***			0.23***			0.25		
s.e.	0.07			0.04			0.04			0.37		
a_T		0.58***	0.81***		0.22***	0.27***		0.23***	0.34***		0.32	0.71*
s.e.		0.06	0.08		0.04	0.10		0.04	0.09		0.32	0.35
a_N		-0.07	−0.25***		−0.20**	0.09		−0.19**	0.06		0.40	0.02
s.e.		0.09	0.12		0.09	0.20		0.09	0.18		0.42	0.48
OULC	0.64***	0.64***		0.48***	0.47***		0.48***	0.47***		0.90**	0.90**	
s.e.	0.05	0.04	’	0.02	0.02		0.02	0.02		0.37	0.32	
CONC	0.09***	0.06**		0.051***	0.06***		0.06***	0.06***		0.15	0.09	
s.e.	0.03	0.03		0.02	0.02		0.02	0.02		0.15	0.13	
TOT	−1.42**	−1.20**	1.47***	0.39***	0.39**	3.33***	0.38***	0.38**	3.33***	-2.76	−2.85*	-2.72
s.e.	0.56	0.52	0.53	0.17	0.17	0.30	0.17	0.17	0.30	1.77	1.52	1.84
observations	281	281	281	281	281	281	281	281	17	17	17	17

Dependant variable: q is log real exchange rate using aggregate CPI expressed as country i relative to the US. a_i is the log of TFP level of traded relative to non-traded sector in country i ($a_{T,i,t} - a_{N,i,t}$) relative to the US. $a_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors using sectoral outputs as weights. $a_{N,i,t}$ is a TFP aggregation of nontraded sectors. $OULC_{it}$ is orthogonalized relative unit labour costs calculated as are the residuals of a relative ULC regression on nominal exchange rate (expressed at the correct average level). TOT is export over import price *levels* expressed in logs relative to the US. The data sample is 1990-2007 (see Table 10). 'Pool' is a pooled regression with all countries and periods sharing the same estimate of a constant and a slope. 'Fixed effects' is a panel regression with countries as cross-sections. 'Random effects' is a random effects panel with countries as cross sections. 'Cross-section' is a regression which uses the time-average value for each country and runs a cross sectional regression. Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance.

Table 9: Robustness of q-TFP regressions to the inclusion of rate differential

	Pool		FE		RE		XS	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
$a_T - a_N$	0.47***		0.15***		0.17***		0.54*	
s.e.	0.06		0.04		0.04		0.28	
a_T		0.51***		0.15***		0.17***		0.58*
s.e.		0.06		0.04		0.04		0.28
a_N		−0.18**		−0.18**		−0.17*		-0.24
s.e.		0.09		0.09		0.09		0.44
OULC	0.46***	0.49***	0.48***	0.48***	0.48***	0.48***	0.80**	0.81**
s.e.	0.04	0.04	0.01	0.01	0.01	0.01	0.32	0.33
CONC	0.08***	0.06**	0.06***	0.06***	0.06***	0.06***	0.08	0.07
s.e.	0.03	0.03	0.02	0.02	0.02	0.02	0.13	0.13
RIRDIFF	0.04***	0.03***	0.01***	0.01***	0.01***	0.01***	0.15**	0.12
s.e.	0.01	0.01	0.00	0.00	0.00	0.00	0.06	0.07
observations	272	272	272	272	272	272	17	17

Dependant variable: q is log real exchange rate using aggregate CPI expressed as country i relative to the US. a_i is the log of TFP level of traded relative to non-traded sector in country i ($a_{T,i,t} - a_{N,i,t}$) relative to the US. $a_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors using sectoral outputs as weights. $a_{N,i,t}$ is a TFP aggregation of nontraded sectors. $OULC_{it}$ is orthogonalized relative unit labour costs calculated as are the residuals of a relative ULC regression on nominal exchange rate (expressed at the correct average level). TOT is export over import price *levels* expressed in logs relative to the US. $RIRDIFF$ is real long run interest rate differentials to the US. The data sample is 1990-2007 (see Table 10). 'Pool' is a pooled regression with all countries and periods sharing the same estimate of a constant and a slope. 'FE' is a fixed effects regression with countries as cross-sections. 'RE' is a random effects panel with countries as cross sections. 'XS' is a regression which uses the time-average value for each country and runs a cross sectional regression. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance.

B Data Appendix

Table 10: Time series used

Country	Series	Main source	Start	End
Australia	TFP	Australian Bureau of Statistics (2014b)	1983	2012
	GVA	Australian Bureau of Statistics (2014a)[23]	1971	2012
	CPI_G and CPI_S	Haver (ANZ)	1998	2012
Austria	TFP	EUKLEMS(Rev.4,July 2012)	1980	2009
	GVA	EUKLEMS(Rev.4,July 2012)	1970	2010
	CPI_G and CPI_S	Haver (EUDATA)	1998	2012
Belgium	TFP	EUKLEMS(Rev.4,December 2012)	1970	2011
	GVA	EUKLEMS(Rev.4,December 2013)	1970	2011
	CPI_G and CPI_S	Haver (EUDATA)	1991	2011
Czech Republic	TFP	EUKLEMS(Rev.3,March 2011)	1995	2007
	GVA	EUKLEMS(Rev.3,March 2011)	1995	2007
	CPI_G and CPI_S	Haver (EUDATA)	1999	2012
Denmark	TFP	EUKLEMS(Rev.3,March 2011)	1980	2007
	GVA	EUKLEMS(Rev.3,March 2011)	1970	2007
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
Finland	TFP	EUKLEMS(Rev.4,December 2013)	1975	2012
	GVA	EUKLEMS(Rev.4,December 2013)	1975	2012
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
France	TFP	EUKLEMS(Rev.4,July 2012)	1980	2009
	GVA	EUKLEMS(Rev.4,July 2012)	1970	2010
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
Germany	TFP	EUKLEMS(Rev.4,October 2012)	1970	2009
	GVA	EUKLEMS(Rev.4,October 2012)	1970	2010
	CPI_G and CPI_S	Haver (EUDATA)	1995	2012
Hungary	TFP	EUKLEMS(Rev.3,March 2011)	1995	2007
	GVA	EUKLEMS(Rev.3,March 2011)	1991	2007
	CPI_G and CPI_S	Haver (EUDATA)	2000	2012
Ireland	TFP	EUKLEMS(Rev.3,March 2011)	1988	2007
	GVA	EUKLEMS(Rev.3,March 2011)	1970	2007
	CPI_G and CPI_S	Haver (EUDATA)	1995	2012
Italy	TFP	EUKLEMS(Rev.4,October 2012)	1972	2010
	GVA	EUKLEMS(Rev.4,October 2012)	1970	2010
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
Japan	TFP	EUKLEMS(Rev.4,May 2013)	1973	2009
	GVA	EUKLEMS(Rev.4,May 2013)	1973	2009

[23] Backdated using EUKLEMS(Rev.3,March 2011).

Table 10: Time series used

Country	Series	Main source	Start	End
	CPI_G and CPI_S	Statistics Japan (2015)	1970	2012
Netherlands	TFP	EUKLEMS(Rev.4,November 2012)	1970	2009
	GVA	EUKLEMS(Rev.4,November 2012)	1970	2011
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
New Zealand	TFP	Statistics New Zealand (2013)	1978	2012
	GVA	Statistics New Zealand (2014)	1972	2012
	CPI_G and CPI_S	Haver (ANZ)	1988	2012
Spain	TFP	EUKLEMS(Rev.4,July 2012)	1980	2009
	GVA	EUKLEMS(Rev.4,July 2012)	1970	2009
	CPI_G and CPI_S	Haver (EUDATA)	1992	2012
Sweden	TFP	EUKLEMS(Rev.4,December 2013)	1993	2011
	GVA	EUKLEMS(Rev.4,December 2013)	1993	2011
	CPI_G and CPI_S	Haver (EUDATA)	1990	2012
United Kingdom	TFP	EUKLEMS(Rev.4,October 2012)	1972	2009
	GVA	EUKLEMS(Rev.4,October 2012)	1970	2010
	CPI_G and CPI_S	Haver (EUDATA)	1995	2012
United States	TFP	WorldKLEMS(April 2013 update)	1970	2010
	GVA	WorldKLEMS(April 2013 update)	1970	2010
	CPI_G and CPI_S	Haver (USECON)	1970	2012
All countries	$CPI_{Aggregate}$	OECD (CPI: All groups), except Japan from Haver (G10 database)	1970	2012
	$RIRDIFF_{i,t}$	Bloomberg (generic 10Y government bonds)[24] and Haver (CPI: All items (year on year percentage change)	1970[25]	2012
	ULC	OECD (2015b), except OECD (2015a) and series SUNZZZI from SNZ for NZ.	1970[26]	2012[27]
	Exchange rates	IMF (IFS)	1970[28]	2012[29]
	EPRC, EPR, EPT	OECD Indicators of Employment Protection (version 1)	1985	2012[30]
	AUTH, CONC, CENT, UD, AdjCov	Visser (2013)	1970	2011
	RR	Gnocchi et al. (2015)	1970	2008[31]

[24] Except for the Czech Republic and Hungary for which rates are based on the series CZGB10YR and GHGB10YR.
[25] Cze data starts in 2000, 1999 for HUN, EMU starts in 1997.
[26] 1990 for NZ, 1992 for CZE,HUN.
[27] 2011 for the US, JPN, AUS.
[28] 1993 for the Czech Republic, 1995 for Russia.
[29] 2011 for the US, Japan, Australia.
[30] CZE only starts in 1993, HUN and NZL from 1990.
[31] No data for CZE, HUN, FIN, ITA, SWE only to 2003, NETH to 2007.

Table 11: Cross section data used

Series	Data Source	Description	Industry coverage
TFP levels, 1997	GGDC (EU KLEMS Growth and Productivity Accounts (2014))	Multifactor productivity (value added based, double deflated)	48 industry categories
Gross value added levels, 1997	GGDC (EU KLEMS Growth and Productivity Accounts (2014))	Gross value added at current basic prices	48 industry categories
Consumer expenditure shares, 2011	ICP (The World Bank (2011))	Expenditure shares (GDP = 100)	13 expenditure categories
Consumer PPPs, 2011	ICP (The World Bank (2011))	PPPs (USD=1) by category	13 expenditure categories
CPI PPPs, 2011	ICP (The World Bank (2011))	PPP (USD=1) for actual individual consumption	
NZ:AU TFP levels, 2009	Mason (2013)	Based on aligned industry data	26 industry categories
Terms of trade levels	Feenstra et al. (2015)	Based on export and import price levels relative to US GDP(output) in 2005=1	Not applicable

B.1 Total factor productivity

The construction of the panel of industry TFP levels (compared to the US as numeraire) is described in Steenkamp (2015). Industries are matched at the 1-digit level for each data type across data sources and aggregated into 11 sectors for each economy. Thereafter, the 11 industries are categorised as tradable and non-tradable and aggregated. The industry concordances used in this paper are discussed in greater detail in Steenkamp (2015) and summarised in Table 3 of that paper.

All TFP estimates in this paper are based on GVA data. To compare the value of output across countries, adjustment for relative price levels is required. To account for price differences in across countries, output values are adjusted using PPPs specifying relative prices for a good/service or bundle of these between economies. The GGDC, EU KLEMS and World KLEMS TFP level comparisons used in this study are constructed from double deflated GVA (i.e. gross output and intermediate inputs are deflated by their own PPPs).[32] The panel of sectoral TFP levels is constructed by linking GGDC TFP level comparisons to the US for the benchmark year of 1997 (EU KLEMS Growth and Productivity Accounts 2014) to time series TFP estimates from EU KLEMS (O'Mahony and Timmer 2009) and the World KLEMS database (WorldKLEMS database 2014). Tradable and non-tradable aggregations of industry data are constructed by weighting each industry by its share in 1997 constant price GVA. As New Zealand is not included in these datasets, estimates of New Zealand industry TFP levels are constructed using Mason (2013)'s 2009 year benchmark comparisons between New Zealand and Australia (as Australia is in the GGDC database and can be used to express New Zealand figures relative to the US).[33] To update Mason (2013)'s industry TFP levels, nominal gross value added is converted to common currency using Mason (2013)'s update of the GGDC PPP exchange rates expressed in USD in 2009.

Several alternative sets of TFP estimates are also constructed to assess the sensitivity of the empirical results to the use of different datasets or different aggregation approaches (see Steenkamp 2015 for more detail). These include alternative TFP estimates based on different vintages of data (such as the older ISIC Rev.3 datasets available for all economies except New Zealand), different industry concordances, and different weighting schemes when aggregating industries into tradable and non-tradable categories. An aggregation of core European Monetary Union (EMU) economies (Austria, Spain, France, Germany, Italy and the Netherlands) is also created using

[32] Defined as follows: $lnTFP_i^{GVA} = ln\frac{GVA_i/PPP_i^{GVA}}{GVA_{US}} - \hat{w}_L ln\frac{L_i/PPP_i^L}{L_{US}} - (1 - \hat{w}_K) ln\frac{K_i/PPP_i^K}{K_{US}}$ where GVA_i is GVA-based output in volumes, K_i a quantity index of capital services, L_i is a quantity index of labour services, $\hat{w}_K$ denotes the average share of capital services in total costs between country i and the US, $\hat{w}_L$ is the average labour share in value added labour compensation between the countries defined similarly. Each bilateral PPP for country pair i and US are aggregated taking a geometric mean of all Tornqvist indices and applying an EKS procedure to $lnPPP_i^{GVA} - lnPPP_{US}^{GVA}] = \frac{1}{1-\hat{w}_{II,i,US}}[(lnPPP_i^{GO} - lnPPP_{US}^{GO}) - \hat{w}_{II,i,US}(lnPPP_i^{II} - lnPPP_{US}^{II})$ where $\hat{w}_{II,i,q}$ is the share of intermediate inputs in output averaged over the relevant countries and PPP^{II} is PPP for intermediate inputs aggregated over input types for each country (expressed relative to the geometric average over all countries) and PPP^{GO} is likewise defined for gross output. The impact of PPP measures used is discussed in more detail in Timmer et al. (2007) and OECD and Eurostat (2008).

[33] Mason (2013) estimates TFP as $lnTFP_{i,NZ:AU} = ln(GVA_{i,NZ:AU}) - \hat{\alpha}_{i,NZ:AU} ln(L_{i,NZ:AU}) - (1 - \hat{\alpha}_{i,NZ:AU}) ln(K_{i,NZ:AU})$ where $GVA_{i,NZ:AU}$ is relative value added with nominal output converted to common currency, $L_{i,NZ:AU}$ is relative labour inputs , $K_{i,NZ:AU}$ denotes relative capital inputs, $\hat{\alpha}_{i,NZ:AU}$ denotes the average share of labour in value added across the two countries.

industry GVA weights for the period 1991 to 2009.[34]

B.2 Relative price levels

A cross-country panel of tradable and non-tradable consumer price levels is constructed using a similar approach as with TFP above. The cross-sectional sectoral price parity and expenditure shares for the 18 countries considered are taken from the International Comparison Program (Feenstra et al. 2013) for a 2011 year benchmark.

The cross-section of industry expenditure PPPs is created by categorising expenditures into tradables and non-tradables. Tradable categories are taken to be food and nonalcoholic beverages, alcoholic beverages, tobacco, and narcotics, clothing and footwear, net purchases abroad (and half-weights on furnishings, household equipment and maintenance and miscellaneous goods and services), while the non-tradable categories are health, transport, communication, recreation and culture, education, restaurants and hotels (and half-weights on furnishings, household equipment and maintenance and miscellaneous goods and services), and their respective PPP levels relative to the US are aggregated using their expenditure shares.

Goods- and services consumer price indices were sourced from Haver (and directly from the statistical agency for Japan) are used as proxies for tradables and non-tradables price timeseries. For the US, the 'Commodities' category, which corresponds to the 'goods' category for other countries is used.[35] These series may not be good proxies of trade exposure, but alternative proxies have conceptual problems of their own. Value-added deflators, for example, capture

[34] This is because TFP growth for the financial intermediation category for Germany is only available from 1991. An alternative EMU aggregation is also created from all of the EMU countries for which data are available, which has a shorter sample of 1995 to 2007 and is available on request. Although estimates of GVA-based MFP growth rates are available for Korea from the Asia KLEMS project and Canada from the World KLEMS project, they are not included in this comparison as they do not have 1997 levels comparisons available in the GGDC dataset.

[35] There are some differences between expenditure categories for some countries. For instance, 'Commodities' in the US series includes nondurables, food (which includes food away from home), and durables, as well as energy (including services like utilities and gas, but excludes water and sewer and trash collection services). For Australia on the other hand, the 'goods' CPI series does include both gas and other household fuels and water and sewage, while excluding restaurant meals. For countries in the EMU, water supply, electricity, gas, solid fuels and heat energy are included in the goods category, while refuse and sewerage collection and restaurants and canteens are included in services.

prices of the output by domestic production industries, but will not pick up import price effects. Some statistical agencies, such as those in Australia and New Zealand, publish official tradables and non-tradables CPI series but these unfortunately do not have a long sample.

The benchmark series for real exchange rates relative to the US (q) are constructed for 17 economies using nominal exchange rates (period average, market rates) and aggregate CPI series and aggregate consumer price PPPs. Exchange rates are constructed as:

$$q_{i:US,t} = \frac{NER_{i:US,t} \times p_{aggCPI,i,t}}{p_{aggCPI,US,t}} \times PPP_{aggCPI,i,t} \tag{6}$$

where the nominal rate ($NER_{NZ:i,t}$) defined as the foreign currency price of one New Zealand dollar relative to country i at time t[36] and where aggregate price levels are created for each country by weighting p_t^T and p_t^N using ICP price parities for aggregate consumer prices $PPP_{aggCPI,i,t}$. To create the panel of relative consumer price levels, each country's relative PPP levels are multiplied by the ratio of their CPI timeseries vis-a-vis the US (which have been re-scaled to 2011 = 100), which are converted to common currency to generate the tradable real exchange rate. The tradable and non-tradable real exchange rate are defined as follows:

$$q_{T,i:US,t} = NER_{i:US,t} + p_{i,t}^T - p_{US,t}^T \tag{7}$$

and the non-tradable real exchange rate for each economy relative to the US:

$$q_{N,i:US,t} = NER_{i:US,t} + p_{i,t}^N - p_{US,t}^N \tag{8}$$

Tradable and non-tradable price levels are created as $p_{i,t}^T = PPP_{i,T} \times CPI_{i,t}^T$ and $p_{i,t}^N = PPP_{i,N} \times CPI_{i,t}^N$ where PPPs have been adjusted by the nominal exchange rates to get them in common terms. Nominal exchange rates are re-based to an index where 2011 = 1. Exchange rates here are specified as up for appreciation against the US, so appreciation makes a country more expensive relative to the US. The relative price of non-traded goods is $p_{N,t} = q_t^N - q_t^T$.

B.3 Unit labour costs

Unit labor costs (ULC) series are obtained from the OECD (2015b), and defined as nominal total economy labour costs over real output (2005 base

[36] Constant euro conversion rates are applied to the exchange rates of euro zone economies before 1999.

year), adjusted for exchange rate change.[37] ULCs are expressed relative to the US (which only has data to 2011), in logarithms (see Figure B.3). To remove nominal exchange rate variability from the ULC measures, ULC is orthogonalised to the NER for each country by regressing the ULC measure on the NER and the residuals added to the mean of the ULC to avoid introducing bias in fixed effects estimation (as the residuals alone will be mean zero). Consequently, the orthogonalised $OULC_i$ series identify the difference in ULC between country i and the US at any point of time.

B.4 Terms of trade

Relative terms of trade levels are measured using Feenstra et al. (2015)'s quality-adjusted price levels of exports and imports which are obtained by dividing export and import PPPs by the nominal exchange rate.[38] These price levels are then normalised to the US using the US national accounts deflator relative to 2005. We construct relative terms of trade level as the difference between export to import levels relative to the same expression for the US in logarithms.

B.5 Real long run interest rate differentials

Bilateral long-run real interest rate differentials ($RIRDIFF_{i,t}$) to the US are based on 10 year government bond yields obtained from Bloomberg. We calculate the real interest rate differentials as the difference between a 10-year government bond yields in country i minus in the US, in a given year, and then adjusted for CPI inflation differentials.

B.6 Labour market indicators

A large number of indicators of structural differences between countries' labour markets were considered. The OECD provide three indicators of employment

[37] To convert nominal unit labour costs into common currency, the series was divided by nominal exchange rates after indexing each exchange rate to 1 in 2010, the base year for the OECD's GDP data. For New Zealand, official total economy ULC series stop in 2009 and have been updated using the nominal ULC index from SNZ to 2012.

[38] The quality adjustment is necessary since export and import prices are calculated as unit values (as opposed to prices as in the ICP), see Feenstra et al. (2015) for details. Note also that these export and import prices are based on merchandise trade only.

protection that are available from 1985 onwards, while the Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (ICTWSS) dataset (Visser 2013) provides 182 indicators of various characteristics of labour markets for a large cross-section of countries for a long time span.

Several of these indicators have been shown to perform well in characterizing wage setting and labour market developments. For example, Gnocchi et al. (2015) show that these labour market indicators are related to cyclical movements in real wages, labour productivity and unemployment in OECD economies.[39]

On this basis, the following ICTWSS indicators are considered individually: $CONC_{i,t}$ (summary measure of concentration of unions at aggregate and sectoral levels), $AUTH_{i,t}$ (summary measure of formal authority of unions regarding wage setting at aggregate and sectoral levels), $CENT_{i,t}$ (centralisation of wage bargaining measured by weighting national and sectoral concentration of unions by level of importance)[40], $UD_{i,t}$ (the union density rate), $haff_{i,t}$ (measure of authority of unions in wage setting at national and industry level), $hcf_{i,t}$ (membership concentration at the industry level within confederations). Indicators that do not range between 0 and 100 are scaled up by multiplying by 100. These indicators are then expressed as natural log differences to US levels.

We also consider the following categorical variables from ICTWSS: $coord_{i,t}$ (coordination of wage-setting), $ext_{i,t}$ (existence of mandatory extension of collective agreements by public law), $govint_{i,t}$ (government intervention in wage bargaining), $level_{i,t}$ (degree of centralisation in wage bargaining), $tc_{i,t}$ (the existence of a tripartite council) and $sector_{i,t}$ (a measure of sectoral organization of employment relations) and express them as the value for country i less that of the US.

We also include replacement rates, $RR_{i,t}$ (ratio of disposable income when unemployed to expected disposable income) provided by Gnocchi et al. (2015), along with $EPRC_{i,t}$ (the strictness of employment protection legislation), $EPR_{i,t}$ (the strictness of employment protection on individual contracts), $EPT_{i,t}$ (employment protection on temporary contracts) from the OECD. All of these individual indicators are expressed as log differences to the US and

[39] The indicators they investigate are RR, UD, $CONC$, $CENT$, $Minwage$, Ext, $Wcoord$, $Govint$, $Level$, $EPRC$, EPR, EPT and UC.

[40] $CENT$ is a broader measure than $CONC$, as $CENT$ also incorporates internal and external demarcations between union confederations.

for all individual variables, higher values imply a relative more rigid labour market compared to the US.

Apart from including individual indicators, we also created our own summary measures of the various indicators in the ICTWSS dataset. The first summary measure $Lab4avg_i$ is a simple average of the unadjusted values of UD, $AUTH$, $CONC$ and $AdjCov_{i,t}$ (Bargaining or Union Coverage) for each economy i, and then logged and expressed relative to the US.

The second is the first principal component extracted from indicators for each economy.[41] Before principal components were extracted, variables which are not available for any years for all of the countries in our sample were excluded, as were similar indicators that were very highly correlated with other variables. Out of the 182 indicators, 53 are selected, most of which are ranked categorical variables. To enhance interpretability of results, we transformed the ICTWSS series where necessary to ensure that a higher value of each of indicator implies a relatively more rigid labour market compared to the US. Principal components for each economy are expressed relative to the value of the US equivalent and denoted $LabPC_{i,t}$. All numerical series are expressed as log differences vs US and all categorical series are expressed simply as differences to the US. All indicators standardised to prevent series with larger variances dominating the principal component. A high value of $LabPC_{i,t}$ implies a relatively inflexible labour market compared to the US.[42]

The commonly used Balassa-Samuelson model predicts that an increase in tradable to non-tradable TFP should cause a proportional increase in the domestic relative price of non-tradables, while wage equalisation would imply that relative wages would remain unchanged. The correlation between domestic relative TFP differentials and relative wages is negative in our data over the benchmark sample, and positive with relative prices (Figure 9). Figure 10 shows that a 1 percent differential between traded and non-traded TFP is associated with lower relative wages, contrary to the prediction of the textbook BS model. Relative prices rise in some countries and fall in others, again in contrast to the Balassa-Samuelson hypothesis. Bertinelli et al. (2016) find similar results using value added deflators, industry labour

[41] Gnocchi et al. (2015) also extract principal components from their various indicators to obtain a summary measure of overall labour market rigidity, unionisation and wage setting. They use four principal components capturing over 75 percent of the variation of their indicators. To control for endogeneity with other macroeconomic variables, they use start period values for the principal components and period averages for macroeconomic variables.

[42] Details about the construction of the principal component measure is omitted for the sake of brevity, but available on request.

compensation over hours worked to measure wages, labour productivity for OECD economies.

As a check of the role of labour market structure in the transmission of relative price changes domestically, Figure 11 shows that countries with higher values of our preferred labour market indicator, $CONC$ (indicator a more tightly regulated labour market), experience larger changes in both relative wages and relative prices domestically. Whereas changes in domestic relative prices are all positive in our sample, relative wage changes are negative for many countries, but less negative for countries with higher average levels of labour market regulation. In a timeseries dimension, however, $CONC$ has a negative correlation with relative wages, while it has a positive correlation with relative prices over the benchmark sample. Using different data for a longer timeseries but similar sample of countries, Bertinelli et al. (2016) show that labour productivity gains biased to the tradables sector tend to drive down non-tradable to tradable wages, while tighter labour market regulation is associated with larger falls in relative wages. We obtain the same result when using the same indicators (such as EPR) in our sample.

Figure 9: Domestic relative wages, productivity and prices (changes, 1990-2007)

Note: a_T and a_N traded and non-traded TFP indices, p_N is domestic non-traded to traded price indices, $relativewage$ is the total economy to manufacturing wage ratio based on OECD data. Note that for the Czech Republic the p_N chart sample starts in 1999 and for Hungary in 2000, while for New Zealand, a_N starts in 1996.

Figure 10: Relative wage vs relative price growth (unbalanced panel)

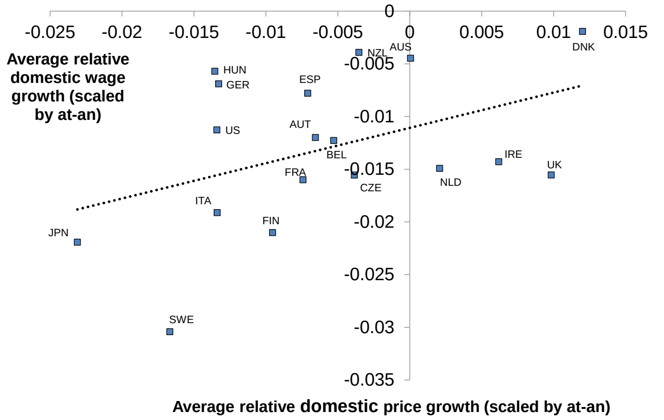
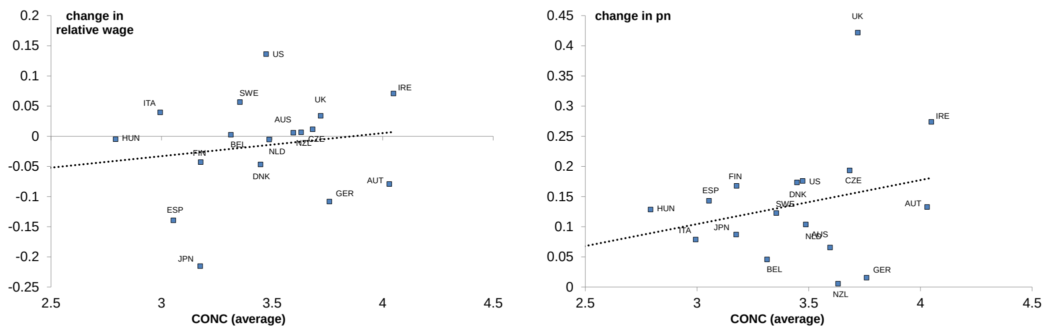


Figure 11: Labour market structure and price changes



Note: p_N is domestic non-traded to traded price indices and $relativewage$ is the total economy to manufacturing wage ratio based on OECD data.

C Model Appendix

This appendix section describes the model, focusing on the material added to the model of Berka et al. (2018). There are two countries, each populated by an infinitely-lived representative agent maximizing:

$$U_t = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \chi_t \frac{N_t^{1+\psi}}{1+\psi} \right), \quad \beta < 1. \tag{9}$$

where C_t is a composite consumption bundle and N_t is the supply of labour, and χ is a country-specific time-varying disutility of labour supply. The composite consumption good is a CES aggregator of traded and non-traded composite consumption (C_T and C_N). Traded consumption is a composite of home or foreign traded consumption goods (C_H and C_F). In line with the literature, these traded consumption goods at the retail level are CES aggregates of pure wholesale traded product and a retail input V which is non-traded. Hence, at home:

$$\begin{aligned}
C_t &= \left(\gamma^{\frac{1}{\theta}} C_{Tt}^{1-\frac{1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{1-\frac{1}{\theta}} \right)^{\frac{\theta}{\theta-1}} \\
C_{Tt} &= \left(\omega^{\frac{1}{\lambda}} C_{Ht}^{1-\frac{1}{\lambda}} + (1-\omega)^{\frac{1}{\lambda}} C_{Ft}^{1-\frac{1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}} \\
C_{Ht} &= \left(\kappa^{\frac{1}{\phi}} I_{Ht}^{1-\frac{1}{\phi}} + (1-\kappa)^{\frac{1}{\phi}} V_{Ht}^{1-\frac{1}{\phi}} \right)^{\frac{\phi}{\phi-1}} \\
C_{Ft} &= \left(\kappa^{\frac{1}{\phi}} I_{Ft}^{(1-\frac{1}{\phi}} + (1-\kappa)^{\frac{1}{\phi}} V_{Ft}^{1-\frac{1}{\phi}} \right)^{\frac{\phi}{\phi-1}}
\end{aligned}$$

In the above equations, θ, λ and ϕ are elasticities of substitution between traded and nontraded goods, home and foreign tradables, and the wholesale traded good and non-traded input in retail sectors. γ, ω and κ are the steady-state shares of traded consumption in overall consumption, home bias in traded goods, and the weight of wholesale consumption in overall traded retail bundle. The optimal price indexes are:

$$\begin{aligned}
P_t &= \left(\gamma P_{Tt}^{1-\theta} + (1-\gamma) P_{Nt}^{1-\theta} \right)^{\frac{1}{1-\theta}}, \\
P_{Tt} &= \left(\omega \tilde{P}_{Ht}^{1-\lambda} + (1-\omega) \tilde{P}_{Ft}^{1-\lambda} \right)^{\frac{1}{1-\lambda}}, \\
\tilde{P}_{Ht} &= \left(\kappa P_{Ht}^{1-\phi} + (1-\kappa) P_{Nt}^{1-\phi} \right)^{\frac{1}{1-\phi}} \\
\tilde{P}_F &= \left(\kappa P_{Ft}^{1-\phi} + (1-\kappa) P_{Nt}^{1-\phi} \right)^{\frac{1}{1-\phi}}
\end{aligned}$$

where P_T and P_N are home country's price indexes of traded and non-traded aggregates, $\tilde{P}_H$ and $\tilde{P}_F$ are price indexes of Home and Foreign retail traded goods, and P_H and P_F are prices of Home and Foreign wholesale traded goods, measured at Home. We assume that law of one price holds in traded goods at wholesale level, and so $SP_H = P_H^*$ and $SP_F = P_F^*$. The real exchange rate is defined as

$$Q_t = \frac{P_t S}{P_t^*}$$

In our world of complete risk sharing, marginal utilities of consumption must equal between countries, when expressed in the same currency:

$$\frac{C_t^{-\sigma}}{P_t} = \frac{C_t^{*-\sigma}}{P_t^*} \tag{10}$$

The first order conditions imply the usual sets of equations. The implicit labour supply is governed by:

$$W_t = \chi_t P_t C^\sigma N_t^\psi$$

Where W_t is the nominal wage. The demand equations for consumption components are given by:

$$C_{Tt} = \gamma \left(\frac{P_{Tt}}{P_t}\right)^{-\theta} C_t, \qquad C_{Nt} = (1-\gamma)\left(\frac{P_{Nt}}{P_t}\right)^{-\theta} C_t$$

$$C_{Ht} = \omega \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt}, \qquad C_{Ft} = (1-\omega)\left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt}$$

$$I_{Ht} = \kappa\omega \left(\frac{P_{Ht}}{\tilde{P}_{Ht}}\right)^{-\phi} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt}, \quad I_{Ft} = \kappa(1-\omega)\left(\frac{P_{Ft}}{\tilde{P}_{Ft}}\right)^{-\phi}\left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt}$$

Foreign consumption bundles, foreign prices, and demand first order conditions, are determined in an analogous fashion, and denoted with an *. Firms in each sector produce using labour and a fixed capital stock: $Y_{Nt} = A_{Nt} N_{Nt}^\alpha$, $Y_{Ht} = A_{Tt} N_{Ht}^\alpha$.

As described earlier, we allow for the existence of sectoral firms-side labour wedges, which can be motivated by the existence of sectoral labour unions. Specifically, we model them as sector-specific price markups $\mu_i,\ i \in (T, N)$ exactly as in Galí et al. (2007) and Karabarbounis (2014):

$$\mu_{j,t} = p_{j,t} - (w_t - MPL_{j,t}),\ j \in \{T, N\}$$

Ceteris paribus, μ raises firm's prices and appreciates q. When $\mu_T \neq \mu_N$, there is an additional effect of the differential sectoral labour wedge.

There are many papers that feature a wedge between the marginal rate of substitution in consumption and the marginal product in production. This literature is largely focused on understanding how labour market inefficiencies might affect labour supply. Sources of a 'labour wedge' could include many factors, including search costs, monopoly power in wage-setting, or sticky nominal wages (see Hall 1997, Chari et al. 2002, Galí et al. (2007), Shimer 2009, Karabarbounis 2014).[43] Irrespective of the underlying source of the wedge, these translate into price changes that are independent of TFP.[44]

We assume that prices are flexible and firms engage in monopolistic competition that yields the usual markup-pricing rule. Monetary policy in each country is characterized by a Taylor-type rule which adjusts nominal interest rates at home as follows:

$$r_t = \rho + \sigma_p \pi_t + \sigma_q (q_t - u_t)$$

where σ_p and σ_q are weights on inflation and real exchange rate stability, respectively, and u_t is a monetary policy shock (see Steinsson 2008). A similar monetary policy rule is followed by a foreign country. It can be shown that this implies that the nominal exchange rate in a symmetric equilibrium is a linear function of the differential monetary policy shocks $s_t = x(u_t^* - u_t)$ where x is a constant.

We focus here on the role of firm-side labour wedges, both between sectors and between countries, in driving the real exchange rate dynamics, in addition to Berka et al. (2018). The Ballassa-Samuelson mechanism implies that sectoral productivity differences influence real exchange rates. An increase in the Home relative (traded vs. non-traded) productivity over the Foreign appreciates the Home real exchange rate. An additional mechanism exists in models where traded goods are imperfect substitutes (such as here): increases in traded productivity additionally lowers the price of home exportables, thus depreciating the terms of trade and the real exchange rate. In usual

[43] Benassy-Quere and Coulibaly (2014) add product-market markups to the model of Gregorio et al. (1994) and show empirically that if markups reflect product market regulations and employment protection, these have a meaningful impact on the eurozone's real exchange rates.

[44] Hall (1988) and Hall (1989) show that imperfect competition implies that measured TFP will itself be affected by demand fluctuations. One way to address this criticism would be to explicitly include estimates of markups for tradables and non-tradables, which is empirically infeasible as far as we are aware.

model calibrations, as well as in empirical studies, the former effect dominates the latter, and relative technological improvements are associated with real exchange rate appreciations.

At the core of both of these mechanisms lies the assumption that labour markets are perfectly competitive, and factors of production receive their marginal products. But there are clear differences in the efficiency of labour market institutions over time (owing to reforms) and also between countries. Such institutional differences play a prominent role in the assessment of international competitiveness. The traded sector first order conditions imply that an international wage difference can be decomposed into endogenous terms of trade movements, productivity differences, and markup differences:

$$w + s - w^* = \tau + a_T - a_T^* - (\mu_T^* - \mu_T)$$

where $\tau \equiv p_H - p_F^* - s$ is the terms of trade. A similar condition can be expressed using the non-traded sectors' first order conditions. With intra-national labour market integration, wages equalise between sectors, which consequently implies that:

$$p_N + s - p_N^* = \tau + [a_T - a_T^* - (a_N - a_N^*)] + [\mu_N - \mu_N^* - (\mu_T - \mu_T^*)]$$

Thus, the real exchange rate for non-traded goods is a function of terms of trade, relative productivities (the Balassa-Samuelson effect) and relative markup differences. If we further assumed that $\kappa = 1$ and $\omega = 0.5$, so that the retail sector does not use non-traded inputs and there is no home bias in traded consumption, we could rewrite the above condition as:

$$p_n = [a_T - a_T^* - (a_N - a_N^*)] + [\mu_N - \mu_N^* - (\mu_T - \mu_T^*)]$$

where $p_n \equiv p_N - p_N^* - (p_T - p_T^*)$ is the relative price of non-traded to traded goods between the countries. In contrast to the standard Balassa-Samuelson model, the 'relative-relative price' of non-traded to traded goods between countries is not equally a function of the deviations in relative productivities, as it is a function of relative differences in sectoral markups. These two drivers, however, obviously have different influences on the equilibrium real exchange rate in a more complete model, because productivity directly increases output as well as relative prices, while the wage markups do not.

The importance of the *relative* difference of price markups is intuitively clear. If the Home country has 10% higher markups than the Foreign country in both sectors, prices will be higher by 10%, ceteris paribus. But the relative price of non-traded goods, a key driver of the real exchange rate, will not be different, since prices of *both* traded and non-traded goods are higher by the same proportion.

We may then ask whether this implies that labour market imperfections have no influence on the real exchange rate in the case when $\mu_T^* - \mu_T - (\mu_N^* - \mu_N) = 0$, that is, when there are *no sectoral* but only *national* differences in firm markups. It turns out that such direct effect also exists, irrespective of whether sectoral wage markups differ, but it is observationally equivalent to the effects of the relative disutility of labour $\chi - \chi^*$. Algebraically, this can be seen from a combination of first order conditions. In logarithms, we can write the implicit labour supply condition as $w^R - q = \sigma c^R + \psi n^R + \chi^R$ where '$.^R$' denotes a value of a Home relative to Foreign variable, expressed in the same currency when necessary. Applying the complete risk sharing condition, this reduces to $w^R = \psi n^R + \chi^R$. We can then use the firm's first order conditions (in either sector) to substitute for w^R, yielding (after substituting for p_N^R):

$$\frac{1}{1-\gamma\kappa} q + a_N^R - \mu^R = \psi n^R + \chi^R$$

where we assume $\mu_N^R = \mu_T^R = \mu^R$. This condition is the only place in the model where μ^R as well as χ^R enter. Consequently, if we define $\tilde{\chi}^R \equiv \chi^R - \mu^R$ we can solve the log-linearized model in the same manner as without labour markups by writing $\tilde{\chi}^R$ instead of χ^R. Then, by construction, the coefficient on μ^R in model's solution (for any variable) must equal the negative of that variable's coefficient on $\tilde{\chi}^R$.

As already reported in Section 3, the general form of the model (assuming no home bias) can be solved for real exchange rate as follows:

$$q = \alpha_\chi \chi^R + \alpha_T a_T^R + \alpha_N a_N^R + \alpha_{\mu_N} \mu_N^R + \alpha_{\mu_N - \mu_T}(\mu_N^R - \mu_T^R)$$

where

$$\begin{aligned}
\alpha_\chi = \alpha_{\mu_N} &= \frac{\sigma(1-\gamma\kappa)}{B} \\
\alpha_{a_T} &= \frac{\sigma(1-\gamma\kappa)}{B}\gamma\kappa\psi(\kappa\lambda + \phi(1-\kappa) - 1) \\
\alpha_{a_N} &= -\frac{\sigma(1-\gamma\kappa)}{B}[1 + \psi(1 + \gamma\kappa(\kappa\lambda + \phi(1-\kappa) - 1))] \\
\alpha_{\mu_N - \mu_T} &= \frac{\sigma(1-\gamma\kappa)}{B}\gamma\kappa\psi(\kappa\lambda + \phi(1-\kappa))
\end{aligned}$$

and

$$B = \sigma + \psi \left(1 + \kappa \left[\sigma(\psi - \theta) + \gamma^2 \kappa (1 - 2\sigma\theta) + \gamma(\sigma(\phi + 2\theta + \kappa(\lambda - \phi - \psi + \theta)) - 2)\right]\right)$$

Under a standard calibration[45] yields coefficients: $\alpha_\chi = \alpha_{\mu_N} = 0.22,\ \alpha_{a_T} = 0.26,\ \alpha_{a_N} = -0.71,\ \alpha_{(\mu_N - \mu_T)} = 0.33$.

[45] Specifically, when $\sigma = 2$, $\kappa = 0.6$ (so that the distribution sector accounts for 40% of retail tradable goods in equilibrium), $\theta = 0.7$, $\gamma = \omega = 0.5$, $\Psi = 1$, $\phi = 0.25$ and $\lambda = 8$. See Berka et al. (2018).

D Impact of data source selection, construction choices and sample selection

Table 12 summarises the impacts on coefficient estimates and statistical significance when varying the sample, dataset and aggregation approaches used. The alternative data series include:

- Using a common sample of 1995-2007;
- Including EMU countries individually as opposed to using an aggregation of these economies;
- Using an alternative exchange rate definition (q_{secp});
- Using alternative construction choices of TFP measures (e.g. using continuous weighting $a_{continiousweighting}$, or including Finance in tradables $FinanceinT$, or excluding sector 11 when constructing non-tradables TFP $a^N_{exsec11}$).;[46]
- Using alternative datasets and industrial classifications (e.g. the ISIC Revision 3 and 4 industrial classifications for all countries ($Rev3all$), or updating Revision 3 data using Revision 4 to obtain longer samples($Rev3+4$), or using Revision 3 for just the US ($USRev3$).

[46] Timeseries of TFP growth for some industries are only available from 1996 for New Zealand, so an alternative non-traded TFP measure ($a^N_{exSec11}$) which excludes real estate, renting and business services is also constructed for all countries. There are also some potentially serious comparability issues for the New Zealand comparisons to other countries because of differing treatment of owner-occupied dwellings in New Zealand and Australia compared with the other countries in the sample, see Steenkamp (2015) for more details.

Table 12: Impact of using alternative data in basic Balassa-Samuelson model vs augmented model

	Pool		FX		RE		XS	
	q on a_T-a_N	q on a_T-a_N and OULC and CONC	q on a_T-a_N	q on a_T-a_N and OULC and CONC	q on a_T-a_N	q on a_T-a_N and OULC and CONC	q on a_T-a_N	q on a_T-a_N and OULC and CONC
1990 to 2007	+	+	+	+	+	+	+	+
1995 to 2007	+	+	+	+	+	+	+	+
Unbalanced panel	+	+	+	+	+	+	+	+
EMUcore (1995 to 2007)	+	+	-	+	+	+	NA	NA
EMUcore (full unbalanced panel)	+	+	-	+	+	+	NA	NA
q_secp (1995 to 2007)	+	+	-	+	+	+	+	+
q_secp (full unbalanced panel)	+	+	+	+	+	+	+	+
a_{N_exsec11} (1995 to 2007)	-	-	-	+	-	+	-	-
a_{N_exsec11} (full unbalanced panel)	-	-	-	-	-	-	-	-
a_{USREV3} (1995 to 2007)	+	+	-	+	-	+	+	+
a_{USREV3} (full unbalanced panel)	+	+	-	-	-	-	+	+
a_{REV3all} (1995 to 2007)	+	+	-	+	-	+	+	+
a_{REV3all} (full unbalanced panel)	+	+	-	-	-	-	+	+
a_{REV3+4} (1995 to 2007)	+	+	+	+	+	+	+	+
a_{REV3+4} (full unbalanced panel)	+	+	+	-	+	-	+	+
a_{T=Manuf} (1995 to 2007)	+	+	-	+	-	+	+	+
a_{T=Manuf} (full unbalanced panel)	+	+	-	+	-	+	+	+
a_{Continious weighting} (1995 to 2007)	+	+	+	+	+	+	+	+
a_{Continious weighting} (full unbalanced panel)	+	+	+	+	+	+	+	+
a_{Finance in T} (1995 to 2007)	+	+	+	+	+	+	+	+
a_{Finance in T} (full unbalanced panel)	+	+	+	+	+	+	+	+

Note: '+' indicates positive coefficient, '-' a negative coefficient, shading indicates statistical significance at 10 percent of the coefficient of $a_T - a_N$. 'Pool' is a pooled regression with all countries and periods sharing the same estimate of a constant and a slope. 'FE' is a fixed effect regression with countries as cross-sections. 'RE' is a random effects panel with countries as cross sections. 'XS' is a regression which uses the time-average value for each country and runs a cross sectional regression.

D.0.1 Alternative relative price measure

The benchmark results are based on real exchange rates constructed using aggregate CPI from the OECD and aggregate consumer price PPPs. Alternatively, aggregate price levels could be measured by weighting our tradable and non-tradable price measures together. For each economy, relative aggregate price levels compared to the US are created by weighting $p^T_{i,t}$ and $p^N_{i,t}$ using country specific weights for each sector as follows:

$$p_{i:US,t} = \alpha_i p^T_{i,t} + (1 - \alpha_i) p^N_{i,t} \tag{11}$$

$$p_{US,t} = \alpha_{US} p^T_{US,t} + (1 - \alpha_{US}) p^N_{US,t} \tag{12}$$

where $p^T_{i:US,t}$ and $p^N_{i:US,t}$ have been adjusted using 2011 $PPP_{i,N}$ (where adjusted by nominal exchange rates to get them in common terms) to convert them into levels relative to the US, α_i, represents the share of tradables in total output of each country[47] and components are in logarithms.

The real exchange rate based on sectoral prices ($q_{secP,i,t}$) is then defined as the relative price of domestic and foreign goods, measured in domestic currency terms:

$$q_{secP,i,t} = NER_{i:US,t} + p_{i,t} - p_{US,t} \tag{13}$$

Although the there is a positive relationship between relative productivity and the real exchange rate in both levels and changes over time internationally (Figure 7), an unconditional positive relationship is only observed for relative tradable to non-tradable price levels across countries and not over time. According to our proxies, the relative price of non-traded goods compared to the US grew the most in the UK and the least in Australia. Relative traded to non-traded TFP grew the most in Japan and the least in Denmark (again, in an unbalanced panel).

Our data show that there is a positive relationship between sectoral price changes and sectoral TFP changes domestically (i.e. using index numbers as in Figure 13) and also across countries (Figure 14) over the full sample.[48] Relative non-tradable to tradable prices (p_N) rose domestically in all countries

[47] The value of alpha is calculated for each country as the 2011 share of tradables in expenditure based on ICP weights.

[48] Note that the domestic relationship is weak for the period 1995 to 2007 (Figure 14).

Figure 12: (Absolute) bias in basic Balassa-Samuelson model relative to augmented model

	Δa_T-a_N			
	Pool	FE	RE	XS
1990-2007	0.17	-0.18	-0.08	0.38
1995-2007	0.17	-0.41	-0.23	0.33
Unbalanced panel	0.08	-0.13	-0.07	0.05
EMUcore (1995-2007)	0.30	-0.11	0.02	NA
EMUcore (full unbalanced panel)	0.34	0.05	0.12	NA
q_secp (1995-2007)	0.09	-0.48	-0.25	0.31
q_secp (full unbalanced panel)	0.07	-0.25	-0.12	0.32
a_{N_exsec11} (1995-2007)	-0.08	-0.71	-0.67	0.27
a_{N_exsec11} (full unbalanced panel)	-0.04	-0.34	-0.33	0.30
a_{USREV3} (1995-2007)	0.09	-0.72	-0.56	0.02
a_{USREV3} (full unbalanced panel)	0.09	-0.33	-0.24	0.05
a_{REV3all} (1995-2007)	0.07	-0.63	-0.50	0.30
a_{REV3all} (full unbalanced panel)	0.09	-0.27	-0.20	0.32
a_{REV3+4} (1995-2007)	0.75	0.99	0.94	0.45
a_{REV3+4} (full unbalanced panel)	0.71	0.54	0.56	0.46
a_{T=Manuf} (1995-2007)	0.15	-0.44	-0.29	0.33
a_{T=Manuf} (full unbalanced panel)	-0.01	-0.09	-0.04	0.41
a_{Continous weighting} (1995-2007)	0.19	0.17	0.21	0.28
a_{Continous weighting} (full unbalanced panel)	0.13	-0.09	-0.03	0.32
a_{Finance in T} (1995-2007)	0.09	0.67	0.60	0.09
a_{Finance in T} (full unbalanced panel)	0.04	0.30	0.33	0.11

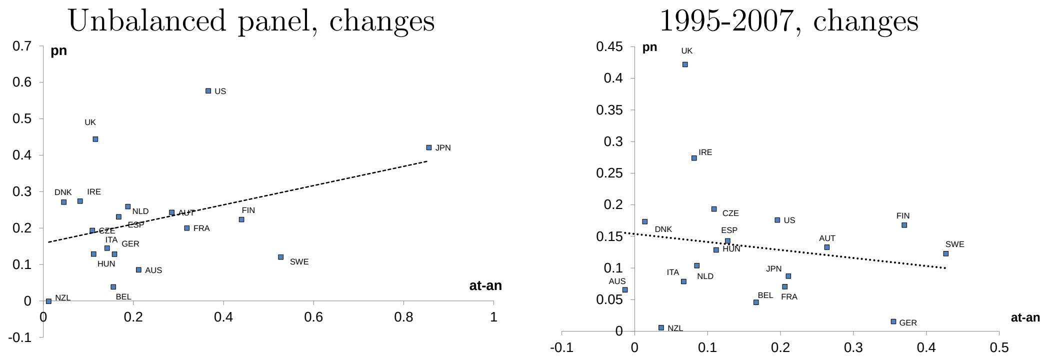
Note: Shading indicates statistical significance at 10 % of the $a_T - a_N$ coefficient estimate in the augmented model. Bias calculated as the difference between the coefficient from the basic Balassa-Samuelson model and the augmented model used in this paper.

(although the increase in New Zealand is negligible according to our price proxies). In cross-section, the relative price of non-traded to traded goods has been highest in Australia, Germany and Spain.[49]

This paper uses consumer price levels as proxies for tradable and non-tradable prices. Figures 15 and 15 compare our measures to value-added based price indices. The correlation between sectoral TFP measures and value added-based price indices is slightly stronger than for consumer price-based indices (16 and 16). Producer price levels are not used in this paper because price level comparisons are not available for all the countries in our sample.

The Balassa-Samuelson model predicts a positive relationship between the real exchange rate and relative non-tradable to tradable prices. Both the cross-sectional and timeseries correlations between relative TFP levels ($a_T - a_N$) and p_N are weaker than with the q levels constructed in this paper. Table 13 however shows that there is a robust statistical relationship between real exchange rates and relative prices based on our p_N data. A comparison of the three different relative price measures constructed is plotted in Figure 17.

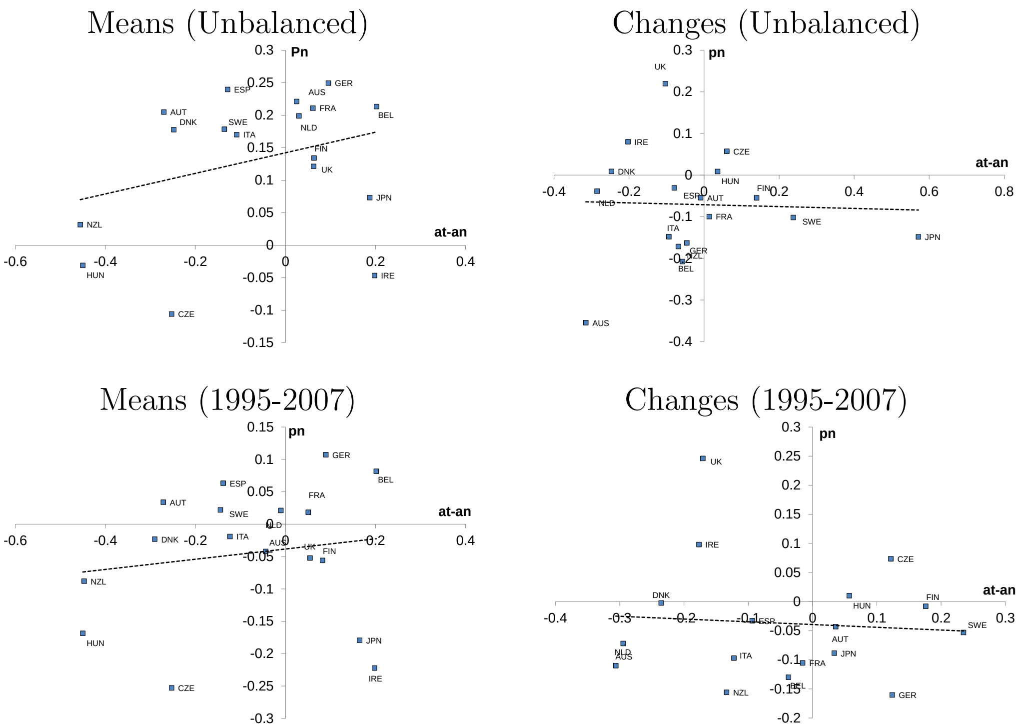
Figure 13: Domestic sectoral price and productivity ratios



Note: All variables specified in logs. a_T and a_N traded and non-traded TFP indices, and $p_N = P_N - P_T$ where P_T and P_N are indices of traded and non-traded consumer prices. Unbalanced sample described in Table 10. Note that for the Czech Republic the p_N chart sample starts in 1999 and for Hungary in 2000, while for New Zealand, a_N starts in 1996.

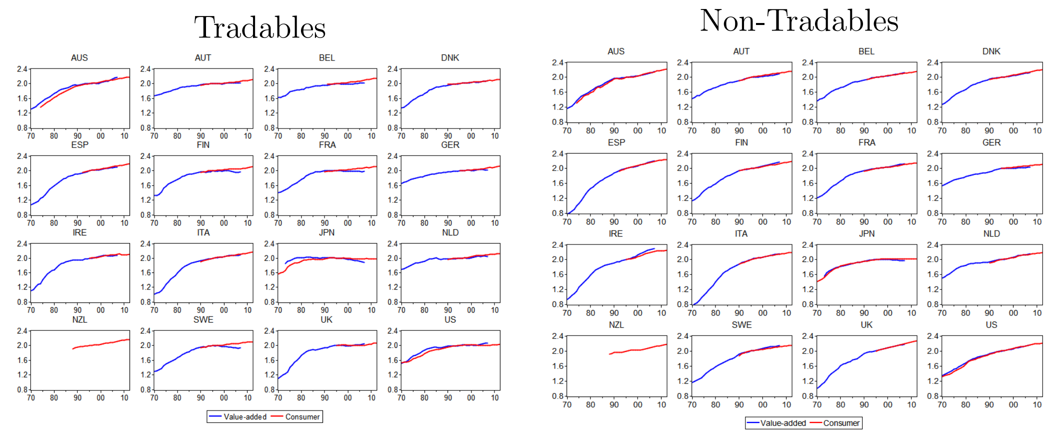
[49] When expressed relative to the US (as in Figure 14), relative sectoral price increases are smaller than in the US for many countries according the price proxies used. Our proxies for tradable prices grew faster in most countries than in the US, while the non-tradable price proxies grew at slower rates than in the US.

Figure 14: Cross country sectoral prices and productivity ratios



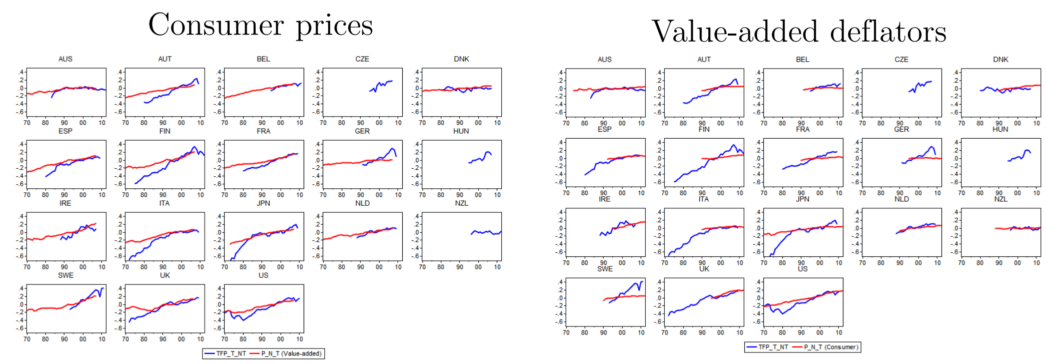
Note: a_T and a_N traded and non-traded TFP levels relative to the US. $p_N = q_N - q_T$ where q_T and q_N are the traded and non-traded real exchange rate against the US. The sample for charts with p_N is shorter than for q for most countries, see Table 10.

Figure 15: Consumer- versus value-added deflator-based price indices (1995=100,log)



Value-added price indices from Bertinelli et al. (2016). Note that there are differences in the industry classifications used to construct the value-added indices and the consumer price-based indices used in this paper.

Figure 16: Domestic sectoral TFP indices and domestic sectoral price indices (1995=100,log)



Value-added price indices from Bertinelli et al. (2016). Note that there are differences in the industry classifications used to construct the value-added indices and the consumer price-based indices used in this paper. $TFP_{T,NT}$ is the log difference between the domestic tradable and domestic non-tradable TFP index, while $P_{NT,T}$ is the ratio of the domestic non-tradable and domestic tradable price index for each economy.

Table 13: Price regressions (Unbalanced, full sample)

	Dependent variable: q			
	Pool	**FE**	**RE**	**XS**
p_n	0.75***	0.30***	0.35**	1.66**
	0.11	0.12	0.11	0.72
N	392	392	392	17
HT	NA	NA	Rejected	NA

Note: q is the bilateral real exchange rate in levels against the US based on aggregate CPI, $p_n = q_N - q_T$ is the cross-country relative price of non-tradables where q_T and q_N are the traded and non-traded real exchange rate against the US. * denotes a 10 percent, ** 5 percent and *** 1 percent significance. *FE* denotes a fixed effects panel regression (countries as cross sections). *RE* denotes random effects regression (countries as cross sections). *XS* is a cross-sectional regression (time-averages of variables in each country). Rejection of the null at 5 percent in Haussman test (HT) implies no difference between FE and RE, viewed as preference for FE.

Figure 17: Three different relative price measures (up as appreciation, log)