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Martin Berka, Michael B. Devereux and Charles Engel

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Abstract

We investigate the link between real exchange rates and sectoral TFP for Eurozone countries. We show that real exchange rate variation, both cross-country and time series, closely accords with an amended Balassa-Samuelson interpretation, incorporating sectoral productivity shocks and a labor market wedge. We construct a DSGE model to generate a cross-section and time series of real exchange rates to compare to data. Estimates from simulated regressions are very similar to estimates for Eurozone data. Our findings contrast with previous studies that have found little relationship between productivity and real exchange rates among high-income countries that have floating nominal exchange rates.

JEL classification: F41, F31
Keywords: Balassa-Samuelson, Real Exchange Rates, Eurozone, Total Factor Productivity, Labor Wedge, Unit Labor Cost

*Massey University, University of British Columbia and University of Wisconsin. E-mail addresses: m.berka@massey.ac.nz, devm@mail.ubc.ca, cengel@ssc.wisc.edu. Corresponding author is Engel. Devereux's research is supported by ESRC Award Number ES/I024174/1 and SSHRC. Engel acknowledges research support from National Science Foundation grant no. 1226007. The authors thank Loukas Karabarbounis for comments, and also thank discussants and participants at numerous seminars and conferences at which this paper has been presented.

1 Introduction

Prices of consumer goods differ substantially across countries, and vary considerably between any two countries over time. In the aggregate, relative goods prices compared across countries are defined as real exchange rates. The most common approach to understanding real exchange rates is the Balassa-Samuelson model, in which persistent movements in real exchange rates over time and across countries are driven by cross-country differentials in sectoral total factor productivity. Yet it is widely acknowledged that the Balassa-Samuelson model does not do well in explaining real exchange rates except over very long time horizons.[1] In most empirical studies, especially in time series data, the evidence for the effect of productivity growth on real exchange rates is quite weak. This problem is especially apparent in the study of real exchange rate movements among high-income, financially developed countries with floating exchange rates.

This paper revisits the investigation of real exchange rate determination using a new data set of European disaggregated prices. The price data covers a large group of European countries, includes the whole consumer basket, and has a high degree of cross-country comparability. Our sample of European countries allows us to construct a panel of real exchange rates over the period 1995-2009. We construct a real exchange rate distribution across countries at any point in time and track the movement of this distribution over time.

In the Eurozone, bilateral nominal exchange rates are fixed. It is well known from the literature on open economy macroeconomics that floating nominal exchange rates are influenced by monetary policy decisions and shocks, financial shocks, and possibly also by non-fundamental shocks. When nominal prices adjust more slowly than the nominal exchange rate, these shocks also influence the real exchange rate. Our working hypothesis is that the real exchange rate among countries that share a common currency is more fertile ground for finding evidence of the Balassa-Samuelson effect because the short-run real exchange rate movements are not driven by these monetary and financial factors that influence nominal exchange rates.

We combine our panel of real exchange rates with measures of sectoral total factor productivities for each country as well as a separate measure of unit labor costs. We then conduct panel regressions of real exchange rates to explore the link between the real exchange rates and productivity. For the Eurozone countries, there is substantial evidence of an amended Balassa-Samuelson effect. An increase in total factor productivity in traded goods is associated with a real appreciation, and an increase in total factor productivity in non-traded goods correlates with a real depreciation. But these links appear only when we separately control for unit labor cost differentials across countries. We find that, holding productivity constant, higher unit labor costs lead to real exchange rate appreciation. One interpretation for this phenomenon is that there are separate institutional forces driving factor prices, independent of factor productivities.[2] In our theoretical model, we allow for this

[1] See for instance Chinn and Johnson (1996), Rogoff (1996), Tica and Družić (2006), Lothian and Taylor (2008), Chong et al. (2012).

[2] This accords well with the concern of European policy-makers with reducing divergences between unit labor costs and productivity developments in the Eurozone that led to the establishment of the Euro Plus

channel by introducing shocks to labor supply that are unrelated to productivity. These are equivalent to a form of 'labor wedge' shocks in the recent macroeconomics literature. Thus, our empirical results imply that in order to reveal the link between sectoral productivity and real exchange rates as implied by the Balassa-Samuelson model, one must control for a measure of the labor wedge.

The Balassa-Samuelson model must be modified to include an endogenous terms of trade when the exports of a country are not perfect substitutes for its imports (e.g. Fitzgerald (2003)). In our theoretical model, it is the movement in the terms of trade which provides the link between labor supply shocks and the real exchange rate. We show in a simple flexible-price model how labor supply shocks cause a rise in relative wages, driving up the relative price of a country's export good, leading to a real appreciation. We construct a small dynamic general equilibrium model of real exchange rates with sticky prices and fixed exchange rates. We use the model to generate a panel of real exchange rate levels and movements over time that matches the European panel for the Eurozone countries. Using the same cross-section and time series dimensions as the data, the model is simulated using shocks to sectoral productivities and labor supply shocks. We find a close relationship between the empirical estimates and the model simulation estimates. Real exchange rates in the model are driven by an amended Balassa-Samuelson pattern of shocks to sectoral productivity and unit labor costs, and the simulation estimates are very close to those in the Eurozone data.

The labor wedge can be defined as the measured difference between the marginal product of hours in production and the marginal rate of substitution between leisure and consumption of households. The literature points to multiple possible sources of movements in the labor wedge - search costs of job finding, taxes on income, monopoly power in wage setting, sticky nominal wages, and other factors. Given the equivalence of labor supply shocks and labor wedge, we show that the labor wedge can be measured indirectly from movements in relative unit labor costs once we have measures of sectoral productivity.[3]

While unit labor costs allow for an indirect measure of the labor wedge, they are also of independent interest since movements in unit labor costs are central to the large policy debate on the disconnect between productivity growth and wage costs in the Eurozone. This disconnect may be due to non-competitive forces in labor markets, fiscal distortions, or other regulatory features of individual Eurozone countries.[4] But whatever the source, the channel

Pact of 2011 (see European Commission (2015)).

[3]The labor wedge can be interpreted either as a price markup - a 'firm wedge', or a wage markup - a 'household wedge'. As discussed further below, the interpretation we follow here views the wedge as a household side shock. Galí et al. (2007) and Karabarbounis (2014a) provide empirical evidence for the US and other OECD economies in favor of the labor wedge as a household wage markup, although in a recent paper Bils et al. (2014) argues for a more important role for the firm wedge in US data. For a range of different theoretical interpretations of the labor wedge, see Hall (1997), Chari et al. (2002), Galí et al. (2007), Shimer (2009), Karabarbounis (2014a) and Karabarbounis (2014b), among others.

[4]Cole and Ohanian (2004) interpret the labor wedge during the Great Depression as a reflection of the non-competitive aspects of the National Recovery Act combined with bargaining power of trade unions. For examples of the emphasis on unit labor costs in the policy debate, see Dadush and Stancil (2011) and Peeters and den Reijer (2012). In addition the Euro Pact 2011 (see European Commission (2015)) focused specifically on the use of relative unit labor costs as a measure of non-productivity related pressures on competitiveness within the Eurozone.

of influence on real exchange rates will be displayed in terms of non-productivity related movements in relative unit labor costs.

Rather than inferring the influence of labor supply shocks from relative unit labor costs, we also compute direct measures of the labor wedge. We find empirical results very similar to those using relative unit labor costs when the estimates are appropriately compared. When controlling for the measured labor wedge shock, Eurozone real exchange rates are related to sectoral productivity as in the Balassa Samuelson model, and again, movements in the labor wedge lead to real appreciation. We also solve a version of the theoretical model using these direct measures of the labor wedge and find results also qualitatively and quantitatively close to those from the empirical regressions.

The paper builds on a large literature on the explanation of secular movements in real exchange rates. A central prediction of many theoretical models (including, but not restricted to the Balassa-Samuelson model) is that the cross-country distribution of real exchange rates should be related to relative GDP per capita. High income countries should have stronger (more appreciated) real exchange rates. Rogoff (1996), for example, uses relative GDP per capita as a proxy for the relative productivity in the traded sector. Rogoff finds in cross-sectional 1990 data that includes poor and rich countries, a strong relationship between relative GDP per capita and the real exchange rate.[5] However, Rogoff then notes "... whereas the relationship between income and prices is quite striking over the full data set, it is far less impressive when one looks either at the rich (industrialized) countries as a group, or at developing countries as a group". In particular, among high-income countries with floating exchange rates, there is little evidence of a relationship between GDP per capita and the real exchange rate.

The Balassa-Samuelson theory suggests real exchange rates should be related to sectoral total factor productivity (TFP) rather than income levels. There are few studies that examine the cross-sectional dimension of the Balassa-Samuelson hypothesis using sectoral data on TFP, because most TFP data that is used for cross-country comparisons is in index form and is only useful for looking at the time-series dimension. The evidence favorable to the Balassa-Samuelson effect is much weaker in the time-series dimension. A number of papers have looked at the relationship between productivity and real exchange rates, but in most cases they can report only evidence of a long run relationship such as cointegration. Thus, Chinn and Johnson (1996) use measures of total factor productivity, and find that when controlling for other variables such as government expenditure, there is evidence of cointegration of the real exchange rate and the relative productivity variable for 14 OECD countries.[6] Canzoneri et al. (1996) find cointegration between relative labor productivities and the real exchange rate for a panel of OECD countries. Lee and Tang (2007) examine the effect of sectoral productivity growth in a panel of OECD economies with floating exchange rates, and find conflicting evidence for the impact of labor productivity as opposed to TFP on the real exchange rate. Their results provide only mild support for the tradi-

[5]Bergin et al. (2006) note that this cross-sectional relationship has strengthened over time, and suggests that the tradability of goods is endogenous and may increase as a sectors productivity grows.

[6]De Gregorio et al. (1994) use the same TFP data and country coverage as Chinn and Johnston to examine the dynamics of the prices of nontradable relative to tradable goods.

tional Balassa-Samuelson mechanism. Gubler and Sax (2017) find no evidence at all for the Balassa-Samuelson prediction.[7]

Bordo et al. (2017) find a long-run relationship between relative income and real exchange rates in a panel of fourteen countries relative to the U.S. with a sample of over 100 years of data. Chen et al. (2015) find that in the cross section of prices provided in the International Comparison Project, the relative price of non-traded goods accounts for two-thirds of the cross-sectional variation in real exchange rates. Choudri and Schembri (2014) extend the Balassa-Samuelson model to allow for differentiated products in exports, and then find time-series support for a long-run relationship between sectoral productivity and the real exchange rate in accounting for the Canada-U.S. real exchange rate.

A notable finding of some of these papers (e.g. De Gregorio et al. (1994), Canzoneri et al. (1996)), Lee and Tang (2007)) is that there is often stronger evidence of the effect of relative sectoral productivity on within-country relative prices than can be found in between-country real exchange rates. This may be due to the presence of nominal exchange rate fluctuations that have little to do with relative productivity differentials. Again, this suggests to us that a focus on real exchange rate determination in a sample where nominal exchange rate movement is absent or minimized may be a fruitful avenue of investigation.

The channel through which relative productivity levels influence real exchange rates is their effect on the relative price of non-traded goods. Engel (1999) produces evidence that little of the variance of changes in U.S. real exchange rates can be accounted for by the relative price of non-traded goods. Almost all of the variance arises from movements in the consumer prices of traded goods in the U.S. relative to other countries. Several studies (e.g., Devereux (1999), Engel (1999), Burstein et al. (2003), Burstein et al. (2005), Betts and Kehoe (2006)) suggest that differences in consumer prices of traded goods across countries may be accounted for by changes in the relative price of non-traded distribution services, but the evidence for this hypothesis is weak for high-income countries. However, the seminal paper by Mussa (1986) documents a number of differences between the behavior of real exchange rates in countries with fixed nominal exchange rates versus countries that have floating rates. Among these are the significantly higher volatility of real exchange rates under floating. Our findings in this paper are striking evidence against "nominal exchange regime neutrality" (using Mussa's famous phrase.)

The price data we use is unique and of very high quality. One major advantage of our study relative to many papers in the literature, is that the price data is in levels, has a broad coverage governing the complete consumer basket in the Eurozone countries studied, and has a very high degree of cross country comparability. In Section 3 as well as in an extensive

[7]Hsieh and Klenow (2007) relate the Balassa-Samuelson model to the well-known finding that the price of investment goods tends to be higher in poorer countries. Using ICP-Penn World Tables data they find that poorer countries have lower TFP in the tradable-investment sector than in the non-tradable consumption sector, leading to lower prices of consumption goods in these countries. Other papers have recently used non-linear convergence techniques. Lothian and Taylor (2008) find a long-run relationship between relative per capita income levels and real exchange rates among the U.S., U.K. and France. Chong et al. (2012) examine the real exchange rates of 21 OECD countries from 1973-2008. That study uses nonlinear time series techniques to purge real exchange rates of short-run monetary and financial factors, and then finds a link between relative income per capita levels and long-run real exchange rates.

data Appendix A, we describe the construction of the data, and additionally in Appendix C we emphasize the extensive set of procedures that Eurostat follows to ensure that goods in each of the categories are measuring very similar products across countries.

The second unique aspect of our data is an annual panel of sectoral TFP levels across nine Eurozone countries. This TFP data allow us to make both cross-sectional and time series comparisons across sectors and countries. To our knowledge, this is the first time that a sectoral TFP panel in levels has been used to study real exchange rate determination and the Balassa-Samuelson hypothesis.

The paper is organized as follows. The next section sets out a basic theoretical model of real exchange rates with shocks to productivity and labor supply, and derives a simple analytical example of the link between real exchange rates, productivity, and unit labor costs. Section 3 outlines our data and shows some properties of European real exchange rates for the Eurozone countries. This section also describes the properties of sectoral productivity and unit labor costs for a restricted sample of countries, and explores the relationship between relative unit labor costs and the labor wedge. We provide empirical estimates of an amended Balassa-Samuelson relationship for the Eurozone. Section 4 calibrates the theoretical model and performs the same regressions on simulated data as were done with the Eurozone data. Some conclusions follow.

2 Real Exchange Rates in a Theoretical Model

2.1 A Basic New Keynesian model

Our data is a balanced panel of European countries' real exchange rates. In the model simulations, we construct a panel of equivalent dimensions. But the theoretical explication of the model can be presented using the standard two-country DSGE approach. Let these countries be called 'Home' and 'Foreign'. We primarily present equations for Home. Equations for the Foreign country are symmetric to those for Home, and Foreign variables are denoted with a *.

The utility of a representative infinitely lived Home country household evaluated from date 0 is defined as:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \Upsilon_t \frac{N_t^{1+\psi}}{1+\psi} \right), \quad \beta < 1. \tag{1}$$

where C_t in (1) is the composite Home consumption bundle, and N_t is Home labor supply. The disutility in labor supply Υ_t is time-varying and country-specific.

The composite consumption good is defined over a traded and non-traded sub-aggregate. Then the traded sub-aggregate is defined over home and foreign retail goods. In turn retail goods are comprised of home and foreign produced goods, combined with inputs of non-traded goods that are used as distribution inputs into home and foreign retail traded goods.

The overall consumption aggregate is:

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

where C_{Tt} and C_{Nt} represent, respectively, the composite consumption of traded and non-traded goods. The elasticity of substitution between traded and non-traded goods is θ. Traded consumption is decomposed into consumption of Home and Foreign retail goods:

$$C_{Tt} = \left(\omega^{\frac{1}{\lambda}} C_{Ht}^{1-\frac{1}{\lambda}} + (1-\omega)^{\frac{1}{\lambda}} C_{Ft}^{1-\frac{1}{\lambda}}\right)^{\frac{\lambda}{\lambda-1}},$$

where λ is the elasticity of substitution between the Home and Foreign traded good. Home households put weight ω on Home consumption goods in their consumption basket. In the Foreign country, households put weight ω on Foreign consumption goods. When $\omega > 1/2$ households have a home bias, i.e. a preference for the good produced in their own country.

As noted, retail consumption of traded goods requires the use of non-traded goods in order to facilitate consumption.[8] This can be rationalized by the presence of costs of distribution of traded goods which must be incurred by local (i.e. non-traded) inputs. Hence, we assume that the production of consumption-related retail goods in sectors H and F are assembled according to:

$$\begin{aligned} C_{Ht} &= \left(\kappa^{\frac{1}{\phi}} I_{Ht}^{1-\frac{1}{\phi}} + (1-\kappa)^{\frac{1}{\phi}} V_{Ht}^{1-\frac{1}{\phi}}\right)^{\frac{\phi}{\phi-1}} \\ C_{Ft} &= \left(\kappa^{\frac{1}{\phi}} I_{Ft}^{(1-\frac{1}{\phi})} + (1-\kappa)^{\frac{1}{\phi}} V_{Ft}^{1-\frac{1}{\phi}}\right)^{\frac{\phi}{\phi-1}} \end{aligned}$$

where I_{Ht} represents inputs of the Home export good into the retail consumption of that good, and V_{Ht} represents input of the Home non-traded good into the retail consumption of the export good. The elasticity of substitution between non-traded inputs and the export good itself is ϕ.

The consumption aggregates imply the following price index definitions:

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

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

where P_{Tt} and P_{Nt} represent traded and non-traded price levels, and $\tilde{P}_{Ht}$ and $\tilde{P}_{Ft}$ are retail prices of consumption of Home and Foreign traded goods.

A key feature of the price indices is that traded goods retail prices depend on prices at the dock as well as the non-traded goods price. Hence:

$$\tilde{P}_{Ht} = \left(\kappa P_{Ht}^{1-\phi} + (1-\kappa) P_{Nt}^{1-\phi}\right)^{\frac{1}{1-\phi}}$$

[8]The importance of distribution costs in real exchange rate determination has been emphasized in the literature on exchange rate pass-through. See for example Burstein et al. (2003). Engel (1999) investigates the link between distribution costs and traded consumer prices in accounting for real exchange rate volatility. The role of a distribution sector in regard to the predictions of the Balassa-Samuelson model has been emphasized theoretically by Devereux (1999) and empirically by MacDonald and Ricci (2005).

$$\tilde{P}_F \quad = \quad \left(\kappa P_{Ft}^{1-\phi} + (1-\kappa)P_{Nt}^{1-\phi}\right)^{\frac{1}{1-\phi}}$$

We define the real exchange rate as the price of Foreign relative to Home consumption

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

Real exchange rate variation arises because prices of non-traded consumption goods and distribution services are not equalized across the Home and Foreign countries, and because of the possibility that consumption baskets differ. Note that the nominal exchange rate between the Home and Foreign country is fixed at one because countries in the Eurozone share a common currency.

We assume that international financial markets are complete.[9] This implies a risk sharing condition given by:

$$\frac{C_t^{-\sigma}}{P_t} = \frac{C_t^{*-\sigma}}{P_t^*} \tag{2}$$

Households choose consumption of individual goods and labor supply in each sector in the usual way. The implicit labor supply for Home households is given by:

$$W_t = \Upsilon_t P_t C^\sigma N_t^\psi \tag{3}$$

where W_t is the nominal wage. Note that Υ_t is written here as a preference shock, but in the model it is equivalent to 'labor wedge', as we discussed in the introduction and further below. The demand for traded and non-traded goods is described as:

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

Demand for Home and Foreign composite traded goods is denoted as:

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

We can express the individual consumption demand for Home and Foreign traded goods (net of the distribution services) as:

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

Firms in each sector produce using labor and a fixed capital stock.[10] A typical firm in the non-traded (traded) sector has production function $Y_{Nt}(i) = A_{Nt}N_{Nt}(i)^\alpha$, $(Y_{Ht}(i) =$

[9]It has been shown in many cases that open economy models with limited asset markets have characteristics that are very similar to models with complete markets (e.g. Chari et al. (2002)). In particular, the behaviour of the real exchange rate in our model would be almost identical if we instead assumed a market structure with trade only in non-contingent bonds.

[10]The implications for real exchange rates would not differ materially were we to allow for endogenous capital accumulation.

$A_{Ht}N_{Ht}(i)^{\alpha})$. Thus, there are two productivity shocks - shocks to the non-traded sector A_{Nt}, and to the traded sector A_{Ht}. In addition to the labor supply shock Υ_t, these shocks are the key fundamental driving forces of equilibrium real exchange rates in the model.

With flexible prices, assuming that each firm is a monopolistic competitor with constant elasticity of substitution between varieties within each sub-sector, a firm in the Home country would set its price equal to marginal cost adjusted by a constant markup. For the typical non-traded goods firm and a Home traded goods producing firm, we have, in a flexible price environment:

$$P_{Nt}^{flex} = \Omega\frac{W_t}{\alpha A_{Nt}L_{Nt}^{\alpha-1}}, \qquad P_{Ht}^{flex} = \Omega\frac{W_t}{\alpha A_{Ht}L_{Ht}^{\alpha-1}}$$

where Ω is a constant markup depending on the elasticity of substitution between varieties.

We assume that firms cannot reset prices freely but must follow a Calvo price adjustment specification where the probability of price adjustment equal to $1-\zeta_i$, where $i = N, F$. Home firms use domestic household nominal marginal utilities as stochastic discount factors. When prices are reset, firms set their price equal to a discounted present value of current and anticipated future fully flexible prices:

$$\begin{aligned} P_{Nt} &= \frac{E_t\sum_{\tau=t}^{\infty}\Gamma_{N,\tau}P_{N\tau}^{flex}}{E_t\sum_{\tau=t}^{\infty}\Gamma_{N,\tau}}, \\ P_{Ht} &= \frac{E_t\sum_{\tau=t}^{\infty}\Gamma_{H,\tau}P_{H\tau}^{flex}}{E_t\sum_{\tau=t}^{\infty}\Gamma_{H,\tau}} \end{aligned}$$

where $\Gamma_{N,t}$ and $\Gamma_{H,t}$ represent adjusted stochastic discount factors that incorporate the Calvo probability of a firm's price staying constant each period. Foreign firms price Foreign exports, P_{Ft}^{*}, and Foreign non-traded goods, P_{Nt}^{*}, analogously.

The countries of the Eurozone share a common monetary policy. The instrument of monetary policy is the nominal interest rate, and we assume the central bank follows an inflation targeting instrument rule. For simplicity, we assume the central bank targets the inflation rate in the Foreign country:

$$r_t = \rho + \sigma_p\pi_t^{*} \tag{4}$$

where $\pi_t^{*} = p_t^{*} - p_{t-1}^{*}$ is the Foreign inflation rate (and $p_t^{*} = \log(P_t^{*})$).[11] In practice, in simulation results, we find it makes essentially no difference if the central bank targets the Home inflation rate, the Foreign inflation rate, or an average. More generally, as we will see in the simulations of the model, the presence of sticky prices has minimal effects on the results, so as an implication, different specifications of the monetary rule will have little relevance for the conclusions.

Finally, goods market clearing conditions are given as:

$$Y_{Ht} = I_{Ht} + I_{Ht}^{*} \tag{5}$$

[11]In our empirical work, the Foreign country is a set of 15 members of the European Union, 12 of which are in the Eurozone. The assumption here that the Foreign inflation rate is targeted is meant to capture the notion that Eurozone inflation is targeted by the European Central Bank.

$$
\begin{aligned}
Y^*_{Ft} &= I_{Ft} + I^*_{Ft}, \\
Y_{Nt} &= C_{Nt} + V_{Ht} + V_{Ft}, \\
Y^*_{Nt} &= C^*_{Nt} + V^*_{Ht} + V^*_{Ft}.
\end{aligned}
$$

Traded goods production must equal demand derived from Home and Foreign consumers' consumption of retail traded goods. Non-traded goods production is equal to that accounted for by consumers and that used in the distribution services of traded goods in each country.

In addition, we must have labor market clearing in each country so that:

$$N_t = N_{Nt} + N_{Ht} \tag{6}$$

$$N^*_t = N^*_{Nt} + N^*_{Ht} \tag{7}$$

The definition of equilibrium is standard and we omit it to save space.

2.2 The Real Exchange Rate Decomposition

The model real exchange rate depends on structural differences across countries and time-varying country-specific shocks. Following Engel (1999), we write a log linear approximation of the real exchange rate around a symmetric steady state. Omitting time subscripts for ease of notation, we have:

$$q = (1 - \gamma) q_n + q_T \tag{8}$$

where $q_n \equiv (p^*_N - p^*_T - (p_N - p_T))$, and $q_T \equiv p^*_T - p_T$.

The first expression on the right hand side is the difference across countries in the relative price of non-traded to traded goods. A rise in the Foreign relative price, relative to the Home relative price causes a Home real exchange rate depreciation. The second expression on the right hand side is the traded goods real exchange rate at the retail level. With distribution costs in retail, this term is also affected by the relative price of non-traded goods. So we further decompose q_T as:

$$q_T = \frac{1-\kappa}{\kappa} q_n + (2\omega - 1)\tau + p^*_H - p_H \tag{9}$$

where $\tau = p^*_F - p^*_H = p_F - p_H$ is the terms of trade of the Home country and $p^*_H - p_H$ is the deviation from the law of one price in Home traded goods. This expression tells us that the traded goods real exchange rate is driven by a) differences in relative non-traded goods prices across countries (when there is a non-traded distribution content in traded goods; i.e. $\kappa < 1$, b) the terms of trade, when there is home bias in preferences (i.e. $\omega > \frac{1}{2}$), and c) deviations from the law of one price - a higher Foreign price of identical goods relative to the Home price is associated with a real exchange rate depreciation. From (8) and (9), it follows that the aggregate real exchange rate is

$$q = \frac{1-\kappa\gamma}{\kappa} q_n + (2\omega - 1)\tau + p^*_H - p_H$$

The model of CES demand with monopolistic competition does not feature any explicit price-discrimination across countries. So there is no pricing to market by sellers.[12] Moreover, because our model describes a single currency area, if prices are pre-set, they are done so in the same currency. So the law-of-one-price must apply for equivalent goods across countries: $p_H^* = p_H$ (and also $p_F^* = p_F$).

2.3 Relative Productivity and Real Exchange Rates

Our empirical investigation links the real exchange rate to the fundamental shocks introduced in the theoretical model. We work through a special case of the model in order to motivate this link. The standard Balassa-Samuelson mechanism implies that a rise in relative traded goods productivity causes a rise in the relative price of non-traded to traded goods (when compared across countries), leading to a real exchange rate appreciation. But when Home and Foreign traded goods are not perfect substitutes there is a countervailing effect coming from the endogenous response of the terms of trade. A rise in relative Home traded goods productivity should lead to a terms of trade deterioration. Conditional on the relative price of non-traded goods to domestic goods in each country, this should lead to a real exchange rate depreciation.

We also introduced a labor supply shock Υ, which will be interpreted as a 'labor wedge'. This has an important effect on the real exchange rate independent of sectoral productivity. To illustrate, take a special case of the model where a) $\omega = \frac{1}{2}$ (no home bias), b) $\alpha = 1$, so that output is linear in labor input, and c) $\zeta_i = 0$, so that all prices are perfectly flexible. Again, take a log-linear approximation around a symmetric steady state. Without home bias in retail goods consumption, the real exchange rate is just the ratio of non-traded prices across countries. Hence from (8) and (9) we have:

$$q = (1 - \gamma\kappa)(p_N^* - p_N) \tag{10}$$

where the term $\gamma\kappa$ indicates that non-traded goods prices influence the real exchange rate both directly through the price of consumer non-traded goods and indirectly through the distribution margin of traded goods.[13]

With flexible prices, linearity in labor, and factor mobility between sectors, we have $p_N - p_H = a_H - a_N$, where a_H and a_N represent the log of Home productivity in the traded and non-traded sector, respectively. Since this holds equally for the Foreign country, the real exchange rate becomes:

$$q = (1 - \gamma\kappa)(p_F^* - p_H + (a_F^* - a_H) - (a_N^* - a_N)) \tag{11}$$

This expression separates the real exchange rate into the components driven by relative non-traded goods productivity, relative traded goods productivity, and the terms of trade $p_F^* - p_H$.

[12] We could introduce pricing-to-market through endogenous markups and strategic complementarity as in Itskhoki and Mukhin (2016). This would allow variations in $p_H^* - p_H$ that depend on country specific shocks. But since the real exchange rate and productivity data we employ is at annual frequency, this extension would be unlikely to affect the match between the data and the model.

[13] We assume that the distribution share is identical across countries and for domestic and imported goods.

The original Balassa-Samuelson model assumes that the terms of trade are constant, so the real exchange rate depends only on relative productivity in the traded and non-traded goods sectors.

To allow for a more fundamental structural interpretation of the real exchange rate, we proceed as follows. First, we show the relationship between the terms of trade and relative unit labor costs. Unit labor cost is defined as the nominal wage divided by output per worker. For the Home country, we have

$$\text{ULC} = w - \gamma\kappa(y_H - n_H) - (1-\gamma\kappa)(y_N - n_N) = w - \gamma\kappa a_H - (1-\gamma\kappa)a_N$$

where w is the log of the nominal wage.

Again using profit maximization in the traded goods sector, we have relative unit labor cost for Foreign to Home defined as

$$\text{RULC} = p_F^* - p_H + (1-\gamma\kappa)(a_F^* - a_H) - (1-\gamma\kappa)(a_N^* - a_N) \tag{12}$$

Then substitute (12) into (11) to get

$$q = (1-\gamma\kappa)\ \text{RULC} + (1-\gamma\kappa)\gamma\kappa(a_F^* - a_H) - (1-\gamma\kappa)\gamma\kappa(a_N^* - a_N) \tag{13}$$

Condition (13) represents an amended Balassa-Samuelson specification that controls for terms of trade movements through the use of relative unit labor costs. This equation motivates our main empirical specification in section 3 below. Conditional on relative unit labor costs, the traditional Balassa-Samuelson mechanism will apply; the real exchange rate is positively related to relative (Foreign vs. Home) traded goods productivity and negatively to relative non-traded goods productivity. But in addition, relative unit labor costs play an independent role in real exchange rate determination through their effect on the terms of trade. A rise in relative unit labor costs (Foreign vs. Home) will lead to a real exchange rate depreciation, according to equation (13).

2.4 Solution for special case model

We can explicitly solve the approximated model under assumptions a)-c), and in addition, assumption d) $\theta = \phi = 1$.[14]

Then relative unit-labor cost and the real exchange rate are given by:

$$\text{RULC} = -\frac{\beta_0}{D}(a_F^* - a_H) - \frac{\beta_1}{D}(a_N^* - a_N) + \frac{\sigma}{D}(\chi^* - \chi) \tag{14}$$

$$\begin{aligned} q = {} & \frac{1}{D}\left[\sigma\psi\gamma\kappa^2(\lambda-1)(1-\gamma\kappa)\right](a_F^* - a_H) \\ & -\frac{1}{D}(1-\gamma\kappa)\left[\sigma(1+\psi+\psi\gamma\kappa^2(\lambda-1))\right](a_N^* - a_N) + \frac{\sigma}{D}(1-\gamma\kappa)(\chi^* - \chi) \end{aligned} \tag{15}$$

[14] Again, these assumptions aid in the exposition only. Qualitatively, the results are robust to a more general specification.

where $D > 0$, [15] and

$$\begin{aligned}\beta_0 &\equiv \gamma\kappa[(1+\psi)\sigma + \psi(1-\gamma\kappa)((1-\gamma\kappa)(1-\sigma) - \sigma\kappa(\lambda-1))] \\ \beta_1 &\equiv (1-\gamma\kappa)[(1+\psi)\sigma - \gamma\kappa\psi((1-\gamma\kappa)(1-\sigma) - \kappa\sigma(\lambda-1))]\end{aligned}$$

Relative unit labor costs depend on relative productivity in both sectors, as well as the relative labor supply shock. A labor supply shock directly pushes up wages for given productivity, which leads to a terms of trade appreciation and a real exchange rate appreciation. The impact of sectoral productivity shocks on relative unit labor costs is more complex. On the one hand, a productivity increase in either sector will reduce unit labor costs, holding wage rates constant. But the productivity shock will also lead to changes in hours worked, indirectly impacting wages through labor supply. From (14), we can see that for $\sigma \geq 1, \lambda \geq 1$, the empirically relevant values for these elasticities, RULC is always negatively related to relative productivity in non-tradables. Intuitively, this occurs because in this case, the income effects of non-traded productivity increases tend to dominate substitution effects so that hours worked falls. By contrast, relative unit labor costs may be increasing in $a_F^* - a_H$ for the same configuration of parameter values.

Expression (15) shows the full model solution for the real exchange rate (for the restricted set of parameter values defined above). As in Balassa-Samuelson, (relative) traded goods productivity should lead to real appreciation, while non-traded goods productivity leads to real depreciation. But in addition, shocks to relative labor supply will cause a real appreciation through their effect on the terms of trade.

In the more general model with sticky prices, the real exchange rate cannot be neatly expressed in the form of (15). Nevertheless, as shown below, even with the general specification that involves sticky prices, it is still important to allow a separate role for unit labor costs in a quantitative account of real exchange rate determination.

2.5 Relationship to the labor wedge

The labor supply shock in the model is observationally equivalent to a 'labor wedge'. The labor wedge is defined as the gap between the marginal product of labor and the marginal rate of substitution between consumption and leisure of the representative household. In our model, we have identified $\chi^* - \chi$ as a relative preference shock, but since it is unobserved, it is equivalent to one form of the labor wedge definition used in the literature. Many papers (e.g. Hall (1997), Chari et al. (2007)) have identified the labor wedge as a residual which can account for a substantial fraction of aggregate business cycles.[16] While the wedge in our model is equivalent to a labor supply shock, it could equally be thought of as coming from

[15] In particular, $D = \psi(1-\gamma\kappa)^2 + \sigma(1 + \psi\gamma\kappa(1 - \gamma\kappa + \lambda\kappa + (1-\kappa)))$.

[16] Most of this literature focuses on closed economy business cycles, but Karabarbounis (2014b) explores the role of labor wedges in accounting for international real business cycle moments. He interprets the labor wedge as reflecting unmeasured home production, which is observationally equivalent to the wage mark-up of Galí et al. (2007), and is countercyclical. In a more elaborate model, the labor supply shocks in our paper (which are also countercyclical) could be reinterpreted as reflecting the presence of unmeasured home production.

some underlying distortion in the labor market such as changes in labor taxes, variation in monopoly power in wage setting, sticky nominal wages, search costs in job finding, or other factors. In many instances, such distortions will enter the model in equivalent forms to labor supply shocks.

The exact measurement of the labor wedge usually depends on assumptions on the intertemporal elasticity of substitution, the Frisch elasticity of the labor supply, and the form of the production function. Rather than measure it directly, however, we take an indirect approach, using reported unit labor costs as a variable influenced by both the labor wedge and movements in relative sectoral productivities. This has the advantage that we can avail of published measures of unit labor costs assembled in the same manner as price and productivity data.[17]

An additional advantage in using the relative unit labor cost as an indirect measure of the labor wedge is that it closely relates to the policy debate on the sources of real exchange movements in the Eurozone. The disconnect between wage costs and productivity growth has been a source of substantial discussion in the policy debate over exchange rates and competitiveness in the Eurozone.[18] The source of this disconnect is not fully understood - it may be due to non-competitive forces in labor markets in some European countries or structural impediments in other markets. But whatever the source, the impact of these distortions will be reflected (in our model) in non-productivity related movements in relative unit labor costs, and in turn, with movements in the terms of trade. Appendix A.6 presents evidence of a strong correlation between relative unit labor costs and measures of institutional labor and product market distortions for Eurozone countries. This supports the interpretation of the non-productivity component of RULC as a reflection of the effective labor wedge.

The literature on the labor wedge sometimes draws a distinction between the wedge as the gap between the wage and the household MRS, on the one hand, and the wedge and the firm's MPL on the other (see Karabarbounis (2014a) and Galí et al. (2007)). Our interpretation of the labor wedge is the former one, coming from the household side. In fact, this is an important element in the definition of (13) and (15). If the labor wedge comes from the firm's side, then the expression (13) is no longer an appropriate representation of the real exchange rate, because we would need both RULC *and* the labor wedge as right hand side variables.

Intuitively, when the labor wedge is on the household side, it has its influence on prices through its effect on wages. A wedge that reduces labor supply will increase wages, which drives up prices, and increases the unit labor cost. Holding productivity constant, this means that unit labor costs and the real exchange rate move in the same direction, consistent with our empirical evidence in the next section. A labor wedge on the firm side is a wedge between

[17] In the special case solution (14), relative unit labor costs depend only on sectoral productivities and the labor wedge. Then since (13) already controls for productivity, regression coefficients on RULC using (13) should accurately capture the impact of the labor wedge.

[18] Much of the discussion of the evolution of real exchange rates in Europe has focused on the role of unit labor costs.Felipe and Kumar (2011) indeed document that differences in unit labor costs in the Eurozone are highly correlated with the relative price of output ($p_F^* - p_H$ above). Also see Peeters and den Reijer (2012), Peeters and den Reijer (2014) and Dadush and Stancil (2011).

the price and the marginal cost. An increase in that wedge leads prices and wages to move in the opposite directions. If that were the source of the wedge, the real exchange rate and unit labor costs would move in opposite directions, contrary to our empirical findings.

Appendix H derives the result that in the flexible-price, symmetric model, a regression of the real exchange rate on relative productivity and relative unit labor costs would have a negative coefficient on relative unit labor costs when the wedge is on the firm side. We take this as suggestive evidence that the relevant driver of the labor wedge is the gap between the wage and the households MRS.Karabarbounis (2014a) provides an empirical argument for locating the labor wedge on the household rather than the firms side of the labor market. However, Bils et al. (2014) provides evidence in the U.S. market that the firm-side distortion is an important component of the labor wedge, so the question is not settled.[19]

2.6 Measures of the labor wedge

Motivated by (13), our main empirical specification indirectly infers the impact of labor supply shocks from an estimate of the conditional response of the real exchange rate to movements in relative unit labor costs. As an alternative however, we also estimate real exchange rate equations using direct measures of the labor wedge.

We will explore two alternative direct measures of the labor wedge. The first measure comes from inferring the labor wedge using the equilibrium of the static flexible price model as described in (14). All variables in (14) are observable except $\chi^* - \chi$. Thus, with knowledge of (14) and under an assumed setting for parameters, we can back out a measure of the labor wedge. In this case, the labor wedge, is

$$\chi^* - \chi = \frac{1}{\sigma} \left(\beta_0(a_F^* - a_H) + \beta_1(a_N^* - a_N) + D \text{ RULC}\right) \tag{16}$$

where the coefficients are defined in the previous section. Then, using the calibrated parameter values which are discussed in section 4.1 below, equation (16) gives us a panel of labor wedges for the Eurozone sample.

As an alternative to (16), we could measure the labor wedge directly from equation (12), incorporating the equilibrium conditions for traded goods firms, $p_F^* - p_H = w^* - w - (a_F^* - a_H)$, the labor supply conditions (3) and the risk sharing condition (2). This gives the expression:

$$\chi^* - \chi = \text{RULC} + \gamma\kappa(a_F^* - a_H) + (1 - \gamma\kappa)(a_N^* - a_N) - \psi(\ell^* - \ell) \tag{17}$$

Using measured unit labor costs and sectoral productivities, along with cross-country data on hours worked, the labor wedge can be inferred from (17), for given values of the parameters γ, κ, and the Frisch elasticity of labor supply ψ. The difference between (14) and (17) is that the former condition uses the labor market equilibrium values for hours,

[19] Karabarbounis (2014a) separately estimates the explanatory power of the firm and household labor wedges for the overall labor wedge in Austria, Finland, France, Germany, Ireland, Italy and Spain. Averaging over countries, the firm wedge explains 12% of the cyclical variation in the total wedge, while the household wedge explains 66% (the total does not add to unity because the separate wedges are not independent). In all countries, the explanatory power of the household wedge is at least twice that of the firm wedge.

assuming the presence of the labor wedge distorting hours worked, while the latter condition needs data on hours. Appendix A.6 shows that the labor wedge measured from (17) is also positively correlated with measures of institutional labor and product market distortions for the Eurozone.[20]

2.7 Demand shocks and the real exchange rate

We have not introduced other independent sources of real exchange rate variation, coming from shocks to aggregate demand, such as country specific shocks to taxes, government spending or fiscal deficits.[21] In Appendix D, we show that the addition of government spending or fiscal deficits to specification (13) does not alter our empirical results.[22]

2.8 The role of the terms of trade

Our real exchange rate decomposition rests on the role of shocks to both sectoral productivity and the labor wedge. But equation (11) implies that the real exchange rate should depend positively upon the terms of trade. Although in principle, we could bring this relationship directly to the data, this alternative strategy encounters a number of conceptual and empirical difficulties. First, the terms of trade is an endogenous relative price just as is the real exchange rate and so is simultaneously determined with the real exchange rate. Directly estimating (11) would then involve regressing one relative price on sectoral productivity plus another relative price. But even aside from this, we lack the relevant data needed to test condition (11) directly. Our data as described below allows for a relatively clean decomposition of goods broken down by the degree of tradability. But we do not have any information

[20] In the closed economy context, the wedge can be measured using only physical quantities of consumption, hours, marginal product of labor. But because producer prices and consumer prices differ in an open economy model, measuring the labor wedge inevitably involves using some international relative price, such as RULC in equation (17).

[21] It is well established in the literature that shocks to aggregate demand can affect the real exchange rate, at least in the short run. Most of the research on this linkage focuses on countries with floating exchange rates. Some exceptions are Duarte and Wolman (2008), who show that in a currency union, transitory government spending raises home inflation and leads to real appreciation, Mendoza (2005), who models the real exchange rate in a small two-sector economy with fixed exchange rates, and Altissimo et al. (2005), who build a model with imperfect substitutability of labor types to explain determinants of inflation differentials in a monetary union, and show that intra-country dispersion of wages magnifies the standard Balassa-Samuelson propagation. Honohan and Lane (2003) conduct an empirical study of the aggregate demand-real exchange rate linkage in the eurozone. They find that inflation differentials within the eurozone are driven by the US dollar-euro exchange rate, fiscal surpluses and differential output movements. In US data, Kim and Roubini (2008) show that real exchange rate depreciates in response to government deficit shocks, as identified in a VAR.

[22] An alternative interpretation of a demand side shock is to consider a temporary shock to the household's marginal utility of consumption. This is analogous to a transitory shock to the time discount factor. In our model, this would be isomorphic to the efficiency wedge in Chari et al. (2007). We choose to focus on the labor wedge as a source of real exchange rate variability, as there is considerable evidence from other studies that the labor wedge is a more important source of business cycle volatility than the efficiency wedge, and because separately, as discussed below, the labor wedge in our model is highly correlated with independent institutional measures of labor market distortions.

on the breakdown by direction of trade, or indeed whether the product is traded at all. In order to implement condition (11) empirically, we would need bilateral terms of trade for our sample of Eurozone countries, both as changes over time but also in comparable levels across countries. These data are currently not available.[23]

3 Data: Real Exchange Rates and Productivity

3.1 Real Exchange Rates in European Data

We construct Eurozone real exchange rates from disaggregated price data. The data are provided by Eurostat as part of the Eurostat-OECD PPP Programme. They are arranged in the form of 'Price Level Indices', or PLI's. A PLI gives the price of a good at a given time for a given country, relative to a reference country price. Hence, it is a good-specific PPP, although within the Eurozone this measure does not involve different currencies. The reporting frequency is annual, 1995-2009 and the PLI's are available for 146 "basic headings" of consumer goods and services. These include food (including food away from Home), clothing, housing costs, durable goods, transportation costs, as well as medical and educational services. They cover 100% of the consumption basket. The full list of PLI's for the basic headings of consumer goods and services is contained in Table A1 in the Appendix. For each item, the reference price is constructed as a ratio of the European average price of each good.[24] Hence the prices are comparable in levels, so that both cross section and time series real exchange rate variation can be examined. Our sample data contains 9 countries that entered the Eurozone in 1999.[25] [26] We construct aggregate and sectoral real exchange rates from the underlying price series, using expenditure weights. The expenditure weights are constructed using euro expenditures on every basic heading in every country and every year. Thus, the expenditure weights are time-varying, year by year.[27] Let q_{it} be the real

[23] One option is to use a measure of the terms of trade constructed from the Penn World Tables, which report manufacturing good price series designed to be cross-country comparable in levels. In Appendix E we report estimates using within-Eurozone terms of trade constructed in this way. We find a substantial positive correlation between the terms of trade as measured in this manner and relative unit labor costs, as suggested by the theoretical model (e.g. equation (12)). Using these estimates, in real exchange rate regressions, we find a very high and significant coefficient on (our constructed measure) of $p_F^* - p_H$, and also significant and correctly signed estimates on both measures of sectoral productivity in a pooled regression. In the time series however, the high correlation between $p_F^* - p_H$ tends to dominate the estimates, making sectoral productivity insignificant (although correctly signed).

[24] The average is taken over the 15 European Union countries given by: Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Spain, Sweden, Portugal, Finland and the United Kingdom.

[25] These are Belgium, Germany, Spain, France, Ireland, Italy, Netherlands, Austria, and Finland. While it is possible to include more Eurozone countries' PLI's (e.g., Luxembourg, Greece and Portugal), this would be pointless as those countries do not have TFP data we need for our analysis (see below).

[26] Note that our sample includes the period 1995-1998 before the official inception of the euro. But intra-Eurozone exchange rate fluctuations over this period were very small, with average quarterly standard deviations about 1 percent.

[27] We also experimented with the use of time invariant weights, using average weights over the sample, and the results were essentially identical to those reported below. In addition, we do not explicitly incorporate

exchange rate for country i at time t, and let q_{iTt} (q_{iNt}) represent the average real exchange rate for the subset of traded (non-traded) goods. As in the model, real exchange rates are measured so that an increase represents a depreciation for the home country.[28]

Relative to other studies that have compared price levels internationally, these data have a number of advantages. They cover the entire consumer basket. This contrasts with recent studies that have used only prices from a single supermarket chain (for example, Gopinath et al. (2011)), or from a single international retailer of household goods (Haskel and Wolf (2002) and Baxter and Landry (2012)), or from a small number of online retailers (Cavallo et al. (2014)). Some studies have used a more comprehensive selection of prices from the Economist Intelligence Unit survey (for example, Engel and Rogers (2004) or Crucini and Shintani (2008).) However, that data is not as comprehensive as the Eurostat data, and it does not strive for the degree of comparability across countries of goods and services that are priced. Appendix C quotes extensively from the Eurostat-OECD PPP manual to help to convey the care taken to make these prices comparable. Here we mention only a few points. First, while Eurostat reports prices for 146 basic headings, within each heading are numerous subheadings for which prices are compared. For example, in the category "other bakery products" price comparisons are made for "crispbread, rusks, toasted bread, biscuits, gingerbread, wafers, waffles, crumpets, muffins, croissants, cakes, tarts, pies, quiches and pizzas". For each of these items, an exhaustive effort is made to ensure comparability of the goods that are priced. The project also strives to price a product at the various types of outlets (for example, department store, supermarket, specialty outlet) in proportion to the share of national expenditure on the item that is made at each type of outlet. When prices from various similar outlets show higher variation within a country, more products are sampled.

We separate goods into traded and non-traded categories using criteria reported in the Appendix. Using these aggregate measures, some descriptive statistics are reported in Table 1. The Table first reports the average log real exchange rate over the sample for each country, denoted $\bar{q}$, as well as the equivalent measures for the traded goods real exchange rate $\bar{q}_T$, the non-traded goods real exchange rate, $\bar{q}_N$, and also the relative price of non-traded goods $\bar{q}_n = \bar{q}_N - \bar{q}_T$.

Composition of the consumption baskets differs across goods, countries and time. We construct expenditure weights for each good, country and year, using the expenditure data provided in the same Eurostat-OECD Programme. Specifically, for good i, country j and year t, we construct a weight $\gamma_{i,j,t} = \frac{exp_{i,j,t}}{\sum_i^{146} exp_{i,j,t}}$ where exp is the local expenditure. We then construct expenditure-weighted PLI's for all countries using $\gamma_{i,j,t}$.

Denoting $p_{i,j,t}$ as the log of a PLI, in year t, for a good i in EU15 relative to country j, we calculate the log of the real exchange rate of country j, $q_{j,t}$, as the expenditure-weighted

VAT differences, but Berka and Devereux (2013) show that there are only small differences in VAT across these European countries, and they change very little over the sample.

[28]Therefore, q_{it} represents the *inverse* of the average price level for country i, relative to the European average.

arithmetic average:

$$q_{j,t} = \sum_{i=1}^{146} \gamma_{i,j,t} p_{i,j,t}$$

Note that, in line with the literature, this measure is expressed such that an increase in $q_{j,t}$ is a real depreciation.

The characteristics of the sectoral real exchange rates, and the average relative price of non-traded goods closely mirror the aggregate real exchange rates. In general, we see that if for a given country i, we have $\bar{q}_i > 0$, (< 0), we also have $\bar{q}_{Ti} > 0$, (< 0), $\bar{q}_{Ni} > 0$, (< 0), and $\bar{q}_{Ni} - \bar{q}_{Ti} > 0$, (< 0). That is, if a country has a low (high) average price level relative to the European average, its non-traded goods price tends to be proportionately lower (higher) than its traded goods price, relative to the average. This offers some initially encouraging evidence for the Balassa-Samuelson model, in the sense that differences across countries in real exchange rates are mirrored by differences in internal relative sectoral prices in a manner consistent with Balassa-Samuelson.

The right panel of Table 1 reports standard deviations of annual real exchange rates. They are approximately 3 percent for most countries. We would anticipate that the standard deviation of non-traded real exchange rates exceeds that of the traded real exchange rates. We find this to be true for 8 of the 12 Eurozone countries. For the other countries, the difference between the standard deviation across sectors is too small to report.

Table 2 reports averages across all countries and over time. For comparison purposes, we also include data from the non-Eurozone high income European countries (these are Denmark, Iceland, Norway, Sweden, Switzerland and the UK), and a group of emerging market, mostly Eastern European countries (these are Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania and Turkey for the RER data). The first panel gives the average time series volatility of aggregate and sectoral real exchange rates. The second panel reports the cross country dispersion in aggregate and sectoral real exchange rates. The high income non-Eurozone economies have substantially higher time series standard deviations of real exchange rates, roughly twice that of the Eurozone countries. For the Eastern European economies, time series standard deviations are about 3 times that of the Eurozone [29]

The cross country dispersion of aggregate real exchange rates within the Eurozone is over 11 percent, about the same as that for the floating exchange rate countries. Table 2 suggests that the main difference between the Eurozone and the floating rate countries of Western Europe arises from the differences in their time-series standard deviations, which is quite intuitive.

Figure 1 illustrates some properties of real exchange rates in the Eurozone. Panel a) shows the pattern of mean annual standard deviations of all consumer good PLI's for the Eurozone as a whole. If PPP held at the goods level, this would be zero all the time. The

[29]Note that these are standard deviations of logs, rather than log differences. For the Eurozone and the floating exchange rate high income countries, there is little apparent trend in the real exchange rate over time. For many of the Eastern European countries, there is more of a clear trend downwards (towards appreciation) over the sample.

Figure indicates that overall dispersion fell progressively over the sample. However, panels b)-d), charting the level and time path of national aggregate and sectoral real exchange rates, tells a somewhat different story. First, there is considerable persistence in real exchange rate differentials over the whole sample between the lowest and highest countries, and secondly, there is substantial movement over time in relative positions.

3.2 Productivity and Unit Labor Cost data

We compute measures of total factor productivity that match the real exchange rate sample. This requires estimates of productivity in levels, both in the aggregate and by sector, for the same sample period as in the real exchange rate data. We construct a concordance between the sectors included in the Groningen Growth and Development Center's (GGDC thereafter) 1997 TFP level database, and the sectors included in the KLEMS time-series database. These two databases are meant to be used in conjunction, as described in Inklaar and Timmer (2008). Then, the cross-sectional TFP database and the time-series TFP database are linked using the constructed concordance to obtain annual sectoral panel TFP level data. We then use measures of the tradability of each sector and sectoral weights to construct level and time series of TFP for traded and non-traded sectors in each country. Following this, we organize the aggregate and sectoral TFP data so that they can be matched to the analogous real exchange rate measures: i.e. TFP in the EU relative to country i TFP. [30] Our panel dataset of TFP levels by sector then spans period 1995 - 2007.[31] The details of the construction are in Appendix A.

Tables 1 and 2 report descriptive statistics for traded and non-traded goods productivity in the same form as the real exchange rate data. In general, we see also that traded goods productivity is more volatile than non-traded goods productivity.

If there are country specific labor supply shocks, driven for instance by labor market institutions, unionization or regulatory changes, which are independent of productivity shocks, we should see this reflected in real wage movements that are not attributable to movements in aggregate or sectoral TFP. We capture this possibility by including unit labor costs as a separate variable in the regressions reported below. The theoretical justification for relating χ to unit labor costs is discussed in Section 2. Relative unit labor costs (RULC) are computed from the OECD STAN database, and expressed as average ULC in the EU17 (provided by the OECD) relative to ULC in country i (the same way as the sectoral productivity and real exchange rate data). A key feature of the OECD ULC measures is that they are constructed so as to be comparable across countries as well as over time. Tables 1 and 2 also report

[30] The matching is not quite perfect, because only 9 of the 12 Eurozone countries in the sample have TFP data: Belgium, Germany, Spain, France, Ireland, Italy, the Netherlands, Austria, and Finland. We lack TFP data for Greece, Luxembourg, and Portugal.

[31] While an extension of the dataset by two years is possible in principle, it requires a use of a new ISIC Revision 4 - based TFP index series from KLEMS. These are only available for a limited number of countries (e.g., Ireland as well as several countries we use in our EU12 base group do not have this data). Perhaps more importantly, the new index data is reported in ISIC Revision 4, which makes it more difficult to construct a concordance mapping to the 1997 cross-section vis-a-vis the US. Furthermore, this new dataset has several missing observations for the US, requiring imputation of data. We use the 1995-2007 panel.

descriptive statistics on unit labor costs.

According to (14), unit labor costs should be driven by a combination of sectoral productivity shocks and labor wedge shocks. As we discussed, the labor wedge may come from a number of possible distortions in labor markets. It is well known that that both labor and product markets of many European countries are characterized by various regulatory and other non-market frictions. European policymakers have emphasized the importance of monitoring divergence between growth in unit labor costs and productivity growth as signals of the erosion of competitiveness within the Eurozone (European Commission (2015)).[32]. Peeters and den Reijer (2014) compare wage and productivity developments across different Eurozone countries, emphasizing the importance of unit labor costs as a measure of non-productivity related pressures on wage rates. As an additional piece of evidence, in Appendix A.6, shows that relative unit labor costs display a high positive correlation with a number of measures of labour and product market distortions in the Eurozone.

Figure 2 illustrates the properties of traded and non-traded productivity for the subset of countries in the categories of Figure 1 for which we have sectoral productivity data. Recall that a rise in country i's productivity implies a fall in relative productivity of the EU relative to country i TFP, in order to have an equivalent comparison with real exchange rates. The Figure indicates that there are substantial differences in both the average levels of sectoral productivity across the countries measured, as well as strongly asymmetric trends over the sample.

Figure 2c illustrates our measures of EU unit labor cost relative to each country. Both in levels and movements over time, this is quite different from sectoral productivity, thus justifying our use of unit labor cost as a separate determinant of real exchange rates. At the beginning of the sample, Italy had low unit labor costs and Germany very high unit labor costs, but Italy's unit labor costs increase progressively in relative terms, while Germany's unit labor costs fall progressively. It is notable that the trend in Germany's unit labor cost is a lot more pronounced than that in its sectoral productivity.

3.3 Real Exchange Rates, Relative Prices and Productivity

Tables 3 and 4 report the results of panel regressions of real exchange rates and various definitions of relative prices, as well as real exchange rates and productivity. We present four different approaches to handling the data. In the first, we pool the data and estimate a simple ordinary least squares regression. In the second, we introduce a fixed effect for each country. The fixed effects approach does not take advantage of the fact that our unique price and productivity data allow us to make cross-country comparisons of the levels of real exchange rates and their explanatory variables. We consider a third approach that only takes account of the cross-sectional relationships, averaging variables over time for each country, and estimating a cross-sectional OLS regression. Finally, we estimate a random effects model.

[32] To quote from Euro Plus Pact, 2011, "For each country, ULCs will be assessed for the economy as a whole and for each major sector (manufacturing; services; as well as tradable and non-tradable sectors). Large and sustained increases may lead to the erosion of competitiveness.. ". See European Commission (2015).

Under random effects, the intercept term for each country may differ, but these intercept terms are assumed to be independent random variables.

A basic prediction of the Balassa-Samuelson model, captured also by the decomposition in (8), is that there should be positive relationship between the aggregate real exchange rate and the ratio of non-traded to traded goods prices. More generally, much of the recent literature on open economy macroeconomics develops models in which traded consumer prices are strongly affected by nontraded distribution services.[33] Despite this, there are few empirical papers which relate movements in the real exchange rate to the relative prices of nontraded goods. Table 3a indicates that this relationship is highly robust in the data for the 12 Eurozone countries. This is true both for the pooled regressions, as well as the regressions with fixed or random effects. This contrasts with properties of exchange rates among floating exchange rate countries, where even at relatively low frequencies it is difficult to detect any clear relationship between relative non-traded goods prices and aggregate real exchange rates (e.g. Engel (1999)).

Table 3b explores the relationship between the traded goods real exchange rate and the relative price of non-traded goods, captured by the expression (9). In the presence of distribution costs in the traded goods sector (i.e. $\kappa < 1$), this relationship should be positive. We see that this is true in the Eurozone data.

The third panel (Table 3c) shows that a one-to-one relationship between the traded goods real exchange rate and the overall real exchange rate, which is the second expression on the right hand side of (8), is strongly supported in both time series and cross section.

Table 4 introduces the main empirical relationship of this paper - the link between the real exchange rate and its determinants, relative traded and non-traded total factor productivity, and relative unit labor costs. Our preferred specification, which relates the real exchange rate to all three determinants as in equation (13), is supported by all four empirical approaches (pooled, cross-section, fixed effects and random effects). In every case, traded TFP enters with the correct sign and is significant at the 5 percent level. Unit labor costs also enter with the correct sign in every specification, and are significant at the 5 percent level. Non-traded TFP also takes on the correct sign under all four approaches, and is significant at the 5 percent level in three of the four cases (while marginally insignificant in the cross-sectional regression.) As in the Balassa-Samuelson hypothesis, an increase in traded productivity tends to increase a country's overall consumer price level (relative to the price level of the EU as a whole). An increase in non-traded productivity, on the other hand, is associated with a real depreciation. Also, holding productivity constant, an increase in unit labor costs raises the country's relative consumer price level, causing a real appreciation.

Table 4 also shows that the specifications that are less complete do not perform well in accounting for real exchange rates in the Eurozone. When we try to explain the real exchange rate using only aggregate TFP (without distinguishing between traded and non-traded TFP), and without controlling for unit labor costs, we find that there is a significantly positive association between TFP and the real exchange rate in the pooled and cross-sectional regressions, but very little association is found in the fixed-effects or random effects regres-

[33]See Campa and Goldberg (2010) for a survey of some of the literature.

sions. Likewise, when we use sectoral measures of productivity, but without relative unit labor costs, we do not see a consistent relationship between TFP and the real exchange rate.

Table 5 reports regressions similar to Table 4, but using the inferred labor wedge instead of relative unit labor costs as a right hand side variable.[34] The results are even stronger in this case. All variables are significant and of the right sign, once we include both sectoral productivities and the labour wedge in the regression. Given the decomposition implied by (14), the coefficient on sectoral productivity increases in absolute value, while the coefficient on the labor wedge is about one third the size of the coefficient on RULC from Table 4.

The key aspect of the results in both Table 4 and Table 5 is that it is necessary to add to the regression either RULC or the labor wedge in order to reveal the importance of sectoral productivity in affecting real exchange rates. When we use sectoral (traded and non-traded) measures of productivity, but do not include unit labor costs as an explanatory variable, the results are mixed at best. In the pooled and cross-section regressions, traded productivity has the predicted sign and is significant, and in the fixed effects and random effects regressions, non-traded productivity is significant with the correct sign. But neither measure of productivity is significant in all the specifications that do not include relative unit labor costs in Table 4 or the labor wedge in Table 5.

This provides strong evidence for the role of shocks independent of productivity in driving eurozone real exchange rates, and more generally for a conditional form of the Balassa-Samuelson relationship between traded goods productivity and real exchange rates. For this relationship to apply, it must be that the labor wedge shocks covary with sectoral productivity, since if they were independent, the coefficients on sectoral productivity in Table 5 would be unchanged by the addition of the labor wedge. We saw evidence for this already in Table 4, where the measured labor wedge, averaged across all countries, covaries negatively with traded goods productivity and positively with non-traded goods productivity. Hence, in order to establish the importance of sectoral productivity, it is necessary to control for the labor wedge.[35]

We can alternatively use our direct measure of the labor wedge, obtained from (17), that requires an independent cross-country comparison of hours worked across Eurozone countries. Appendix F reports the results of regressions analogous to Table 5 for this measure. We again find strong support for the empirical relationship between the real real exchange rate and sectoral productivity, conditional on the labor wedge. All variables are of the expected sign and only traded goods productivity fails to be significant in the fixed effects specification.

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[34]Of course since (16) uses the same right hand side variables as Table 4, there is a linear relationship between the coefficients in the two Tables.

[35]The covariance between the labor wedge and productivity opens up interesting questions about the political and economic drivers of the labor wedge. The full understanding of these links lies outside the scope of this paper. It is worth noting again however that the measured labor wedge has a highly positive covariance with measures of labor market distortions as illustrated in Appendix A.6.

4 Model Determined Real Exchange Rates

We now return to a more detailed quantitative analysis of the properties of the model of Section 2. We solve and simulate a model-produced sample with the same dimensions as the data. This gives us a simulated panel of 9 countries over a 15 year period. As in the empirical analysis, each simulated observation represents data for a given country relative to the EU average. Although we only have two countries in the model, we can map the simulated data into the empirical observations by treating the Home country as the relevant EU country, and assuming that the Foreign country represents the EU average in each case. We characterize the time series and cross section properties of real exchange rates and compare the properties of the simulated real exchange rates to those we observe for the empirical sample of Eurozone countries.

4.1 Model Calibration

Table 6 lists the calibration values. For the 9 countries used in our complete sample, the average expenditure share on non-traded goods in the PLI data set on consumer goods is 49.9%, so we set γ, the share of consumption spent on traded goods, equal to 0.5. Campa and Goldberg (2010) estimate the share of distribution services in consumption goods for a number of OECD countries. Their average estimate of the share of distribution services in consumption for the 9 countries in our sample is 41 percent. Hence, we set $\kappa = .6$ ($1-\kappa$ is the share of distribution services in traded goods consumption.). We assume a common value of κ for both Home and Foreign goods consumption in both countries. These parameter values together imply that (given other parameter settings) the overall share of non-traded goods in final consumption, including distribution services, is 70 percent.

The elasticity of substitution between Home and Foreign retail goods, λ, is set at 8, which is the estimate used in Corsetti et al. (2010).[36] For smaller λ , real exchange rate volatility increases, but larger values tend to make the Balassa-Samuelson effect stronger.

We do not have observations on ω, the weight on Home goods in the composite consumption for traded goods. The presence of non-traded goods in consumption and distribution services already imparts a considerable degree of Home product bias in the overall composition of consumption. Given the presumed relative homogeneity of Eurozone countries in terms of consumption bundles, we therefore set $\omega = 0.5$. Also, we set α, the elasticity of labor in the production function, equal to one.[37] The parameter σ, the coefficient of relative risk aversion, is set to equal to 2, a standard consensus estimate used in DSGE modelling. In addition, the standard value employed for the inverse of the Frisch elasticity of labor supply is unity, so we set $\psi = 1$. The elasticity of substitution between the physical good and the

[36]Corsetti et al. (2010) show that this translates into a lower elasticity of substitution between traded wholesale goods, due to the presence of distribution services.

[37] A linear labor technology is a standard assumption in the open macro literature, and as regards the cross section representation of the model, linearity in labor is a long-run equilibrium property of a model with endogenous capital accumulation and an interest rate determined by a constant subjective rate of time preferences.

distribution service, ϕ is set to 0.25[38].

The elasticity of substitution between traded and non-traded goods, θ, is set to 0.7, which is a standard estimate from previous literature (e.g. Benigno and Thoenissen (2008)). In addition, β, the discount factor, set equal to 0.99 for quarterly data.

We report results from three different price adjustment assumptions. In Sticky Price Model A, we assume that prices adjust at a rate of 10 percent per quarter, which given the time-dependent pricing mechanism in the Calvo model, implies that the half life of a price is approximately 7 quarters. In Sticky Price model B, prices adjust at a quarterly frequency of 20 percent, implying a half life of price of about 3.5 quarters. Finally, we solve the model with instantaneous price adjustment, so that all nominal variables are fully flexible.

The model has three different kinds of shocks; productivity shocks in each of the two sectors, a_{it}, $i = H, N$, and shocks to the labor wedge χ.[39] Since the key contribution of the model is to facilitate a comparison of the response to the real exchange rate to productivity and labor wedge shocks in a parallel way to the empirical estimates, we follow the data in calibrating the shock processes. Appendix B describes in detail our calibration procedure for each of the shocks. Here we give a brief description of this procedure.

Although the model allows for all shocks to occur in both the Home and Foreign country, we set Foreign shocks equal to zero, and calibrate each of the Home country shocks using data relative to the EU set of countries. Since shocks enter the model in relative terms, this is equivalent to treating the EU12 as the Foreign country. Of course, while Foreign shocks are set to zero, the presence of the Foreign country is important because in equilibrium there is a general equilibrium feedback between the Home and Foreign country.

We produce a set of simulated shocks by generating normally distributed random variables for 9 artificial countries that have the same moments as the data. Specifically, the artificial data have the same means, serial correlation, and covariance matrix as the data.

We create moments for traded and non-traded productivity from the same measures of productivity used to construct Tables 1-4. In calibrating the labor wedge shock, we follow the two approaches described in section 2. First, we obtain estimates of $\chi^* - \chi$ directly from the equilibrium of the flexible price model as described in (14), using our calibration assumptions for all parameters. This is used in conjunction with the sectoral productivity shocks to produce the simulation shock process described in the previous paragraph. From the estimates of $\chi^* - \chi$, again using the sectoral productivity shocks, we can derive a series for RULC for each country to be used in the regressions on the simulated data.

In the Appendix F, we also report estimates of the simulated model where the labor wedge is computed directly from (17), using observations on national hours worked. As discussed in section 2, we have somewhat less confidence in this specification for the labor

[38]Corsetti et al. (2010) set this equal to zero. The argument for a low elasticity of substitution is that wholesale goods have to be purchased in fixed supply to obtain a given amount of retail goods, so there is almost no ability to substitute between the distribution services and the wholesale goods themselves in retail production.

[39]We note that in the model with sticky prices, there is an endogenous component of the labor wedge due to the fact that the firm's markup is endogenous. But in the absence of shocks to labor supply, this has no quantitative effect on the results.

wedge given the difficulty of comparing hours data across countries.

Our regressions use annual data for 15 years, but we calibrate a period to be one quarter in the model. The length of the period matters particularly when considering the effects of price stickiness. Hence, we create artificial data for 60 quarters. We suppose that the log of quarterly relative TFP (both traded and non-traded) as well as labor wedge shocks follow first-order autoregressions given by:

$$a_t^q - \bar{a} = \rho^q (a_{t-1}^q - \bar{a}) + u_t^q \tag{18}$$

where a_t for each of the 9 countries $\bar{a}$ is directly estimated as in Tables 1-4. We then aggregate the artificial data into annual data by taking averages over quarters in order to compare the statistics generated by the model to the data. Appendix F describes how we translate the moments of the annual data into quarterly data for the model. In particular, ρ^q is computed by taking the quartic root from an AR(1) estimate on the annual data. The variance covariance matrix over u_t is estimated based on the assumption that u_t is i.i.d. at quarterly frequency. Theoretically this would make the annual shock an MA(4). In practice, we find that an i.i.d. annual shock adequately captures the dynamics of the annual data. We calculate a covariance matrix in the u_t in the data across countries, and across the measures of the exogenous variables (traded productivity, nontraded productivity and the labor wedge), using the 27 x 27 covariance matrix of the innovations to those series to create the covariance matrix of the normal distribution from which we draw shocks for our model's artificial data.

Table 7 reports the results of the shock estimates in cross section and time series. Table 7a reports the mean of relative TFP and labor supply shocks for each country. For the productivity measures, this Table reflects the same information as Figure 2 above, except averaged over the sample.[40] We see considerable variation across the country sample in average sectoral productivities as well as the average relative labor wedge term.

Table 7b reports the estimates of persistence and volatility of the shocks for each country using the estimates from (18) above. We see that the traded good productivity shock is substantially more volatile and persistent than the non-traded goods shock. This is consistent with other estimates of sectoral productivity shocks in Benigno and Thoenissen (2008) and Devereux and Hnatkovska (2013).

4.2 Simulation Results

Table 8 illustrates the standard deviation and persistence properties of real exchange rates in the simulations, and provides the data equivalents for comparison. As in the data, everything is reported at annual frequency. In the model, the time series standard deviation varies between 4.9 and 5.4 percent across the different price setting assumptions, compared with the empirical estimate of 3.3 percent. The fact that the model generated real exchange rate volatility exceeds that of the data represents an interesting contrast with most of the

[40]Note that the labor supply shock is relevant for, but separate from the RULC term reported in section 3. The RULC measure represents a combination of all shocks, including the labor supply shock.

discussion of real exchange rates under floating rates, where part of the PPP puzzle, as defined by Rogoff (1996), arose from the inability of simple general equilibrium models to generate real exchange rate volatility as large as that seen in the data. Here we find real exchange rate volatility in the Eurozone that falls short of that coming from an equilibrium model.[41]

The model produces cross section standard deviations of around 14 percent, substantially higher than the time series standard deviation. This variation reflects the cross-country heterogeneity in mean sectoral TFPs and mean relative labor supply parameters. This heterogeneity is also apparent in the data - the cross country standard deviation of the real exchange rate in the data is 11 percent.

The annual frequency persistence in the simulated model is close to that in the data, and particularly close for flexible price version of the model. Again, it is worth noting that this simple model without floating exchange rates can produce real exchange rate persistence of a realistic magnitude – an important hurdle for standard general equilibrium models as stressed in Chari et al. (2002).

Table 9 reports the results obtained from running the same regressions of the real exchange rate on relative prices as is done in Table 3, except on the model-simulated data. Recall that these relationships are implied in the model by the decompositions (8) and (9). In the data, we find a relationship of the same order of magnitude, although larger in cross section than in time series. For the regressions of q on q_n, and q_T on q_n, the model produces a regression coefficient above that of the data. This is not surprising since equations (8) and (9) ascribe all variation in real exchange rates to variation in q_n. In fact, it is quite likely that the cost of non-traded distribution services contains a component that is not accurately measured by observed prices of non-traded goods. If that is the case, then in the results from Table 3 the coefficient on q_n in the regression of q on q_n (and similarly for the regression of q_T on q_n) will be biased downwards due to classical measurement error. This point is established more formally in Appendix F. However, the results of Tables 3 and Table 9 illustrate a clear consistency between the model and the data to the extent that they ascribe a major role for the internal relative price of non-traded goods in driving real exchange rate variation in these Eurozone countries.

Table 9 also shows the results comparable with Table 3c, regressing the model simulated relative price q on q_T. Again the estimates are the same order of magnitude but still somewhat higher than those in the data.

Tables 10 and 11 present our main set of results from the simulations. These results are obtained by simulated regressions of the real exchange rate from the model on sectoral TFP and RULC as implied by the simulated model, and following that, by regressions of the

[41] One reason that the time series real exchange rate volatility is larger than that observed in the data may be that there are common demand shocks experienced across the Eurozone that are not part of our model. Such shocks may lead to a higher cross-country correlation in prices than we obtain in our simulated data. But as argued in section 3 above, with supporting estimates given in Appendix D, incorporating demand shocks into the model does not affect the conditional responses of the real exchange rate to sectoral productivity and labor wedge shocks. That is, even if we allowed for demand shocks, the properties of the amended Balassa Samuelson interpretation of the real exchange rate still obtain.

simulated real exchange rate on sectoral TFP and our measure of the labor wedge. In both cases, we report results separately for the time series and cross section versions of the model. Tables 10 and 11 then are to be seen as the model simulated analogue to the empirical results in Tables 5 and 6. For ease of comparison, Tables 10 and 11 reproduce the results from the data regressions of the full specification for the real exchange rate in each case.

Table 10a establishes a strong coherence between the model and the time series data. As we already established in Table 4, the data provide compelling support for an amended version of the basic Balassa-Samuelson model for Eurozone real exchange rates. Conditional on relative unit labor costs, a one percent rise in traded goods productivity leads to an 0.18 percent appreciation of the real exchange rate. A one percent rise in non-traded goods productivity leads to a 0.36 percent *depreciation* of the real exchange rate. On the other hand a one percent increase in relative unit labor costs is associated with a 0.46 percent real exchange rate appreciation.

In all three specifications for price adjustment, the estimated model coefficients are the same sign and the same order of magnitude as those from the empirical regressions. Both Sticky Price Models A and B in particular lead to simulated regression coefficients extremely close to those in the data; in model A, a one percent rise in traded goods productivity leads to a 0.18 percent appreciation, a one percent rise in non-traded good productivity leads to a 0.23 percent real exchange rate depreciation, and a one percent rise in the relative unit labor cost leads to a 0.44 percent real exchange rate appreciation. Hence, the sticky price model gives a more accurate representation of the time series response of the real exchange rate to all shocks.

Table 10b reports the cross section results. Here, the difference in price adjustment frequencies across the three models has much less importance. But all different specifications lead to regression coefficients of the right sign, and in the case of relative unit labor cost shock, the simulation estimates are very close to those in the data. The data indicates that a country with a non-traded goods productivity one percent above the average will have a real exchange rate about 0.3 percent below the average. The simulated model indicates a depreciation of around 0.5 percent. The data suggest that a country with relative unit labor costs one percent above average will have a real exchange rate 0.4 percent above the average. The simulated regression coefficient matches this very closely. With respect to the traded good productivity shock, the simulated model coefficient produces the right sign, but the implied real exchange rate response is a bit under half that found in the data.

Table 11 reports the results where we replace RULC with the measure of the labor wedge from (16). Table 11a shows the time series simulations, and as in the previous case, there is a close correspondence between the model and data. All three model specifications lead to estimates that are the correct sign and same order of magnitude for each shock. Table 11b gives the analogous cross section estimates when the measured labor wedge is used as the explanatory variable. Here again, we find that the simulation estimates for the traded good productivity coefficient is higher than that of the data, but for the non-traded productivity shock, and the relative unit labor cost shock, the estimated coefficients are very close to those of the data.

What role do sticky prices play in the explanation? From Table 10a and 11a, we see that sticky prices play a role in tempering the response of the model to the different shocks. In general, flexible price DSGE models enhance the response of real variables to 'supply shocks', and lessen the response to 'demand' shocks. We might think of both the labor wedge shock and the traded goods productivity shock as more akin to supply shocks, and the non-traded goods productivity shock as more of a demand shock.[42] With flexible prices, the simulated regressions produced an exaggerated real exchange rate response to traded goods productivity shocks and to relative unit labor cost shocks, while limiting the response to the non-traded goods productivity shock. Under sticky prices, the impact of the supply shocks are reduced and the response to the demand shock is enhanced. In general however, the comparison across the different specifications for price flexibility do not strongly favour sticky prices over flexible prices.

These results establish that a very basic open economy macro model amended to allow for labor wedge shocks can provide an accurate representation of the time series and cross section behaviour of Eurozone real exchange rates. Morever, both model and data offer strong support for an amended form of the traditional Balassa-Samuelson approach to real exchange rates. In Table 4 and 5, we also showed that a basic version of Balassa-Samuelson did not fit the data well. The importance of sectoral productivity only appears when the regressions include RULC or the measured labor wedge, in each case. The same characteristic holds in the simulated regressions. Table 12 shows the results of a regression on the simulated data using the basic Balassa-Samuelson model with sectoral productivity variables alone, omitting RULC, or the labor wedge. In both cases, we see that the traditional Balassa-Samuelson determinants of the real exchange rate are insignificant, except for non-traded productivity coefficient in the time-series case. Thus, if there are labor wedge shocks, it is a mistake to leave them (or RULC) out of the regression. Sectoral productivities become significant only when conditioned on the presence of the labor wedge.

Finally, Table A13 in Appendix F reports results for the alternative measure of the labor wedge, coming from (17), using cross country comparisons of hours worked. The results are quite similar to Table 11. The simulated regression estimates are all of the correct sign and roughly of the same order of magnitude as those of the data. We show also in that case, that sectoral productivities only become significant when the labor wedge is included in the regression.

Overall, these estimates are remarkable for the fact that they indicate that the relationship between real exchange rates and sectoral productivity can be well accounted for by a standard two-sector New Keynesian model, in a manner which closely resembles the empirical relationship estimated from Eurozone data. Moreover, both model and empirical estimates offer a new lease on life for an amended version of the Balassa-Samuelson model of real exchange rate determination.

[42] Shocks to traded goods productivity can be more easily smoothed out through capital markets, while shocks to non-traded goods productivity must feed fully into domestic consumption.

5 Conclusions

Real exchange rates in the Eurozone closely reflect differences in the relative prices of non-traded to traded goods across countries, and in turn differences in the relative productivity levels in the traded versus non-traded sectors, as well as variations in unit labor costs, which themselves are driven at least partly by non-productivity related factors. Under the assumption of empirically relevant degrees of price stickiness, the actual pattern of prices and real exchange rates closely mirrors the pattern produced in the simulations from our model.

It may seem surprising that even when nominal prices are sticky, real exchange rate behavior accords well with the Balassa-Samuelson theory, which has been until now primarily considered a theory of long-run equilibrium real exchange rates. There are perhaps three reasons why the theory fits well for the Eurozone data. First, the initial accession rates in the Eurozone were set in effect to minimize deviations in traded goods prices across countries. So in 1999, the real exchange rates within the Eurozone were effectively initialized at levels that reflect the differences in their non-traded goods prices and differences in distribution costs.

Second, relative productivity shocks over time within the Eurozone simply are not that big. That is, the equilibrium or flexible-price real exchange rate within the Eurozone does not change very much over time. If the initial real exchange rates are near the equilibrium level then even with no further adjustment of the actual real exchange rates, they will not differ too much from the equilibrium rates simply because the equilibrium rates do not stray very far from the initial levels. In a sense, this observation merely restates the point made by Rogoff (1996) in the context of the puzzling behavior of real exchange rates under floating nominal rates. He said that real exchange rate volatility we observe among floating rate countries is impossible to explain if only real productivity shocks drove real exchange rates - that monetary and financial factors must play a role: "existing models based on real shocks cannot account for short-term exchange rate volatility" (p. 648). Equilibrium real exchange rates are not very volatile, and since the currency union eliminates relative monetary shocks, the real exchange rate under a currency union is also not very volatile.

Third, nominal prices do adjust over time, so even in a currency union there is real exchange rate adjustment. It is worth emphasizing that the choice of exchange rate regime only matters for real exchange rate adjustment because nominal prices are sticky. The speed of adjustment of real exchange rates is limited only by the speed of adjustment of nominal prices. While the point is obvious, it still is often overlooked. For example, it is frequently argued that the Eurozone is a poor candidate for a currency union because labor is not very mobile within the Eurozone. But the degree of labor mobility can only matter for the choice of exchange-rate regime if mobility can substitute for nominal wage and price adjustment. That is, labor immobility may well mean that adjustment to real shocks in the Eurozone is slower than in the U.S. where labor is more mobile. However, this refers to an equilibrium adjustment – the problem would exist in the Eurozone even if prices and wages were flexible. Put another way, labor mobility can substitute for nominal exchange rate adjustment only if labor moves at higher frequencies than prices and wages adjust.

Of course, there are other sources of shocks that may affect real exchange rates in the Eurozone. Appendix D shows that aggregate demand variables may have a significant impact on eurozone real exchange rates, but the significance of productivity and relative unit labor costs as in our baseline model remains unchanged.

Finally, because our empirical analysis does not include the period of the sovereign debt crisis in Europe, our model does not consider real exchange rate adjustment in crises situations. It might well be the case that under a crisis, the real exchange rate adjustment that occurs under floating rates is more desirable than what occurs in a currency union. Schmitt-Grohe and Uribe (2016) show that the combination of downward nominal wage rigidity and credit constraints could be very important in the inhibiting efficient real exchange rates under fixed exchange rates during a crisis.

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Tables

Table 1: **Country summary statistics**

Country							Variable					
			Mean						Standard deviation			
	$\overline{q}$	$\overline{q_T}$	$\overline{q_N}$	$\overline{qn}$			s(q)	s(q_T)	s(q_N)	s(qn)		
BE	0.00	0.01	-0.01	-0.02			0.03	0.02	0.03	0.02		
GER	-0.01	0.02	-0.05	-0.07			0.04	0.02	0.07	0.06		
SPA	0.17	0.17	0.18	0.01			0.02	0.02	0.02	0.03		
FRA	-0.03	0.02	-0.08	-0.10			0.03	0.03	0.04	0.02		
IRE	-0.10	-0.08	-0.11	-0.03			0.08	0.05	0.10	0.05		
ITA	0.05	0.02	0.09	0.08			0.04	0.04	0.04	0.02		
NET	0.02	0.03	-0.00	-0.03			0.02	0.02	0.03	0.03		
AUS	0.01	-0.00	0.03	0.04			0.04	0.03	0.04	0.01		
FIN	-0.16	-0.13	-0.19	-0.06			0.03	0.03	0.03	0.01		
	$\overline{a_T}$	$\overline{a_N}$	$\overline{a_T - a_N}$	$\overline{rulc}$	$\overline{lw5}$	$\overline{lw99}$	s(a_T)	s(a_N)	s($a_T - a_N$)	s($rulc$)	s($lw5$)	s($lw99$)
BE	-0.05	-0.03	-0.03	-0.06	-0.23	-0.20	0.04	0.035	0.02	0.01	0.04	0.02
GER	-0.02	-0.08	0.06	-0.13	-0.55	-0.13	0.015	0.011	0.02	0.06	0.17	0.04
SPA	0.12	-0.02	0.14	0.06	0.06	-0.01	0.10	0.05	0.05	0.06	0.08	0.07
FRA	-0.01	-0.07	0.06	-0.05	-0.31	-0.17	0.02	0.018	0.02	0.01	0.07	0.03
IRE	-0.25	-0.03	-0.22	0.22	0.65	0.11	0.05	0.02	0.05	0.11	0.30	0.05
ITA	0.03	0.10	-0.08	-0.02	0.19	-0.02	0.10	0.04	0.07	0.03	0.05	0.04
NET	-0.13	-0.23	0.09	-0.03	-0.57	-0.10	0.02	0.03	0.05	0.04	0.19	0.06
AUS	0.05	-0.01	0.06	-0.11	-0.34	-0.05	0.06	0.02	0.04	0.04	0.10	0.02
FIN	-0.20	-0.16	-0.05	-0.01	-0.31	-0.18	0.08	0.04	0.05	0.01	0.07	0.04

All real exchange rate variables (q, q_T, q_N, q_n) are expressed as EU15 average relative to home country. q is the expenditure-weighted log real exchange rate (an increase is a depreciation). q_T (q_N) is the real exchange rate for traded (nontraded) goods only, both relative to EU15 average (an increase is a depreciation). $q_n \equiv q_N - q_T$. $s(.)$ denotes standard deviation. a_T (a_N) is a logarithm of traded (nontraded) TFP of EU12 relative to home country. Traded is an aggregate of 1-digit sector's TFP levels aggregated using sectoral gross outputs as weights. $rulc$ is a logarithm of relative Unit Labour Costs of EU17 relative to home country. $lw5$ and $lw99$ are our two measures of labor wedges, as described in the Appendix A.7. The balanced sample period is 1995 - 2007.

Table 2: **Standard deviation and Serial correlation**

variable	mean(std$_i$(.)) All	EZ	Float	East	std(mean$_i$(.)) All	EZ	Float	East	AR(1) EZ
q	0.067	0.033	0.070	0.098	0.328	0.113	0.103	0.193	0.669
q_T	0.061	0.028	0.060	0.091	0.238	0.087	0.109	0.154	0.597
q_N	0.088	0.044	0.084	0.129	0.471	0.158	0.120	0.275	0.716
q_n	0.045	0.032	0.043	0.059	0.253	0.107	0.119	0.133	0.767
a_T	0.059	0.055	0.075	0.055	0.129	0.121	0.083	0.014	0.937
a_N	0.031	0.031	0.019	0.045	0.155	0.093	0.078	0.017	0.879
$a_T - a_N$	0.049	0.040	0.070	0.052	0.119	0.111	0.151	0.027	0.835
$rulc$	0.088	0.053	0.092	0.128	0.113	0.097	0.151	0.093	1.009

All real exchange rate variables (q, q_T, q_N, q_n) are expressed as EU15 average relative to home country. q is the expenditure-weighted log real exchange rate (an increase is a depreciation). q_T (q_N) is the real exchange rate for traded (nontraded) goods only, both relative to EU15 average (an increase is a depreciation). $q_n \equiv q_N - q_T$. $s(.)$ denotes standard deviation. a_T (a_N) is a logarithm of traded (nontraded) TFP of EU12 relative to home country. Traded is an aggregate of 1-digit sector's TFP levels aggregated using sectoral gross outputs as weights. $rulc$ is a logarithm of Unit Labour Costs of EU17 relative to home country. $lw5$ and $lw99$ are our two measures of labor wedges, as described in the Appendix A.7. The balanced sample period is 1995 - 2007. The left panel reports average time series standard deviation (std$_i$(.), where i indexes countries) and the middle panel standard deviation of average real exchange rates (mean$_i$(.), where i indexes countries). The right panel reports the autocorrelation coefficient from a fixed-effects panel AR(1) regression.

Table 3: **Price regressions**

Table 3a: Regression of q on the q_n

	1 Pool	2 FE	3 RE	4 XS
$\mathbf{q_n}$	**0.70*****	**0.60*****	**0.61*****	**0.71****
	(0.058)	(0.076)	(0.07)	(0.247)
$\overline{R}^2$	0.44	0.93	0.36	0.40
N	180	180	180	12
HT	–	–	not reject	–

Table 3b: Regression of q_T on q_n

	5 Pool	6 FE	7 RE	8 XS
$\mathbf{q_n}$	**0.26*****	0.11	**0.12***	**0.89*****
	(0.057)	(0.076)	(0.07)	(0.12)
$\overline{R}^2$	0.10	0.89	0.02	0.70
N	180	180	180	12
HT	–	–	not reject	–

Table 3c: Regression of the q on q_T

	9 Pool	10 FE	11 RE	12 XS
$\mathbf{q_T}$	**1.19*****	**1.08*****	**1.09*****	**1.20*****
	(0.038)	(0.053)	(0.048)	(0.11)
$\overline{R}^2$	0.84	0.98	0.77	0.83
N	180	180	180	12
HT	–	–	not reject	–

Real exchange rate q is expressed as the logarithm of expenditure-weighted real exchange rate EU15 average relative to country i (an increase is a depreciation). q_T is the logarithm of the expenditure-weighted real exchange rate of tradables in EU15 on average, relative to country i (an increase is a depreciation). q_n is the log of the relative price of nontraded to traded goods (all expenditure-weighted) in EU15 on average, relative to country i ($q_n \equiv q_N - q_T$). The sample period for all variables is 1995-2009. *Pool* is a pooled regression with all countries and years sharing the same estimate of a constant and a slope. FE is a fixed-effects panel regression with countries as cross sections. RE is a random effects regression with countries as cross sections. XS is a cross-sectional regression which uses time-average values of variables in each country. All standard errors are computed using a panel adjustment robust to serial correlation (except for XS, where Newey-West adjustment is used). Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Eurozone countries in our sample are: Austria, Belgium, Germany, Greece, France, Finland, Italy, Ireland, Luxembourg, the Netherlands, Portugal, and Spain. Rejection of the null at 5% in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table 4: **RER - TFP regression**

	Pool			Fixed effects			Random effects			Cross-section		
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
TFP	**0.43*****	–	–	-0.10	–	–	-0.04	–	–	**0.51****	–	–
	(0.067)			(0.11)			(0.094)			(0.21)		
TFP_T	–	**0.50*****	**0.76*****	–	0.003	**0.18****	–	0.05	**0.26*****	–	**0.67*****	**0.93*****
		(0.059)	(0.062)		(0.11)	(0.090)		(0.09)	(0.079)		(0.145)	(0.19)
TFP_N	–	-0.09	**-0.29*****	–	**-0.36***	**-0.36****	–	**-0.29***	**-0.36*****	–	-0.05	-0.27
		(0.08)	(0.078)		(0.22)	(0.18)		(0.16)	(0.13)		(0.184)	(0.22)
$RULC$	–	–	**0.43*****	–	–	**0.46*****	–	–	**0.46*****	–	–	**0.43****
			(0.079)			(0.072)			(0.077)			(0.20)
$\overline{R}^2$	0.25	0.41	0.57	0.84	0.85	0.90	-0.007	0.02	0.32	0.28	0.62	0.76
N	117	117	117	117	117	117	117	117	117	9	9	9
HT	–	–	–	–	–	–	reject	reject	reject			

Dependant variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a depreciation). TFP_i is the log of TFP level of traded relative to non-traded sector in EU12 ($\log(TFP_{T,EU12,t}/TFP_{N,EU12,t})$) relative to country i. $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. $RULC_{it}$ comes from OECD.Stat database and is defined as a ratio of nominal Total Labor Costs for the economy relative to real output (2005 base year), expressed as EU 17 value relative to country i. ULC are converted to euro for all countries. Balanced data sample period is 1995 - 2007. "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. All standard errors (except in $Cross-section$) are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). The standard errors in $Cross-section$ are Newey-West standard errors. Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Included Eurozone members are: Austria, Belgium, Germany, Finland, France, Ireland, Italy, the Netherlands and Spain. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table 5: **RER - TFP regression with Labor Wedge**

	Pool			**Fixed effects**			**Random effects**			**Cross-section**		
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
TFP	**0.43*****	–	–	-0.10	–	–	-0.038	–	–	**0.51****	–	–
	(0.067)			(0.11)			(0.094)			(0.21)		
TFP_T	–	**0.50*****	**0.81*****	–	0.003	**0.24****	–	0.049	**0.32*****	–	**0.67*****	**0.98*****
		(0.059)	(0.068)		(0.11)	(0.090)		(0.09)	(0.082)		(0.15)	(0.13)
TFP_N	–	-0.09	**-0.65*****	–	**-0.36***	**-0.75****	–	**-0.29***	**-0.74*****	–	-0.05	**-0.62***
		(0.08)	(0.123)		(0.22)	(0.18)		(0.16)	(0.143)		(0.18)	(0.254)
LW	–	–	**0.15*****	–	–	**0.17*****	–	–	**0.16*****	–	–	**0.15****
			(0.028)			(0.025)			(0.025)			(0.038)
$\overline{R}^2$	0.25	0.41	0.58	0.84	0.85	0.91	-0.007	0.025	0.34	0.28	0.62	0.76
N	117	117	117	117	117	117	117	117	117	9	9	9
HT	–	–	–	–	–	–	reject	reject	reject			

Dependent variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a depreciation). TFP_i is the log of TFP level of traded relative to non-traded sector in EU12 ($\log(TFP_{T,EU12,t}/TFP_{N,EU12,t})$) relative to country i. $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. LW_{it} is constructed using a calibrated version of (16) (*** $laborwedge5 = -0.33a_T + 2.33a_N + 2.8rulc$), and is a linear combination of productivity in each sector and relative unit labor costs as described in Table 5. LW in EU 17 relative to country i (an increase is a depreciation) is used in regressions. Balanced data sample period is 1995 - 2007. "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. All standard errors (except in $Cross-section$) are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). The standard errors in $Cross-section$ are Newey-West standard errors. Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Included Eurozone members are: Austria, Belgium, Germany, Finland, France, Ireland, Italy, the Netherlands and Spain. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table 6: **Calibration**

Households			
Share of C on traded goods	γ	0.5	
Share of wholesale traded goods in C_T	κ	0.6	
E.O.S. between H and F retail Traded goods	λ	8	Corsetti et al. (2010)
E.O.S. between traded good and retail service	ϕ	0.25	
E.O.S. between traded and nontraded goods	θ	0.7	
Weight on H goods in C_T	ω	0.5	No home bias
Coefficient of relative risk aversion	σ	2	
Frisch elasticity of labor supply	ψ	1	
Discount factor	β	0.99	
Firms			
Elasticity of labor in Y	α	1	
Speed of Calvo price adjustment		0.10, 0.20/quarter	Bils and Klenow (2004)
Monetary policy			
Weight on inflation targeting	σ_p	2	Steinsson (2008)

Table 7: **Properties of TFP and Labor Wedge shocks**

Table 7a. Cross-sectional properties of relative TFP and Labor Wedge shocks				**Table 7b. Time-series properties of relative TFP and Labor Wedge shocks**						
	mean values				AR(1) coefficients			standard deviations		
	$\bar{a}_T$	$\bar{a}_N$	$\bar{LW}$		ρ_{a_T}	ρ_{a_N}	ρ_{LW}	σ_{a_T}	σ_{a_N}	σ_{LW}
BEL	0.054	0.028	0.227	BEL	0.99	0.95	0.88	1.11	0.82	2.86
GER	0.019	0.078	0.547	GER	0.94	0.90	0.99	1.75	0.62	3.21
SPA	-0.119	0.025	-0.061	SPA	0.99	0.97	0.99	1.65	0.86	3.53
FRA	0.009	0.069	0.307	FRA	0.89	0.91	0.97	1.24	1.18	3.75
IRE	0.251	0.028	-0.647	IRE	0.89	0.69	0.99	3.69	1.79	7.96
ITA	-0.028	-0.103	-0.187	ITA	0.99	0.98	0.73	0.91	1.14	3.17
NET	0.131	0.225	0.567	NET	0.92	0.99	0.98	1.43	1.03	4.10
AUS	-0.049	0.014	0.345	AUS	0.98	0.96	0.98	2.02	0.95	3.10
FIN	0.202	0.156	0.313	FIN	0.99	0.97	0.87	1.34	1.24	4.32
AVG	0.052	0.058	0.157	AVG	0.95	0.92	0.93	1.68	1.07	4.00

Table 7a reports, for each country, the sample average level of the of TFP and Labor wedge as described by Appendix A.1. and A.7. Table 7b reports, for each country, the first-order autocorrelation coefficient, and the standard deviation of the residual series, for TFP and Labor supply shocks. The last row reports the average value across 9 countries.

Table 8: **Properties of model Real Exchange Rates**

	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4
STD (Time Series)	0.049 (0.039,0.060)	0.051 (0.041,0.062)	0.054 (0.045,0.066)	0.033
STD (Cross Section)	0.138 (0.086,0.227)	0.138 (0.087,0.229)	0.140 (0.089,0.230)	0.113
Serial Correlation	0.768 (0.688,0.843)	0.739 (0.653,0.821)	0.673 (0.577,0.759)	0.670

Results in the "Data" column are from Table 3. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1$.). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

Table 9: **Model price regressions**

	Table 9a: Time Series Regressions				Table 9b: Cross Section Regressions			
	Sticky price A	Sticky price B	Flexible price	Data	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4	5	6	7	8
Regression of q on q_n	1.193 (1.166,1.246)	1.193 (1.166,1.245)	1.192 (1.167,1.242)	0.60	1.199 (1.152,1.267)	1.198 (1.153,1.268)	1.198 (1.153,1.269)	0.71
Regression of q_T on q_n	0.677 (0.637,0.710)	0.677 (0.637,0.708)	0.676 (0.638,0.705)	0.11	0.686 (0.645,0.761)	0.686 (0.645,0.761)	0.685 (0.645,0.759)	0.89
Regression of q on q_T	1.750 (1.680,1.869)	1.751 (1.682,1.870)	1.752 (1.685,1.869)	1.08	1.726 (1.636,1.858)	1.727 (1.636,1.859)	1.729 (1.635,1.862)	1.20

Results in the "Data" column repeat those from Table 3. Results in the other columns are based on regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1$.). As in our data, panels of synthetic data are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. The calibration in column "Sticky price A" assumes a 10% price adjustment per quarter. "Sticky price B" assumes a 20% price adjustment per quarter.

Table 10: **Model regressions with RULC**

	Table 10a. Time Series Regression Results				Table 10b. Cross Section Regression Results			
	Sticky price A	Sticky price B	Flexible price	Data	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4	5	6	7	8
Traded TFP	0.176 (0.066,0.302)	0.186 (0.103,0.283)	0.205 (0.170,0.254)	0.18	0.281 (0.074,0.534)	0.283 (0.078,0.533)	0.288 (0.088,0.547)	0.93
Nontraded TFP	-0.227 (-0.412,-0.028)	-0.212 (-0.362,-0.076)	-0.208 (-0.288,-0.166)	-0.36	-0.491 (-0.766,-0.286)	-0.491 (-0.770,-0.293)	-0.505 (-0.791,-0.303)	-0.27
RULC	0.438 (0.366,0.501)	0.521 (0.455,0.573)	0.687 (0.606,0.716)	0.46	0.453 (0.332,0.540)	0.455 (0.293,0.770)	0.460 (0.333,0.551)	0.43

Results in the "Data" column are from Table 4. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1$.). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

Table 11: **Model regressions with Labor Wedge**

	Table 11a. Time Series Regression Results				**Table 11b. Cross Section Regression Results**			
	Sticky price A	**Sticky price B**	**Flexible price**	**Data**	**Sticky price A**	**Sticky price B**	**Flexible price**	**Data**
	1	2	3	4	5	6	7	8
Traded TFP	0.173 (-0.054,0.409)	0.200 (-0.027,0.439)	0.264 (0.044,0.504)	0.24	0.171 (-0.181,0.395)	0.175 (-0.178,0.404)	0.179 (-0.178,0.416)	0.98
Nontraded TFP	-0.642 (-0.940,-0.339)	-0.690 (-0.983,-0.397)	-0.798 (-1.078,-0.519)	-0.75	-0.585 (-0.957,-0.086)	-0.592 (-0.974,-0.087)	-0.604 (-0.997,-0.085)	-0.62
Labor Wedge	0.084 (0.013,0.249)	0.089 (0.013,0.263)	0.097 (0.015,0.284)	0.17	0.199 (0.070,0.341)	0.199 (0.070,0.342)	0.200 (0.070,0.344)	0.15

Results in the "Data" column are from Table 5. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1.$). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

Table 12: **Model regressions with TFP only**

Labor wedge: method 1

	Table 12a. Time Series Regression Results				**Table 12b. Cross Section Regression Results**			
	Sticky price A	**Sticky price B**	**Flexible price**	**Data**	**Sticky price A**	**Sticky price B**	**Flexible price**	**Data**
	1	2	3	4	5	6	7	8
Traded TFP	0.175 (-0.145,0.465)	0.202 (-0.122,0.509)	0.264 (-0.074,0.578)	0.00	-0.074 (-0.715,0.394)	-0.070 (-0.717,0.399)	-0.060 (-0.720,0.490)	0.67
Nontraded TFP	-0.618 (-1.088,-0.187)	-0.676 (-1.151,-0.254)	-0.781 (-1.272,-0.340)	-0.36	-0.038 (-0.481,0.767)	-0.043 (-0.485,0.764)	-0.049 (-0.490,0.745)	0.05

Labor wedge: method 2

	Table 12c. Time Series Regression Results				**Table 12d. Cross Section Regression Results**			
	Sticky price A	**Sticky price B**	**Flexible price**	**Data**	**Sticky price A**	**Sticky price B**	**Flexible price**	**Data**
	1	2	3	4	5	6	7	8
Traded TFP	0.177 (-0.055,0.455)	0.206 (-0.035,0.491)	0.271 (-0.023,0.585)	0.00	0.199 (-0.123,0.464)	0.200 (-0.124,0.475)	0.200 (-0.128,0.482)	0.67
Nontraded TFP	-0.644 (-1.034,-0.183)	-0.691 (-1.105,-0.232)	-0.806 (-1.242,-0.330)	-0.36	-0.451 (-0.839,0.075)	-0.452 (-0.844,0.080)	-0.459 (-0.858,0.091)	-0.05

Results in the "Data" column are from Table 5. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1.$). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

Figures

Figure 1: Properties of Real Exchange Rates

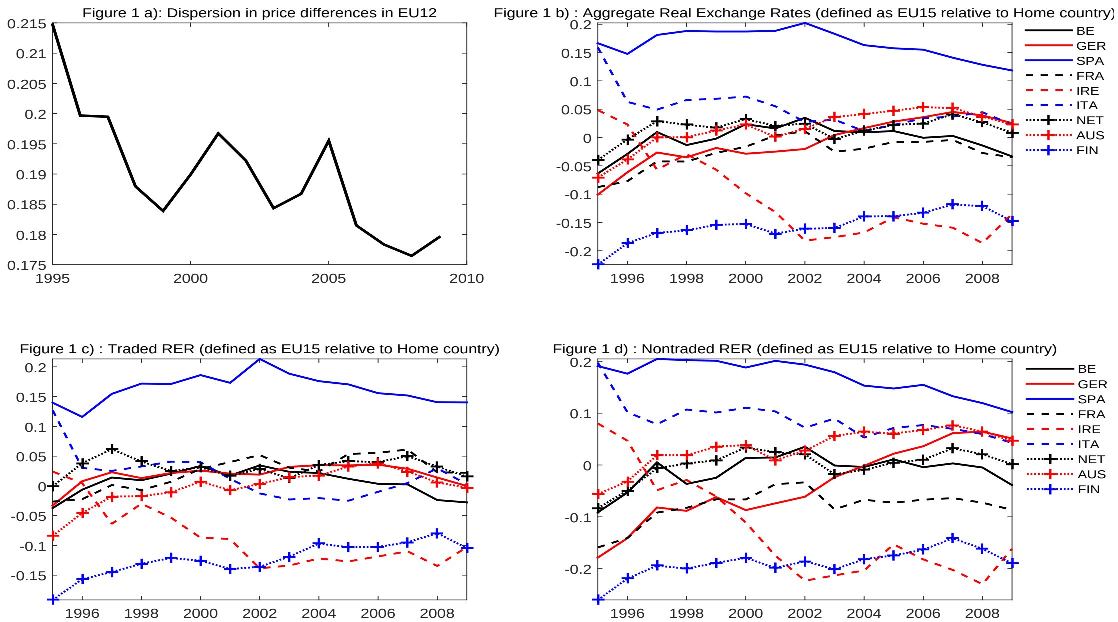
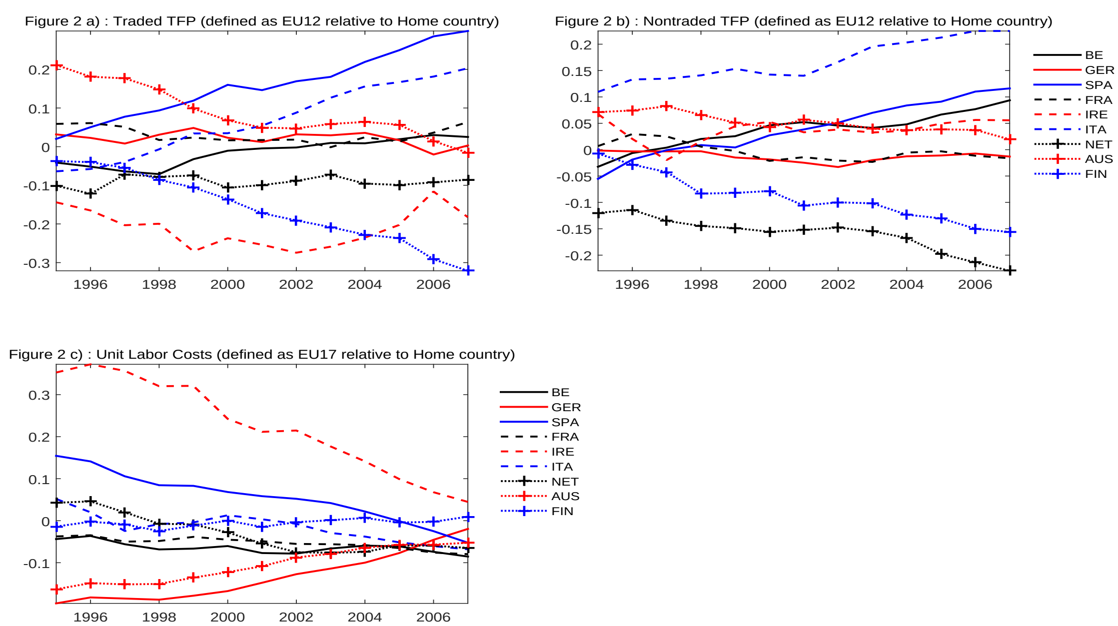


Figure 2: Properties of Total Factor Productivity and Unit Labor Costs



For Online Publication

A Data Appendix

A.1 Construction of the panel of sectoral TFP levels across Europe

This section documents the construction of the TFP level panel dataset at sectoral level. The reason for the construction of this dataset is to provide a match for the level data of real exchange rates across Europe. To construct the dataset, we perform a concordance between the sectors included in the Groningen Growth and Development Center's (GGDC thereafter) 1997 TFP level database, and the sectors included in the KLEMS time-series database. These two databases are meant to be used in conjunction, as outlined in Inklaar and Timmer (2008). The cross-sectional TFP database and the time-series TFP database are linked using the constructed concordance to obtain annual sectoral panel TFP level data.

Table A4 lists the sectors included in the TFP 1997 level database and Table A5 the sectors in the TFP time-series sectoral growth rate database. Table A6 shows the concordance between the two, the names of the 21 overlapping sectors, and their tradability descriptor.

A.1.1 1997 TFP levels

The construction of the 1997 GGDC TFP level database[43] is described in Inklaar and Timmer (2008) (IT thereafter). The database is constructed for 30 OECD countries using an improved version of the methodology of Jorgenson and Nishmizu (1978)[44]. We use the output-based measure of TFP which IT argue better reflects technology differences than the two other value-added measures (see IT pp. 23).

TFP 1997 level estimates are constructed vis-à-vis the U.S. levels in two stages. First, symmetric Input-Output Tables and input PPPs are constructed for 45 sub-industries. The second stage consists of two steps. First, PPPs for capital, labor and intermediate inputs for 29 industries (based on 45 sub-industries) are constructed using a price-variant of index number approach in Caves et al. (1982) known as the CCD method. These are used to implicitly derive quantities of all inputs and outputs. The second step, known as primal level accounting, sees industry comparative productivity levels constructed on the basis of input and output quantities in a bilateral Tornqvist model as in Jorgenson and Nishimizu (1978). Specifically, for sector i in country j in 1997, IT estimate the level of sectoral TFP as:

$$\ln A_{i,j} \equiv \ln TFP_{i,j}^{SO} = \ln \frac{Q_{i,j}^{SO}}{Q_{i,US}^{SO}} - \hat{\nu}_K \ln \frac{Q_{i,j}^{K}}{Q_{i,US}^{K}} - \hat{\nu}_L \ln \frac{Q_{i,j}^{L}}{Q_{i,US}^{L}} - \hat{\nu}_{II} \ln \frac{Q_{i,j}^{II}}{Q_{i,US}^{II}} \tag{19}$$

where Q_j^K is a quantity index of capital services, Q_c^L is a quantity index of labor services and Q_j^{II} is a quantity index of intermediate input services. $\hat{\nu}_K$ is the share of capital services in

[43]See http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database.

[44]The improvements include the use of sectoral IO measures that exclude intra-industry flows, the application of multilateral indices at the industry level, and the use of relative output prices from the production side and the use of the exogenous approach to capital measurement.

total costs averaged over the two countries: $\hat{\nu}_K = 0.5(\nu_j^K + \nu_j^{US})$ where $\nu_j^K \equiv \frac{V_j^K}{V_j^K + V_j^L + V_j^{II}}$ and V_j^K is the nominal value of capital services. In order to facilitate quantity measure comparisons, $Q_j^{SO} = \frac{V_j^{SO}}{PPP_j^{SO}}$ where V_j^{SO} is the nominal value of output in country j. Similarly for intermediate inputs Q_j^{II}. For labor input Q_j^L, the same ratio measure is justified by the need to aggregate various labor types (high- vs. low-skill), and the construction of PPP_j^L which is constructed based on relative wages. For capital input, $Q_j^K = \frac{\tilde{V}_j^K}{PPP_j^K}$ where $\tilde{V}_j^K$ is the ex-ante nominal compensation of capital $\tilde{V}_j^K = V_j^K - V_j^R$ where V_j^R is "supra-normal profits" (see IT section 4.1 for a detailed discussion).

A.1.2 TFP time series

A European Commission-funded project, EU KLEMS data contains annual observations for 25 European countries, Japan and the US from 1970 onwards. The data is described in detail in O'Mahony and Timmer (2009, OT thereafter). We use KLEMS' Total factor productivity growth March 2011 update to the November 2009 release[45]. The TFP is estimated in the growth accounting approach as a measure of disembodied technological change[46]. The growth accounting in KLEMS proceeds under standard neoclassical assumptions of constant returns to scale and perfect competition[47] allows a full decomposition of industry i output:

$$\begin{aligned} \Delta \ln Y_{it} &= \bar{\nu}_{it}^X \bar{\omega}_{it}^E \Delta \ln X_{it}^E + \bar{\nu}_{it}^X \bar{\omega}_{it}^M \Delta \ln X_{it}^M + \bar{\nu}_{it}^X \bar{\omega}_{it}^S \Delta \ln X_{it}^S \\ &\quad + \bar{\nu}_{it}^K \bar{\omega}_{it}^{ICT} \Delta \ln K_{it}^{ICT} + \bar{\nu}_{it}^K \bar{\omega}_{it}^N \Delta \ln K_{it}^N \\ &\quad + \bar{\nu}_{it}^L \Delta \ln LC_{it} + \bar{\nu}_{it}^L \Delta \ln H_{it} + \Delta \ln B_{it}^Y \end{aligned} \tag{20}$$

where Y is output, K is an index of capital service flows, L is an index of labor service flows, X is an index of intermediate inputs, H is hours worked, LC is labor composition[48] and B is an index of disembodied (Hicks-neutral) technological change. Intermediate inputs are further split into energy (E), materials (M) and services (S), each with a respective period-average share $\bar{\omega}$ in total input costs. Each of the inputs K, L, X^E, X^M, X^S is constructed as a Törnqvist quantity index of individual sub-types ($\Delta \ln I_{it} = \sum_l \bar{\omega}_{l,it}^I \Delta \ln I_{l,it}$). $\bar{\nu}$ are two-period average shares of each input in the nominal output.

A.1.3 Construction of the TFP level sectoral panel dataset

The construction of TFP level sectoral panel dataset proceeds in four steps. First, the sectors in the 1997 cross-section dataset are matched to the sectors in the TFP growth-rate dataset. Second, a level TFP series is constructed for each sector and country. Third, the TFP level is expressed relative to EU12 average, to match the construction of the real exchange rate

[45]See `http://www.euklems.net/euk09ii.shtml`.

[46]Technical change embodied in new capital goods is excluded from TFP due to the KLEMS' use of quality-adjusted prices.

[47]Consequently, negative TFP growth can be observed in some service industries, which OT argue is a consequence of well-known measurement issues surrounding corporate reorganization and institutional changes (see Basu et al. 2004 and Hulten, 2001).

[48]Labor composition is growth literature's measure of "labor quality" (see Jorgenson et al. 2005). It consists of labor characteristics such as educational attainment, age and gender.

dataset [49]. Fourth, the sectors are aggregated into traded and non-traded aggregates using sectoral output data.

Let A_{ij} be the 1997 GGDC sectoral-output and PPP based TFP of sector i in country j, relative to the US. Let B_{ijt} be the EU KLEMS sectoral-output and PPP based TFP index of sector i in country j and year t, re-scaled so that $B_{i,j,1997} = 100\ \forall i, j$. Both A and B are synchronized to the 21 sectors as in Table A6. Let $B_{i,US,t}$ be the TFP index for each sector in the US, also with the base of 100 in 1997. Then, sectoral TFP level C_{ijt} is constructed as:

$$C_{ijt} = \frac{A_{ij}B_{ijt}}{B_{i,US,t}} \tag{21}$$

and similarly for the EU15 aggregate:

$$C_{i,EU12,t} = \frac{A_{i,EU12}B_{i,EU12,t}}{B_{i,US,t}} \tag{22}$$

The TFP level index is expressed vis-a-vis EU12. It is the ratio of (21) and (22):

$$TFP_{ijt} = \frac{C_{ijt}}{C_{i,EU12,t}} = \frac{A_{ij}B_{ijt}}{A_{i,EU12}B_{i,EU12,t}} \tag{23}$$

The aggregate traded and non-traded TFP levels are computed as follows:

$$TFP_{T,j,t} = \frac{\sum_{i\in T}\gamma_{ij,T}C_{ijt}}{\frac{1}{12}\sum_{j\in EU12}(\sum_{i\in T}\gamma_{i,j,T}C_{i,j,t})} \tag{24}$$

$$TFP_{N,j,t} = \frac{\sum_{i\in N}\gamma_{ij,N}C_{ijt}}{\frac{1}{12}\sum_{j\in EU12}(\sum_{i\in N}\gamma_{i,j,N}C_{i,j,t})} \tag{25}$$

where $\gamma_{ij,T}$ ($\gamma_{ij,N}$) is a 1997 sectoral output weight of sector i in traded (non-traded) output of country j (s.t., $\sum_i \gamma_{ij} = 1\ \forall j$). The agriculture sector is omitted from the analysis on the grounds that the EU Common Agricultural Policy's leads to a deviation from many of the assumptions used to calculate sectoral TFP measures.

Consequently, the relative productivity measure in traded to non-traded sectors is constructed as a ratio of (24) and (25). In our empirical analysis we always work with the logarithms of these constructed productivity measures.

A.2 Real Exchange Rates

We use a dataset on price levels from the Eurostat-OECD PPP Programme[50]. The dataset covers most European countries over the 1995-2009 period. The data are annual Price Level Indices, or PLI's. They give the price of the good category at a given time and for a given country, relative to the price in the reference country. The reference country is the EU 15

[49] Only 12 of the EU15 countries have TFP data: Belgium, Germany, Spain, France, Ireland, Italy, the Netherlands, Austria, Finland, Sweden, Denmark and the United Kingdom.

[50] Methodological manuals describing the dataset are available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-RA-12-023 and http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-BE-06-002/EN/KS-BE-06-002-EN.PDF

area[51]. PLI's are available for 146 consumer expenditure headings on goods and services. These are listed in Table A1. At any point of time t, PLI for good i in country j tells us how much more (or less) expensive good i is in country j than in the EU15.

Table A1 also illustrates the breakdown of goods between the categories "Traded" and "Non-traded". The criterion of this breakdown follows the categorization of goods into traded and non-traded in Table A2 of Crucini, et al. (2005). All goods with a positive trade share are categorized as "traded", and those with a zero trade share as "non-traded". Our data contains two types of services that are not in Crucini, et al. (2005): education (at different levels), and prostitution. While some some tertiary education engages international trade, the nature of price setting in this sector suggests that the trade has at most a negligible influence on the price of tertiary education. We categorize both as non-traded.

A.3 Gross wages

Database: Eurostat, National Accounts by 6 branches - aggregates at current prices
Series name: nama_nace06_c
Indicator: D11, Gross wages and salaries. Millions or Euro. Total: all NACE activities.
Link: `http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_nace06_c&lang=en`

A.4 Unit Labor Costs

Database: OECD.Stat, Unit labour costs : Annual indicators
Series name: ULC_ANN
Sector: Total Economy
Measure: Level, ratio, or national currency
Link: `http://stats.oecd.org/Index.aspx?DataSetCode=ULC_ANN`
Relative Unit Labor Costs are expressed as EU17 average (as provided by OECD.Stat) relative to country i.

Table A2 establishes that unit labor costs are positively correlated with two measures of labor market regulations. AUTH represents a summary measure of the authority of unions in wage setting, and CENT is a measure of national and sectoral centralization of wage bargaining. In addition, as discussed in Section 2 of the paper, unit labor costs are positively correlated with a measure of the terms of trade derived from the Penn World Tables. This supports the derivation of equation (13) as a specification for real exchange rate determination.

A.5 Hours worked

Database: OECD Eurostat, Average annual hours actually worked per worker, according to National Accounts concept. The concept used is the total number of hours worked over the year divided by the average number of people in employment. Series names: ANHRS for 1950-2015

[51] That is, Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Spain, Sweden, Portugal, Finland, and the United Kingdom.

Table A1. Comparative properties of relative Unit Labor Costs

T	Rice
T	Other cereals, flour and other cereal products
T	Bread
T	Other bakery products
T	Pasta products
T	Beef and Veal
T	Pork
T	Lamb, mutton and goat
T	Poultry
T	Other meats and edible offal
T	Delicatessen and other meat preparations
T	Fresh, chilled or frozen fish and seafood
T	Preserved or processed fish and seafood
T	Fresh milk
T	Preserved milk and other milk products
T	Cheese
T	Eggs and egg-based products
T	Butter
T	Margarine
T	Other edible oils and fats
T	Fresh or chilled fruit
T	Frozen, preserved or processed fruit
T	Fresh or chilled vegetables other than potatoes
T	Fresh or chilled potatoes
T	Frozen, preserved or processed vegetables
T	Sugar
T	Jams, marmalades and honey
T	Confectionery, chocolate and other cocoa preps
T	Edible ice, ice cream and sorbet
T	Coffee, tea and cocoa
T	Mineral waters
T	Soft drinks and concentrates
T	Fruit and vegetable juices
T	Spirits
T	Wine
T	Beer
T	Tobacco
T	Narcotics
T	Other clothing and clothing accessories
T	Clothing materials
T	Men's clothing
T	Women's clothing
T	Childrens and infants clothing
T	Other clothing and clothing accessories
NT	Cleaning, repair and hire of clothing
T	Men's footwear
T	Women's footwear
T	Children's and infant's footwear
NT	Repair and hire of footwear
NT	Actual rentals for housing
NT	Imputed rentals for housing
T	Materials for maintenance and repair of dwelling
NT	Services for maintenance and repair of dwelling
NT	Water supply
NT	Miscellaneous services relating to the dwelling
T	Electricity
T	Gas
T	Liquid fuels
T	Solid fuels
T	Heat energy
T	Kitchen furniture
T	Bedroom furniture
T	Living-room and dining-room furniture
T	Other furniture and furnishings
T	Carpets and other floor coverings
NT	Repair of furniture, furnishings and floors
T	Household textiles
T	Major household appliances electric or not
T	Small electric household appliances
NT	Repair of household appliances
T	Glassware, tableware and household utensils
T	Major tools and equipment
T	Small tools and miscellaneous accessories
T	Non-durable household goods
NT	Domestic services
NT	Household services
T	Pharmaceutical products
T	Other medical products
T	Therapeutical appliances and equipment
NT	Medical Services
NT	Services of dentists
NT	Paramedical services
NT	Hospital services
T	Motor cars with diesel engine
T	Motor cars with petrol engine of cubic capacity of less than 1200cc
T	Motor cars with petrol engine of cubic capacity of 1200cc to 1699cc
T	Motor cars with petrol engine of cubic capacity of 1700cc to 2999cc
T	Motor cars with petrol engine of cubic capacity of 3000cc and over
T	Motor cycles
T	Bicycles
T	Animal drawn vehicles
T	Spare parts and accessories for personal transport equipment
T	Fuels and lubricants for personal transport equipment
NT	Maintenance and repair of personal transport equipment
NT	Other services in respect of personal transport equipment
NT	Passenger transport by railway
NT	Passenger transport by road
T	Passenger transport by air
NT	Passenger transport by sea and inland waterway
NT	Combined passenger transport
NT	Other purchased transport services
NT	Postal services
T	Telephone and telefax equipment
NT	Telephone and telefax services
T	Equipment for reception, recording and reproduction of sound and pictures
T	Photographic and cinematographic equipment and optical instruments
T	Information processing equipment
T	Pre-recorded recording media
T	Unrecorded recording media
NT	Repair of audio-visual, photographic and information processing equipment
T	Major durables for outdoor recreation
T	Musical instruments and major durables for indoor recreation
NT	Maintenance and repair of other major durables for recreation and culture
T	Games, toys and hobbies
T	Equipment for sport, camping and open-air recreation
T	Gardens, plants and flowers
T	Pets and related products
T	Veterinary and other services for pets
NT	Recreational and sporting services
NT	Photographic services
NT	Other cultural services
T	Games of chance
T	Books
T	Newspapers and periodicals
T	Miscellaneous printed matter, stationery and drawing materials
T	Package holidays
NT	Pre-primary and primary education
NT	Secondary education
NT	Post-secondary education
NT	Tertiary education
NT	Education not definable by level
NT	Restaurant services whatever the type of establishment
NT	Pubs, bars, cafs, tea rooms and the like
NT	Canteens
T	Accommodation services
NT	Hairdressing salons and personal grooming establishments
T	Electric appliances for personal care
T	Other appliances, articles and products for personal care
NT	Prostitution
T	Jewellery, clocks and watches
T	Other personal effects
NT	Social protection
NT	Insurance
NT	Other financial services n.e.c.
NT	Other services n.e.c.

Indicator: Series selected for Employment status: Total Employment
Link: `https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS`

A.6 Construction of the labor wedge

Our standard method uses the model solution (16) to calculate labor wedge using observed variables and calibrated parameter values as described in Table 6.

Table A2. Comparative properties of relative Unit Labor Costs
Correlations with RULC

	$AUTH$	TOT_{PWT}	$CENT$
Time-series	0.56	0.50	0.11
Cross-section	0.79	0.43	0.08
Overall	0.74	0.44	0.08

Table A2 reports correlations of relative Unit Labor Costs measure with AUTH (summary measure of formal authority of unions regarding wage setting at aggregate and sectoral levels), a PWT-based measure of the Terms of trade (TOT_{PWT}), and CENT (centralisation of wage bargaining measured by weighting national and sectoral concentration of unions by level of importance). Labor wedge is described in Appendix A.1. and A.7. "Time-series" refers to the correlation of de-meaned (by country) concatenated vectors of 117 observations. "Cross-section" refers to the correlation of 9 mean values (1 per country). "Overall" refers to the correlation of concatenated vectors of 117 level observations.

An alternative measure (Method 2) of labour wedge uses the first-order condition (17) instead:

$$\chi^* - \chi = \text{RULC} + \gamma\kappa(a_F^* - a_H) + (1 - \gamma\kappa)(a_N^* - a_N) - \psi(\ell^* - \ell) \tag{26}$$

This alternative measure uses observed data for all three variables, where the ℓ is represented by differences in Hours Worked as described in the Appendix A.5 above. Empirical results with this alternative measure of labour wedge are reported in the Appendix F below.

Table A3 reports correlations of the labor wedge with the institutional labor market measures discussed earlier, and also with the terms of trade.

Table A3. Comparative properties of Labor wedge estimates
Correlations with Labor wedge

	$AUTH$	TOT_{PWT}	$CENT$
Time-series	0.51	0.34	0.16
Cross-section	0.76	0.53	0.10
Overall	0.74	0.50	0.09

Table A3 reports correlations of Labor wedge (Method 1) with AUTH (summary measure of formal authority of unions regarding wage setting at aggregate and sectoral levels), a PWT-based measure of the Terms of trade (TOT_{PWT}), and CENT (centralisation of wage bargaining measured by weighting national and sectoral concentration of unions by level of importance). Labor wedge is described in Appendix A.1. and A.7. "Time-series" refers to the correlation of de-meaned (by country) concatenated vectors of 117 observations. "Cross-section" refers to the correlation of 9 mean values (1 per country). "Overall" refers to the correlation of concatenated vectors of 117 level observations.

A.7 Government consumption as fraction of GDP

Database: OECD - Annual National Accounts
Subject: Government deficit/surplus, revenue, expenditure and main aggregates
Measure: GP3P: Final consumption expenditure, Millions euro, Current prices
Link: `http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=SNA_TABLE12&ShowOnWeb=true&Lang=en`
Subject: Main aggregates, Gross Domestic Product
Measure: B1_GE: Gross domestic product (expenditure approach), Millions euro, Current prices
Link: `http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=SNA_TABLE1&ShowOnWeb=true&Lang=en`

A.8 Surplus of the government budget

Database: Eurostat, Government deficit/surplus, debt and associated data
Series name: gov_10dd_edpt1
Indicator: General Government Net Lending/ Net Borrowing, percentage of GDP
Link: `http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gov_10dd_edpt1&lang=en`

A.9 Long run real interest rate

Database: OECD - Key Short-term Economic Indicators
Subject: Long-term interest rates, annual data
Measure: Level
Link: `http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=KEI&Coords=%5bSUBJECT%5d.%5bIRLTLT01%5d&ShowOnWeb=true&Lang=en`
Subject: Consumer prices, all items
Measure: Growth over pervious period
Link: `http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=KEI&Coords=%5bSUBJECT%5d.%5bCPALTT01%5d&ShowOnWeb=true&Lang=en`

B Model simulations

The model has three different kinds of shocks in the Home country: productivity shocks in each of the two sectors, $A_{i,t},\ i = H, N$, and shocks to the disutility of labor, χ_t. There is also a Foreign country. We set Foreign shocks equal to zero, and then calibrate each of the Home country shocks using data relative to the EU12 set of countries. Shocks enter the model in relative terms, so this is equivalent to treating the EU12 as the Foreign country. Note that even though Foreign shocks are set to zero, Foreign variables are not constant because in equilibrium there is feedback from the Home to the Foreign country.

We calibrate the model by generating normally distributed random variables for nine artificial countries that have the same moments as the data. Specifically, the artificial data have the same means, serial correlation, and covariance matrix as the data.

The data used to create the moments for traded and nontraded productivity are the same as the data used in our empirical work. There is no direct measure of labor supply shocks. However, we can use equation (14) to construct a measure of the labor wedge, based on the solution in the symmetric flexible price model. This allows us to calculate the labor wedge as a function of the productivity shocks and the unit labor cost. The results from this measure of the labor wedge to simulate the model are reported in Tables 8-12. In Appendix F, we report model results using a measure of the labor wedge constructed from equation (17).

Our regressions use annual data for 15 years, but we calibrate a period to be one quarter in the model. The length of the period matters particularly when considering the effects of price stickiness on the economy. Hence, we create artificial data for 60 quarters. We then aggregate the artificial data into annual data by taking quarterly averages in order to compare the statistics generated by the model to the data.

Here is how we translate the moments of the annual data into quarterly data for the model.

We suppose that the log of quarterly TFP (both traded and nontraded) as well as labor preference shocks follow first-order autoregressions:

$$a_t^q - \bar{a} = \rho^q(a_{t-1}^q - \bar{a}) + u_t^q.$$

Annual productivity is the average of quarterly productivity: $A_t^a = \frac{1}{4}(A_t^q + A_{t-1}^q + A_{t-2}^q + A_{t-3}^q)$. To a first-order approximation, around the point $E(\exp(a_t^a)) = E(\exp(a_t^q)) = \exp(\bar{a})$, we have $a_t^a = \frac{1}{4}(a_t^q + a_{t-1}^q + a_{t-2}^q + a_{t-3}^q)$.

If we had quarterly observations on annual average data, we would find then that the annual data follow a process of:

$$a_t^a - \bar{a} = \rho^q(a_{t-1}^a - \bar{a}) + e_t,$$

where $e_t = \frac{1}{4}(u_t^q + u_{t-1}^q + u_{t-2}^q + u_{t-3}^q)$. In fact, we have annual observations on annual data, which follow the process:

$$a_t^a - \bar{a} = \rho^a(a_{t-4}^a - \bar{a}) + u_t^a,$$

where $\rho^a \equiv (\rho^q)^4$ and $u_t^a \equiv \frac{1}{4}(e_t + \rho^q e_{t-1} + (\rho^q)^2 e_{t-2} + (\rho^q)^3 e_{t-3})$.

We then calculate the serial correlation of the artificial quarterly data using $\rho^q = (\rho^a)^{0.25}$. In a couple of cases, the estimated serial correlation coefficient for the productivity data was above 1.0. Our numerical model assumes stationary productivity, so in those cases we set $\rho^q = 0.99$. The unconditional mean of the quarterly process is taken to be the same as the unconditional mean of the annual process.

Calibrating the variance of the quarterly shocks is more difficult. If the quarterly data followed an AR(1) with uncorrelated shocks, then the annual data should follow an ARMA(1,4) process, but we find that an AR(1) with serially uncorrelated shocks adequately captures the dynamics of the annual data. Hence, we treat the e_t as being serially uncorrelated. When ρ^q is close to one, it implies we should then set $var(u_t^q) = var(u_t^a)$.

We then take the estimated covariance matrix of the u_t^a to be the covariance matrix for generating data at our quarterly frequency. We allow for covariance across countries and across shocks. That is, the covariance matrix is 27×27, representing the covariance of each of three shocks for nine countries.

We calibrate the AR(1) coefficient and unconditional mean for each exogenous random variable (for logs of traded and nontraded productivity and for logs of labor supply shocks) as above from the annual data. We draw the shocks for the artificial data from a Normal multivariate distributions (for each of the three exogenous random variables) for the nine Eurozone countries with the 27×27 variance-covariance matrix calibrated as described above.

B.1 The role of measurement error in the the regression of q on q_n.

In section 3, we noted that the coefficient on q_n in the regression of q on q_n in Table 3a was lower than that which comes out of the simulated regressions in Table 9a. This may be due to the fact that non-traded distribution services are not accurately measured by the observed price of non-traded goods. To see this, take the following example.

Let us use the notation p_S and p_S^* for the true prices of non-traded distribution services. Assume that $p_S = p_N + u$, where u is some exogenous disturbance that makes the price of distribution services different from the general price of non-traded goods and services. Assume that p_N and u are uncorrelated. Then (10) becomes

$$q = (1 - \gamma\kappa)(p_N^* - p_N) + \gamma(1 - \kappa)(u^* - u) \tag{27}$$

In addition, using the same conditions, we have

$$q_n = (p_N^* - p_T^* - (p_N - p_T)) = \kappa(p_N^* - p_N) - (1 - \kappa)(u^* - u) \tag{28}$$

Using (28) in (27) we arrive at the 'true' relationship between q and q_n given by:

$$q = \frac{(1 - \gamma\kappa)}{\kappa} q_n + \frac{(1 - \kappa)}{\kappa}(u^* - u) \tag{29}$$

Hence, using (28) and (29), our estimate of the slope coefficient in the regression of q on q_n will be

$$\frac{\text{cov}(q, q_n)}{\text{var}(q_n)} = \frac{(1 - \gamma\kappa)}{\kappa} - \frac{(1 - \kappa)^2}{\kappa} \frac{\text{var}(u^* - u)}{\text{var}(q_n)}$$

The coefficient estimate is biased downwards from $\frac{1-\gamma\kappa}{\kappa}$. The bias is larger, the larger is the share of the non-traded distribution service.

C Further discussion of Eurostat data procedures

Here we quote extensively, but selectively, from the Eurostat-OECD PPP manual, Chapter 4, to convey a sense of the efforts that are put in to make the price data comparable across countries. We say that our quotations are 'selective' because the manual itself is over 400 pages long, covering far too many issues for us to mention here. The data on prices comes from 6-monthly survey. The first set of prices is collected in April to May, and the second set in October to November each year.

The composition of a basket of goods within each basic heading (e.g., "rice") is "defined as one that accounts for a significant share of a country's expenditure within a basic heading because this means that its price level will be close to country's average price level for all products in the basic heading.".

The manual argues this data is specifically designed for inter-national comparisons, and is better suited for that purpose than CPI data (section 4.9 on page 63).

"Faced with such an array [.. of goods within each basic heading ...], selecting a subset of products for a basic heading that can be priced over a number of countries is clearly going to be difficult, much more difficult than it is to select the products to be priced at the elementary level of a consumer price index (CPI) within a single country. There, within broad guiding parameters, the selection can be left to the price collector whose choice may differ from outlet to outlet providing it does not change over time. This initiative cannot be allowed to price collectors collecting prices for Eurostat and OECD comparisons because they are spatial comparisons."

Regarding the 'representativeness' of prices that are surveyed:

"Equal representativity or 'equi-representativity' - does not require all participating country to price the same number of representative products for a basic heading. As explained in Chapter 7, the method used by Eurostat and the OECD to calculate the PPPs for a basic heading ensures that any imbalance between countries in the number of representative products priced does not produce biased price relatives. The method requires that each participating country price at least one representative product per basic heading. This is a necessary condition to calculate unbiased PPPs, but it is not a sufficient condition to obtain reliable PPPs. For this, each participating country should price that number of representative products which is commensurate with the heterogeneity of the products and price levels within the basic heading and with the importance of its own expenditure on the basic heading."

The manual has this to say about products included in the survey:

"For a product to be included on the product list at least one other country, besides the proposing country, has to agree to price it. This is a minimum condition. It is preferable that more than one country agrees to price it. ... Not all proposals made by countries will be accepted."

Much effort is made to insure goods that are priced are comparable across countries:

"At the start, each country group makes its product selection independently of the other groups and the same products will not necessarily be selected by all groups. Eurostat and the OECD cover all participating countries in a single comparison irrespective of group. It is necessary to make sure before prices are collected that countries can be compared not only with countries in their group but also with countries in the other groups. This is achieved with overlap products - that is, products that are common to more than one group. Overlap products are identified and included after the group product lists have been finalized. The process is described later in the chapter."

"The issue of heterogeneity raised earlier is partly eased by the way basic headings are defined in the Eurostat-OECD expenditure classification. Definitions list the products covered by the basic headings. For example, 'other bakery products' include 'crispbread, rusks, toasted bread, biscuits, gingerbread, wafers, waffles, crumpets, muffins, croissants, cakes, tarts, pies, quiches and pizzas'. The lists are not exhaustive, but they are sufficiently extensive to allow the more heterogeneous basic headings to be subdivided into smaller and more homogeneous product groups. Breaking a basic heading down into a more manageable framework facilitates both product selection and coverage. In anticipation of this, the lists for the more heterogeneous basic headings arrange products in sets. For example, the list for the basic headings covering clothing identifies four sets or subgroups:

- capes, overcoats, raincoats, anoraks, parkas, blousons, jackets, trousers, waistcoats, suits, costumes, dresses, skirts, etc.;
- shirts, blouses, pullovers, sweaters, cardigans, shorts, swimsuits, tracksuits, jogging suits, sweatshirts, T-shirts, leotards, etc.;
- vests, underpants, socks, stockings, tights, petticoats, brassires, knickers, slips, girdles, corsets, body stockings, etc.;
- pyjamas, night-shirts, night dresses, housecoats, dressing gowns, bathrobes, etc."

Following the selection of representative baskets (after Eurostat agrees on the proposals, following negotiations), individual countries collect the actual prices.

"Price collection is the responsibility of the participating countries. On receipt of the final product list for their group, countries are required to price it at a sample of outlets which, even if selected purposively, reflects the purchasing patterns of households. They are expected to price as many items on the product list as comparability and availability allow. After the price survey, countries are required to edit the prices collected for outliers using the software supplied by Eurostat. After making the necessary corrections, they report the individual price observations, the average survey prices and a report on the survey to their group leader. The country reports on the survey, together with the individual price observations, assist the group leader with the editing of the average survey prices.

The goods and services to be priced may differ from survey to survey, but all the surveys share a common objective namely, that each participating country prices a set of internationally comparable products across a representative sample of outlets. Clearly, if this objective is to be met, the price surveys need to be carefully planned and prepared by their national organizers. Before starting price collection, participating countries are expected to carry out a number of tasks. These involve:

- selecting the outlets that are to be visited by price collectors and contacting the outlets selected to explain why they are to be visited;
- preparing pricing materials and other documentation for price collectors (product specifications, survey guidelines, price reporting forms, outlet codes and co-ordinates, schedule of visits, identification and letters of introduction, etc.), including the translation of product specifications and survey guidelines into the national language if necessary;
- identifying which specifications on the final group product list are to be priced and, in the case of generic specifications, which brands are to be priced (if these tasks are not left for the price collectors to do themselves);
- holding a meeting with price collectors to clarify the pricing and supporting materials prepared and issues such as how many items per basic heading, how many prices per item, etc.

The tasks are important because they avoid nonresponse and reduce non-sampling error."

On outlet selection:

"CPIs measure price changes over time by repeatedly pricing the same product at the same outlet, thereby keeping the service element constant. For practical reasons this approach has not been followed in international comparisons of GDP. The 'potato is a potato' rule is applied instead. Each product specified is treated as being homogeneous regardless of where it is priced. If, when averaging the prices collected for the product, no account is taken of the different service elements of the outlets at which they were observed, the average price is likely to be too high or too low. To avoid this, countries participating in Eurostat and OECD comparisons are required to select outlets so that the selection mirrors consumer purchasing patterns at various outlet types for the products being priced. If consumers buy 50 per cent of their clothing from departmental stores, 30 per cent from supermarkets and 20 per cent from specialist shops, then a sample of ten outlets would include five departmental stores, three supermarkets and two specialist shops."

On the number of price observations for each good in each survey:

"The number of prices to be collected for each product could be decided using random sampling techniques. Providing the price variation (CV) of the product is known and the desired degree of accuracy (SE) is specified, sample size (N) is determined by $[t^2CV^2/SE^2]$, where t is Student's t and which is here assumed to equal 2 at 0.95 probability. For example, if it is known from the last time the price survey was conducted that the coefficient of variation for the average price of a product is 20 per cent and the level of precision sought in the forthcoming survey is 10 per cent, the sample size should be 16. With the same price variation and a precision level of 5 per cent, the sample size should be 64. In other words, a twofold increase in accuracy requires a fourfold increase in sample size. ... A coefficient of variation of 20 per cent is high. A coefficient of variation higher than 20 per cent indicates that either the product description was too broad or that the price collection was faulty. In general, price differences for a product within a country should not be more than 10 to 50 per cent, a coefficient of variation of approximately 5 to 15 per cent. Tight specifications usually have a lower coefficient of variation than loose specifications. On this basis, rough upper limits can be assigned to the coefficients of variation for specifications that are brand specific (10 per cent), specifications that cover well-known brands (15 per cent) and specifications that are brandless (20 per cent). Assuming a level of precision of 10 per cent, which is both reasonable and acceptable, application of $[t^2CV^2/SE^2]$ gives sample sizes of around 5 for brand specific specifications, of around 10 for well-known brand specifications and between 15 to 20 for brandless specifications."

The prices are usually collected in the capital city (for most countries). Consequently, countries need to provide a "spatial adjustment factor" that helps to convert those prices to the "national average price".

There is a temporal adjustment to get an annual price uses CPI monthly data. This is done with "temporal adjustment factors", extracted from CPI:

"Participating countries extract the temporal adjustment factors from their CPI data base. COICOP38 is the classification underlying the CPIs of most participating countries. And, as explained in Chapter 3, it is as well the classification underlying the breakdown of individual consumption expenditure by households in the Eurostat-OECD classification of final expenditure on GDP. The correspondence between CPI sub-indices and basic headings is therefore generally high. But when there is no exact match, participating countries are expected to select a sub-index, or an aggregation of subindices, that closely approximates the basic heading in question. CPI sub-indices are usually more detailed than basic headings and often they can be aggregated specifically for a basic heading."

Table A4. Sectors in the GGDC 1997 TFP level database

1	TOTAL INDUSTRIES
2	MARKET ECONOMY
3	ELECTRICAL MACHINERY, POST AND COMMUNICATION SERVICES
4	Electrical and optical equipment
5	Post and telecommunications
6	GOODS PRODUCING, EXCLUDING ELECTRICAL MACHINERY
7	TOTAL MANUFACTURING, EXCLUDING ELECTRICAL
8	Consumer manufacturing
9	Food products, beverages and tobacco
10	Textiles, textile products, leather and footwear
11	Manufacturing nec; recycling
12	Intermediate manufacturing
13	Wood and products of wood and cork
14	Pulp, paper, paper products, printing and publishing
15	Coke, refined petroleum products and nuclear fuel
16	Chemicals and chemical products
17	Rubber and plastics products
18	Other non-metallic mineral products
19	Basic metals and fabricated metal products
20	Investment goods, excluding hightech
21	Machinery, nec.
22	Transport equipment
23	OTHER PRODUCTION
24	Mining and quarrying
25	Electricity, gas and water supply
26	Construction
27	Agriculture, hunting, forestry and fishing
28	MARKET SERVICES, EXCLUDING POST AND TELECOMMUNICATIONS
29	DISTRIBUTION
30	Trade
31	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
32	Wholesale trade and commission trade, except of motor vehicles and motorcycles
33	Retail trade, except of motor vehicles and motorcycles; repair of household goods
34	Transport and storage
35	FINANCE AND BUSINESS, EXCEPT REAL ESTATE
36	Financial intermediation
37	Renting of m. eq. and other business activities
38	PERSONAL SERVICES
39	Hotels and restaurants
40	Other community, social and personal services
41	Private households with employed persons
42	NON-MARKET SERVICES
43	Public admin, education and health
44	Public admin and defence; compulsory social security
45	Education
46	Health and social work
47	Real estate activities

`http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database`

Table A5. Sectors in the March 2009 edition of the KLEMS TFP time-series database

1	TOTAL INDUSTRIES
2	AGRICULTURE, HUNTING, FORESTRY AND FISHING
3	MINING AND QUARRYING
4	TOTAL MANUFACTURING
5	FOOD , BEVERAGES AND TOBACCO
6	TEXTILES, TEXTILE , LEATHER AND FOOTWEAR
7	WOOD AND OF WOOD AND CORK
8	PULP, PAPER, PAPER , PRINTING AND PUBLISHING
9	CHEMICAL, RUBBER, PLASTICS AND FUEL
10	Coke, refined petroleum and nuclear fuel
11	Chemicals and chemical
12	Rubber and plastics
13	OTHER NON-METALLIC MINERAL
14	BASIC METALS AND FABRICATED METAL
15	MACHINERY, NEC
16	ELECTRICAL AND OPTICAL EQUIPMENT
17	TRANSPORT EQUIPMENT
18	MANUFACTURING NEC; RECYCLING
19	ELECTRICITY, GAS AND WATER SUPPLY
20	CONSTRUCTION
21	WHOLESALE AND RETAIL TRADE
22	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
23	Wholesale trade and commission trade, except of motor vehicles and motorcycles
24	Retail trade, except of motor vehicles and motorcycles; repair of household goods
25	HOTELS AND RESTAURANTS
26	TRANSPORT AND STORAGE AND COMMUNICATION
27	TRANSPORT AND STORAGE
28	POST AND TELECOMMUNICATIONS
29	FINANCE, INSURANCE, REAL ESTATE AND BUSINESS SERVICES
30	FINANCIAL INTERMEDIATION
31	REAL ESTATE, RENTING AND BUSINESS ACTIVITIES
32	Real estate activities
33	Renting of m. eq. and other business activities
34	COMMUNITY SOCIAL AND PERSONAL SERVICES
35	PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY
36	EDUCATION
37	HEALTH AND SOCIAL WORK
38	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES
39	PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS
40	EXTRA-TERRITORIAL ORGANIZATIONS AND BODIES

`http://www.euklems.net/euk09ii.shtml`

Table A6. Sectoral concordance

	GGDC sector ID	KLEMS sector ID	Tradability	Names of sectors
1	27	2	T	Agriculture, hunting, forestry and fishing
2	24	3	T	Mining and quarrying
3	9	5	T	Food , beverages and tobacco
4	10	6	T	Textiles, textile , leather and footwear
5	13	7	T	Wood and of wood and cork
6	14	8	T	Pulp, paper, paper , printing and publishing
7	16	9	T	Chemical, rubber, plastics and fuel
8	18	13	T	Other non-metallic mineral
9	19	14	T	Basic metals and fabricated metal
10	21	15	T	Machinery, nec
11	4	16	T	Electrical and optical equipment
12	22	17	T	Transport equipment
13	11	18	T	Manufacturing nec; recycling
14	25	19	N	Electricity, gas and water supply
15	26	20	N	Construction
16	29	21	N	Wholesale and retail trade
17	39	25	N	Hotels and restaurants
18	34	27	N	Transport and storage
19	5	28	N	Post and telecommunications
20	36	30	N	Financial intermediation
21	37	31	N	Real estate, renting and business activities

D Adding aggregate demand variables to the real exchange rate regression

Here we examine the extension of the empirical model of section 3 to allow for other drivers of real exchange rates besides relative sectoral productivities and the labor wedge. We construct panels of variables considered to be potentially important in the literature cited in footnote 13: government consumption, government's budget balance, and long-run real interest rates We construct these variables in the same manner as our productivity and price variables, as the average Eurozone levels relative to a particular Eurozone member state. To assess how the addition of these variables changes our baseline results, we follow Hendrys method of sequential elimination of insignificant variables. We perform this exercise in the pool, fixed-effect, and random-effect regressions. [52] The results are reported in Table A7. In the pooled regression (1), the long-run real interest rate is eliminated as insignificant. Government spending and budget surplus variables are both significant; a rise in either variable generates a real exchange rate depreciation. Our baseline coefficient estimates remain highly significant: traded TFP and RULC are very close to the baseline results, while the non-traded TFP has a more negative coefficient. The fixed-effects regression (2) results in a different set

[52] Performing a sequential elimination test would be pointless in our cross-section of 9 countries.

of demand-side variables, with government surplus being eliminated, while the remaining two demand variables remain significant. An increase in government expenditures is again associated with a depreciation of the real exchange rate, while the increase in the long-run real interest rate causes a real exchange rate appreciation. RULC remain highly significant as in our benchmark regression, traded TFP is marginally significant while non-traded TFP is not significant. The random effects regression selects the same demand-side variables as the fixed-effects regression, with similar coefficients. All our baseline repressors remain highly significant and have the predicted signs. In the light of these sensitivity results, we conclude that the inclusion of demand-side variables does not alter the results of our analysis. Importantly, unit labour costs do not appear to proxy for the effects of demand-side variables.

Table A7. RER - TFP regression with Demand-side variables

	Pool	**Fixed effects**	**Random effects**
	1	2	3
TFP_T	**0.69*****	**0.19***	**0.29*****
	(0.061)	(0.099)	(0.081)
TFP_N	**-0.42*****	-0.31	**-0.37****
	(0.081)	(0.202)	(0.147)
$RULC$	**0.43*****	**0.39*****	**0.37*****
	(0.088)	(0.075)	(0.079)
G	**-0.71****	**-1.28***	**-1.4****
	(0.351)	(0.76)	(0.626)
SG	**-1.35*****	–	–
	(0.324)		
LR	–	**1.42****	**1.54****
		(0.554)	(0.560)
$\overline{R}^2$	0.63	0.91	0.37
N	117	117	117
HT	–	–	reject

This table reports regression results with an addition of demand-side variables, after dropping all insignificant demand variables. Dependant variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a depreciation). $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. $RULC_{it}$ comes from OECD.Stat database and is defined as a ratio of nominal Total Labor Costs for the economy relative to real output (2005 base year), expressed as EU 17 value relative to country i. ULC are converted to euro for all countries. G_i is General government's Final consumption expenditure as a fraction of GDP in country i and year t (provided by OECD), expressed as the EU12 average relative to country i. SG_i is Government surplus or deficit as a percentage of GDP in country i, expressed as the EU12 average relative to country i. LR_i is the estimated real long-run interest rate, calculated as a 10-year government bond yield less annual CPI inflation in country i. LR_i is expressed as the EU12 average relative to country i. The balanced data sample is 1995-2007. "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. All standard errors are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

E Results using Terms of Trade

Table A8. RER - TFP regression with Terms of Trade

	Pool	Fixed effects	Random effects	Cross-section
	1	2	3	4
TFP_T	**0.43*****	0.04	**0.14*****	**0.54*****
	(0.033)	(0.06)	(0.05)	(0.04)
TFP_N	**-0.25*****	-0.02	-0.12	-0.22
	(0.046)	(0.12)	(0.09)	(0.13)
TOT	**1.68*****	**1.64*****	**1.72*****	**1.41*****
	(0.088)	(0.15)	(0.13)	(0.31)
$\overline{R}^2$	0.83	0.94	0.63	0.90
N	117	117	117	9
HT	–	reject	–	–

Dependant variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a depreciation). $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. $TFP_{N,i,t}$ is constructed in a similar fashion. TOT_{it} is constructed using "Price of output" series (*pl_gdpo*) from the Penn World Tables 8.1. It is expressed relative to their EU13 average. The balanced data sample is 1995-2007. "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. All standard errors are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

F Results using Labor Wedge Method 2

Table A9. RER - TFP regression with Labor Wedge (Method 2)

	Pool	Fixed effects	Random effects	Cross-section
	1	2	3	4
TFP_T	**0.65*****	0.045	**0.12***	**0.81*****
	(0.057)	(0.088)	(0.0757)	(0.084)
TFP_N	**-0.57*****	**-0.70*****	**-0.72*****	**-0.52***
	(0.12)	(0.18)	(0.147)	(0.22)
LW	**0.31*****	**0.45*****	**0.42*****	**0.29*****
	(0.067)	(0.07)	(0.07)	(0.077)
$\overline{R}^2$	0.53	0.90	0.32	0.70
N	117	117	117	9
HT	–	–	reject	

Dependent variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a depreciation). TFP_i is the log of TFP level of traded relative to non-traded sector in EU12 ($\log(TFP_{T,EU12,t}/TFP_{N,EU12,t})$) relative to country i. $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. LW_{it} is the constructed labor wedge using method 2 (see (17)) (*** $laborwedge99 = rulc + 0.33a_T + 0.7a_N - n$). LW in EU 17 relative to country i (an increase is a depreciation) is used in regressions. The balanced data sample is 1995-2007. "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. All standard errors (except in $Cross-section$) are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). The standard errors in $Cross-section$ are Newey-West standard errors. Standard errors are in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Included Eurozone members are: Austria, Belgium, Germany, Finland, France, Ireland, Italy, the Netherlands and Spain. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table A10. Properties of model Real Exchange Rate (Labor Wedge: Method 2)

	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4
STD (Time Series)	0.046 (0.038,0.056)	0.049 (0.041,0.059)	0.053 (0.045,0.063)	0.033
STD (Cross Section)	0.097 (0.063,0.152)	0.098 (0.063,0.153)	0.098 (0.063,0.154)	0.113
Serial Correlation	0.773 (0.692,0.854)	0.745 (0.656,0.827)	0.689 (0.590,0.775)	0.670

Results in the "Data" column repeat those from Table 2. Other columns are based on regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1$). As in our data, panels of synthetic data are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter. The labor wedge is constructed using Method 2, as described in Appendix A.7 above.

Table A11. Model price regressions (Labor Wedge: Method 2)

Table A11a: Time Series Regressions

	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4
Regression of q on q_n	1.174 (1.159,1.196)	1.173 (1.159,1.196)	1.173 (1.160,1.195)	0.60
Regression of q_T on q_n	0.666 (0.643,0.683)	0.666 (0.644,0.682)	0.665 (0.644,0.682)	0.11
Regression of q on q_T	1.758 (1.714,1.826)	1.758 (1.715,1.826)	1.759 (1.716,1.826)	1.08

Table A11b: Cross Section Regressions

	Sticky price A	Sticky price B	Flexible price	Data
	5	6	7	8
Regression of q on q_n	1.167 (1.139,1.194)	1.167 (1.139,1.194)	1.167 (1.139,1.194)	0.71
Regression of q_T on q_n	0.660 (0.629,0.685)	0.660 (0.629,0.686)	0.660 (0.629,0.686)	0.89
Regression of q on q_T	1.759 (1.703,1.859)	1.759 (1.703,1.860)	1.759 (1.703,1.860)	1.20

Results in the "Data" column repeat those from Table 3. Results in the other columns are based on the regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1$). As in our data, panels of synthetic data are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. The calibration in column "Sticky price A" assumes a 10% price adjustment per quarter. "Sticky price B" assumes a 20% price adjustment per quarter. The labor wedge is constructed using Method 2, as described in Appendix A.7 above.

Table A12. Model regressions with RULC (Labor wedge: Method 2)

Table A12a. Time Series Regression Results

	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4
Traded TFP	0.174	0.184	0.204	0.18
	(0.063,0.312)	(0.103,0.284)	(0.178,0.240)	
Nontraded TFP	-0.223	-0.212	-0.201	-0.36
	(-0.412,-0.044)	(-0.354,-0.074)	(-0.240,-0.169)	
RULC	0.438	0.525	0.693	0.46
	(0.374,0.493)	(0.470,0.570)	(0.659,0.714)	

Table A12b. Cross Section Regression Results

	Sticky price A	Sticky price B	Flexible price	Data
	5	6	7	8
Traded TFP	0.262	0.262	0.270	0.93
	(0.082,0.472)	(0.087,0.479)	(0.090,0.496)	
Nontraded TFP	-0.453	-0.462	-0.466	-0.27
	(-0.669,-0.264)	(-0.672,-0.273)	(-0.694,-0.276)	
RULC	0.415	0.417	0.424	0.43
	(0.264,0.669)	(0.294,0.513)	(0.295,0.519)	

Results in the "Data" column are from Table 4. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1.$). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

Table A13. Model regressions with Labor Wedge (Method 2)

Table A13a. Time Series Regression Results

	Sticky price A	Sticky price B	Flexible price	Data
	1	2	3	4
Traded TFP	0.187	0.219	0.284	0.04 (0.12 in R.E.)
	(0.047,0.331)	(0.073,0.361)	(0.142,0.436)	
Nontraded TFP	-0.620	-0.676	-0.781	-0.70
	(-0.859,-0.356)	(-0.904,-0.424)	(-1.004,-0.524)	
Labor Wedge	0.154	0.160	0.172	0.45
	(0.064,0.344)	(0.025,0.247)	(0.027,0.264)	

Table A13b. Cross Section Regression Results

	Sticky price A	Sticky price B	Flexible price	Data
	5	6	7	8
Traded TFP	0.283	0.284	0.289	0.81
	(0.167,0.404)	(0.168,0.408)	(0.173,0.411)	
Nontraded TFP	-0.716	-0.722	-0.733	-0.52
	(-0.946,-0.425)	(-0.954,-0.408)	(-0.960,-0.432)	
Labor Wedge	0.205	0.208	0.213	0.29
	(0.064,0.344)	(0.066,0.347)	(0.068,0.350)	

Results in the "Data" column are from Table 5. Other columns report regressions with simulated data (500 simulations of the DGP, as described in Appendix B, with $\kappa = 0.6$, $\gamma = 0.5$ and $\psi = 1.$). As in our data, synthetic series are generated for 15-year (60-quarter) periods. 90% confidence intervals are reported in the parentheses. "Sticky price A" assumes a 10% price adjustment per quarter, "B" assumes a 20% price adjustment per quarter.

G Fit of the model

We can evaluate the fit of the model by asking how the model behaves if we feed actual traded and non-traded productivity and the actual labor wedge in as exogenous variables. This is not straightforward because the actual data is annual, but the model is written at quarterly frequency. Also, we want to allow for the fact that empirically there is not an exact fit between these variables and the real exchange rate. So here we compare the fitted value of the empirical model to the fitted value of the theoretical model in the following steps. We treat the model and the data equally. In the model, we first calculate the average fitted real exchange rate $q_F(i)$ for country i as:

$$\overline{q_F}(i) = b_{1b}(\overline{TFP_T}(i)) + b_{2b}(\overline{TFP_N}(i)) + b_{3b}(\overline{RULC}(i))$$

We then construct the fitted real exchange rate for country i at time t as:

$$q_F(i,t) =$$

$$\overline{q_F}(i)+b_{1a}(TFP_T(t,i)-\overline{TFP_T}(i))+b_{2a}(TFP_N(t,i)-\overline{TFP_N}(i))+b_{3a}(RULC(t,i)-\overline{RULC}(i))$$

where $b_{ja},\ b_{jb},\ j \in \{1,2,3\}$ are the coefficients from Tables 10a and 10b, respectively. The first regression then gives the model prediction for the average real exchange rate for each country i, and then the second equation gives us the model predicted real exchange rate over time as the sum of the time-series mean and deviations from the mean.

Equivalently, we construct the average predicted real exchange rates $q_P(i)$ using Table 4's cross-sectional results. For country i:

$$\overline{q_P}(i) = c_{1b}(\overline{TFP_T}(i)) + c_{2b}(\overline{TFP_N}(i)) + c_{3b}(\overline{RULC}(i))$$

Then, we calculate the predicted real exchange rate for country i at time t as:

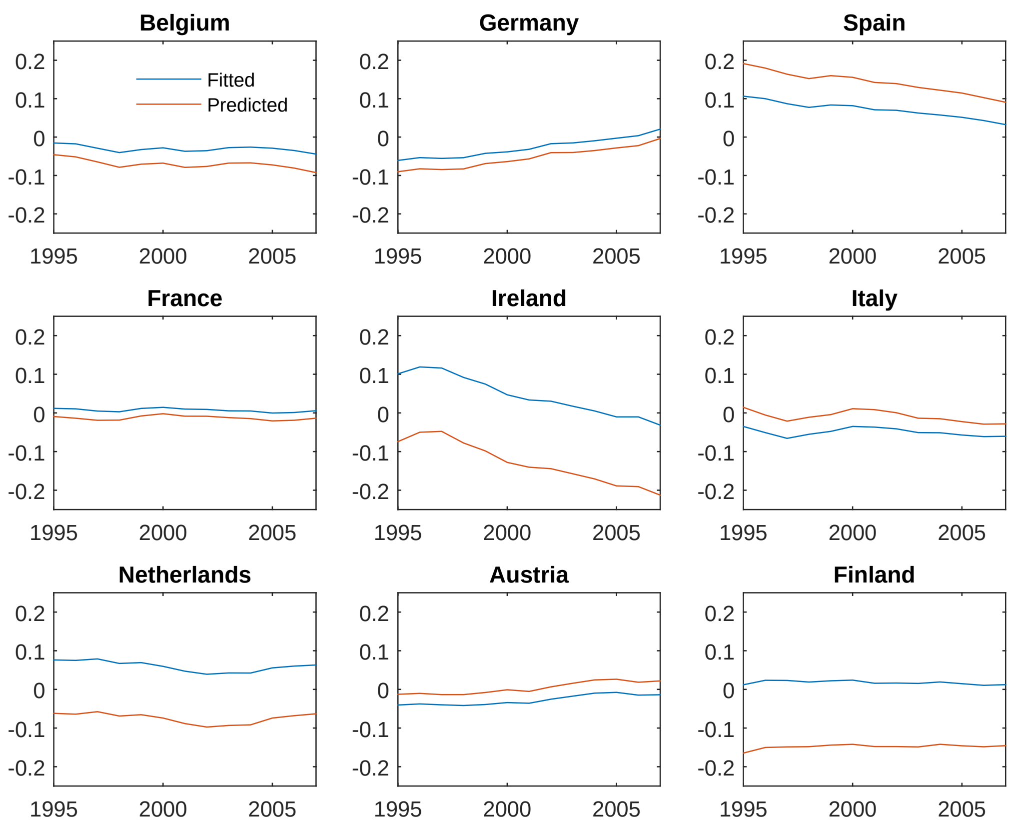
$$q_P(i,t) =$$

$$\overline{q_P}(i)+c_{1a}(TFP_T(t,i)-\overline{TFP_T}(i))+c_{2a}(TFP_N(t,i)-\overline{TFP_N}(i))+c_{3a}(RULC(t,i)-\overline{RULC}(i))$$

where $c_{ja},\ j \in \{1,2,3\}$ are the coefficients from Table 4's fixed-effect results. These equations give us the fitted value from the empirical model for each real exchange rate, calculated in the same way as we did for the theoretical model.

Figure 3 below plots the fitted values $q_F(i,t)$ and the predicted values $q_P(i,t)$ on the same axes for all countries in our sample. We can see that the model matches the average level as well as the temporal movement of real exchange rates very closely for a number of countries, including Germany, France, Italy and Austria. Even in the countries where model gap is exceeds 5 percentage points on average, the temporal movement in the model match remarkably to the predicted movements in the real exchange rates from our estimations.

Figure 3: Predicted real exchange rates: predicted and fitted values



H Model solution with firm-side labor wedge

Here, we assume that the labor wedge enters as a shock to the firm's markup. For simplicity, assume the same shock to firms in the non-traded sector and the traded sector.[53] In addition, as in the example of section 2.3 of the paper, we focus on the flexible price version of the model. Then, with flexible prices, firms set prices equal to marginal cost adjusted by a variable markup. Then prices are given by

$$P_{Nt} = \Omega_t \frac{W_t}{\alpha A_{Nt} L_{Nt}^{\alpha-1}}, \qquad P_{Ht} = \Omega_t \frac{W_t}{\alpha A_{Ht} L_{Ht}^{\alpha-1}}$$

Unlike the model of the main text, here Ω_t is time varying, representing the shock to the markup.

Then, following the same assumptions as in the text we can write the log price levels as

$$p_N = w - a_N + \zeta, \quad p_H = w - a_H + \zeta,$$

where $\zeta = \log(\Omega)$ (as in the text, we drop time subscripts for ease of presentation). The real exchange rate decomposition takes the same form as in the text.

Because the firm's markup shocks are the same in each sector, we have as before $p_N - p_H = a_H - a_N$. Then as before the the real exchange rate becomes:

$$q = (1-\gamma\kappa)(p_F^* - p_H + (a_F^* - a_H) - (a_N^* - a_N)) \tag{30}$$

We wish to show the relationship between the real exchange rate, the terms of trade, and relative unit labor costs for the case where the labor wedge is driven by variable firm markups. As before, unit labor cost is defined as the nominal wage divided by output per worker. For the Home country, we have

$$\text{ULC} = w - \gamma\kappa(y_H - n_H) - (1-\gamma\kappa)(y_N - n_N) = w - \gamma\kappa a_H - (1-\gamma\kappa)a_N$$

Now using the traded good sector pricing equations for the home and foreign country, we have:

$$\text{RULC} = p_F^* - p_H - (\zeta^* - \zeta) + (1-\gamma\kappa)(a_F^* - a_H) - (1-\gamma\kappa)(a_N^* - a_N) \tag{31}$$

In contrast to (13) of the main text, we see that RULC now depends on the terms of trade, relative productivity and also the (firm's) labor wedge itself. Hence, unlike the case where the wedge shock comes from the household side of the labor market, RULC is not a sufficient measure of the labor wedge, conditional on productivity.

Now substituting (31) into (30) we

$$q = (1-\gamma\kappa)\ \text{RULC} + (1-\gamma\kappa)(\zeta^* - \zeta) + (1-\gamma\kappa)\gamma\kappa(a_F^* - a_H) - (1-\gamma\kappa)\gamma\kappa(a_N^* - a_N) \tag{32}$$

Equation (32) shows that the original regression specification in equation (13) of the text is misspecified in the model where the labor wedge is driven by variation in the firm's markup

[53] Assuming different markup shocks in each sector makes the algebra more complicated but does not alter the main message. Also, we do not have any clear evidence of differential sectoral markup shocks.

rather than variation coming from the household side of the labor market. Intuitively, in the model with a household supply side labor wedge, RULC fully reflects movements in the terms of trade, conditional on productivity, because the labor wedge leads to movements in wage rates, which feed into prices and the terms of trade. But with the product market labor wedge, movements in the labor wedge may affect the terms of trade independently of changes in RULC. Hence, movements in RULC and productivity do not provide a complete description of movements in the real exchange rate.

We can go on to show that under the calibration used in the model, the regression equation (13) of the text will give a *negative* coefficient on RULC, which clearly contradicts our empirical findings. To show this, we restate the analytical solutions for RULC and q in the text, but now including the possibility of a firm markup labor wedge. Noting again that we impose the parameter assumptions a)-d), we have the relative unit-labor cost and the real exchange rate given by:

$$\text{RULC} = -\frac{\beta_0}{D}(a_F^* - a_H) - \frac{\beta_1}{D}(a_N^* - a_N) + \frac{\sigma}{D}(\chi^* - \chi) - \frac{D-\sigma}{D}(\zeta^* - \zeta) \quad (33)$$

$$q = \frac{1}{D}\left[\sigma\psi\gamma\kappa^2(\lambda-1)(1-\gamma\kappa)\right](a_F^* - a_H) \quad (34)$$

$$-\frac{1}{D}(1-\gamma\kappa)\left[\sigma(1+\psi+\psi\gamma\kappa^2(\lambda-1))\right](a_N^* - a_N) + \frac{\sigma}{D}(1-\gamma\kappa)(\chi^* + \zeta^* - \chi - \zeta)$$

where the coefficients are as defined in the text. From (34) we see that the firm's markup labor wedge generates a real exchange rate appreciation, and has an impact exactly equivalent to the household labor wedge. This is because both wedges lead to an identical terms of trade appreciation. However, the impact of the product market wedge on RULC is quite different, and is in fact negative, as opposed to the positive impact of the labor market wedge (Note that from the definition of D in the text, $D-\sigma > 0$). The intuition for this is that the elasticity of the terms of trade with respect to the product market wedge is less than unity. Then, looking at equation (31), the direct negative effect of $\zeta^* - \zeta$ on RULC is greater than the indirect positive effect coming through terms of trade appreciation.

It then follows that the population regression coefficient on RULC implied by equation (13) of the text, controlling for productivity shocks and the household side labor market wedge, will be:

$$\frac{\text{cov}(q, \text{RULC})}{\text{var}(\text{RULC})} = -(1-\gamma\kappa)\frac{\sigma(D-\sigma)}{D^2}\frac{\text{var}(\zeta^* - \zeta)}{\text{var}(\text{RULC})} < 0$$

Hence, if the wedge in the data were driven by firm side (or markup) labor wedge shocks, rather than household side labor wedge shocks, we would expect that the regression equations in Table 4 would have a negative coefficient on RULC. This seems to be contradicted by our empirical findings.