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Real Exchange Rates and Sectoral Productivity in the Eurozone†

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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* E12, E23, E24, F31, F33, F43)

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 (TFP). 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 dataset of European disaggregated prices. The price data cover a large group

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[1] See, for instance, Chinn and Johnston (1996); Rogoff (1996); Tica and Družić (2006); Lothian and Taylor (2008); and Chong, Jordà, and Taylor (2012).

of European countries, include the whole consumer basket, and have 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 nonfundamental 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 nontraded 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 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 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

[2] This accords well with the concern of European policymakers with reducing divergences between unit labor costs and productivity developments in the eurozone that led to the establishment of the Euro Plus Pact of 2011 (see European Commission 2015).

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 noncompetitive forces in labor markets, fiscal distortions, or other regulatory features of individual eurozone countries.[4] But whatever the source, the channel 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

[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, Gertler, and López-Salido (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, Klenow, and Malin (2014) argue 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, Kehoe, and McGrattan (2002); Galí, Gertler, and López-Salido (2007); Shimer (2009); and Karabarbounis (2014a, b), among others.

[4]Cole and Ohanian (2004) interpret the labor wedge during the Great Depression as a reflection of the noncompetitive 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.

that include poor and rich countries, a strong relationship between relative GDP per capita and the real exchange rate.[5] However, Rogoff (1996, p. 660) then notes "whereas the relationship between income and prices is quite striking over the full dataset, 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 are used for cross-country comparisons are in index form and are 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 Johnston (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, Cumby, and Diba (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 traditional 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 14 countries relative to the US with a sample of over 100 years of data. Chen, Choi, and Devereux (2015) find that in the cross-section of prices provided in the International Comparison Project, the relative price of nontraded 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-US real exchange rate.

[5] Bergin, Glick, and Taylor (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 sector's productivity grows.

[6] De Gregorio, Giovannini, and Wolf (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.

[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 nontradable consumption sector, leading to lower prices of consumption goods in these countries. Other papers have recently used nonlinear convergence techniques. Lothian and Taylor (2008) find a long-run relationship between relative per capita income levels and real exchange rates among the US, UK, and France. Chong, Jordà, and Taylor (2012) examine the real exchange rates of 21 OECD countries from 1973 to 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.

A notable finding of some of these papers (e.g., De Gregorio, Giovannini, and Wolf 1994; Canzoneri, Cumby, and Diba 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 nontraded goods. Engel (1999) produces evidence that little of the variance of changes in US real exchange rates can be accounted for by the relative price of nontraded goods. Almost all of the variance arises from movements in the consumer prices of traded goods in the US relative to other countries. Several studies (e.g., Devereux 1999; Engel 1999; Burstein, Neves, and Rebelo 2003; Burstein, Eichenbaum, and Rebelo 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 nontraded distribution services, but the evidence for this hypothesis is weak for high-income countries. However, Mussa (1986), a seminal paper, 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 are unique and of very high quality. One major advantage of our study relative to many papers in the literature is that the price data are in levels, have a broad coverage governing the complete consumer basket in the eurozone countries studied, and have a very high degree of cross-country comparability. In Section II as well as in online data Appendix A, we describe the construction of the data, and additionally in online 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. These 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 II 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 III calibrates the theoretical model and performs the same regressions on simulated data as were done with the eurozone data. Some conclusions follow.

I. Real Exchange Rates in a Theoretical Model

A. *A Basic New Keynesian model*

Our data are 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 dynamic stochastic general equilibrium (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 nontraded subaggregate. Then the traded subaggregate is defined over home and foreign retail goods. In turn, retail goods are comprised of home and foreign produced goods, combined with inputs of nontraded 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 nontraded goods. The elasticity of substitution between traded and nontraded 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 nontraded goods in order to facilitate consumption.[8] This can be rationalized by the presence of costs

[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, Neves, and Rebelo (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).

of distribution of traded goods which must be incurred by local (i.e., nontraded) inputs. Hence, we assume that the production of consumption-related retail goods in sectors H and F are assembled according to

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

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 nontraded good into the retail consumption of the export good. The elasticity of substitution between nontraded 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 nontraded 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 nontraded goods price. Hence,

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

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 nontraded 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

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

[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, Kehoe, and McGrattan 2002). In particular, the behavior of the real exchange rate in our model would be almost identical if we instead assumed a market structure with trade only in noncontingent bonds.

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 nontraded goods is described as

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

Demand for Home and Foreign composite traded goods is denoted as

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

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

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

Firms in each sector produce using labor and a fixed capital stock.[10] A typical firm in the nontraded (traded) sector has production function $Y_{Nt}(i) = A_{Nt} N_{Nt}(i)^{\alpha}$, $(Y_{Ht}(i) = A_{Ht} N_{Ht}(i)^{\alpha})$. Thus, there are two productivity shocks: shocks to the nontraded 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 subsector, a firm in the Home country would set its price equal to marginal cost adjusted by a constant markup. For the typical nontraded goods firm and a Home traded goods producing firm, we have, in a flexible price environment:

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

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

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

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:

$$P_{Nt} = \frac{E_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau} P_{N\tau}^{flex}}{E_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau}},$$

$$P_{Ht} = \frac{E_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau} P_{H\tau}^{flex}}{E_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau}},$$

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 nontraded 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

$$\begin{aligned} Y_{Ht} &= I_{Ht} + I_{Ht}^*, \\ Y_{Ft}^* &= I_{Ft} + I_{Ft}^*, \\ Y_{Nt} &= C_{Nt} + V_{Ht} + V_{Ft}, \\ Y_{Nt}^* &= C_{Nt}^* + V_{Ht}^* + V_{Ft}^*. \end{aligned} \tag{5}$$

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

[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.

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.

B. *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 nontraded 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 nontraded 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 nontraded goods prices across countries (when there is a nontraded distribution content in traded goods; that is, $\kappa < 1$); b) the terms of trade, when there is home bias in preferences (that is, $\omega > 1/2$); 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

[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 are at annual frequency, this extension would be unlikely to affect the match between the data and the model.

are preset, 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 $p_F^* = p_F$).

C. *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 nontraded 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 nontraded 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) $\omega = 1/2$ (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 nontraded 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 nontraded goods prices influence the real exchange rate both directly through the price of consumer nontraded 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 nontraded 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 nontraded goods productivity, relative traded goods productivity, and the terms of trade $p_F^* - p_H$. 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 nontraded 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

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

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

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

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

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

Then substitute (12) into (11) to get

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

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 II. Conditional on relative unit labor costs, the traditional Balassa-Samuelson mechanism will apply; the real exchange rate is positively related to relative (Foreign versus Home) traded goods productivity and negatively to relative nontraded 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 versus Home) will lead to a real exchange rate depreciation, according to equation (13).

D. *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

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

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

where $D > 0$,[15] and

$$\beta_0 \equiv \gamma\kappa[(1+\psi)\sigma + \psi(1-\gamma\kappa)((1-\gamma\kappa)(1-\sigma) - \sigma\kappa(\lambda-1))],$$

$$\beta_1 \equiv (1-\gamma\kappa)[(1+\psi)\sigma - \gamma\kappa\psi((1-\gamma\kappa)(1-\sigma) - \kappa\sigma(\lambda-1))].$$

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

[15] In particular, $D = \psi(1-\gamma\kappa)^2 + \sigma(1+\psi\gamma\kappa(1-\gamma\kappa+\lambda\kappa+(1-\kappa)))$. Also, $\chi^* - \chi = \log(\Upsilon^*/\Upsilon)$.

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 nontradables. Intuitively, this occurs because in this case, the income effects of nontraded 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 nontraded 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.

E. *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 (MPL) and the marginal rate of substitution (MRS) 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, Kehoe, and McGrattan 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 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,

[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 markup of Galí, Gertler, and López-Salido (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.

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 noncompetitive 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. Online Appendix A6 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 wage and the firm's MPL on the other (see Karabarbounis 2014a and Galí, Gertler, and López-Salido 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 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.

Online 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

[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, 2014) and Dadush and Stancil (2011).

labor wedge is the gap between the wage and the household's MRS. Karabarbounis (2014a) provides an empirical argument for locating the labor wedge on the household rather than the firm's side of the labor market. However, Bils, Klenow, and Malin (2014) provide evidence in the US market that the firm-side distortion is an important component of the labor wedge, so the question is not settled.[19]

F. *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

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

where the coefficients are defined in the previous section. Then, using the calibrated parameter values which are discussed in Section IIIA, 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

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

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, assuming the presence of the labor wedge distorting hours worked, while the latter condition needs data on hours. Online Appendix A6 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]

[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 percent of the cyclical variation in the total wedge, while the household wedge explains 66 percent (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.

[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).

G. *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 online Appendix D, we show that the addition of government spending or fiscal deficits to specification (13) does not alter our empirical results.[22]

H. *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 allow for a relatively clean decomposition of goods broken down by the degree of tradability. But we do not have any information 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]

[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 the real exchange rate depreciates in response to government deficit shocks, as identified in a vector autoregression (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, Kehoe, and McGrattan (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.

[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 online 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).

II. Data: Real Exchange Rates and Productivity

A. *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 (PLIs). 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 PLIs 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 percent of the consumption basket. The full list of PLIs for the basic headings of consumer goods and services is contained in online Appendix Table A1. 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 contain nine 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 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 (nontraded) 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 2001; Baxter and Landry 2012), or from a small number of online retailers (Cavallo, Neiman, and Rigobon 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, those data are not as comprehensive as the Eurostat data, and do not strive for the

[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' PLIs (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 value-added tax (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.

degree of comparability across countries of goods and services that are priced. Online 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 nontraded categories using criteria reported in the online 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 $\overline{q}$, as well as the equivalent measures for the traded goods real exchange rate $\overline{q}_T$, the nontraded goods real exchange rate, $\overline{q}_N$, and also the relative price of nontraded goods $\overline{q}_n = \overline{q}_N - \overline{q}_T$.

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 $\gamma_{i,j,t} = \frac{exp_{i,j,t}}{\sum_{i=1}^{146} exp_{i,j,t}}$ where exp is the local expenditure. We then construct expenditure-weighted PLIs 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 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 nontraded goods closely mirror the aggregate real exchange rates. In general, we see that if for a given country i, we have $\overline{q}_i > 0$, (< 0), we also have $\overline{q}_{Ti} > 0$, (< 0), $\overline{q}_{Ni} > 0$, (< 0), and $\overline{q}_{Ni} - \overline{q}_{Ti} > 0$, (< 0). That is, if a country has a low (high) average price level relative to the European average, its nontraded 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 three percent for most countries. We would anticipate

Table 1—Country Summary Statistics

	Mean						Variable Standard deviation					
Country	$\overline{q}$	$\overline{q_T}$	$\overline{q_N}$	$\overline{q_n}$			$s(q)$	$s(q_T)$	$s(q_N)$	$s\,(q_n)$		
BEL	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	0.03			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		
	$\overline{a_T}$	$\overline{a_N}$	$\overline{a_{TN}}$	$\overline{rulc}$	$\overline{lw_A}$	$\overline{lw_B}$	$s(a_T)$	$s(a_N)$	$s(a_{TN})$	$s(rulc)$	$s(lw_A)$	$s(lw_B)$
BEL	−0.05	−0.03	−0.03	−0.06	−0.23	−0.13	0.04	0.035	0.02	0.01	0.04	0.03
GER	−0.02	−0.08	0.06	−0.13	−0.55	−0.26	0.015	0.011	0.02	0.06	0.17	0.05
SPA	0.12	−0.02	0.14	0.06	0.06	0.09	0.10	0.05	0.05	0.06	0.08	0.01
FRA	−0.01	−0.07	0.06	−0.05	−0.31	−0.14	0.02	0.018	0.02	0.01	0.07	0.03
IRE	−0.25	−0.03	−0.22	0.22	0.65	0.19	0.05	0.02	0.05	0.11	0.30	0.11
ITA	0.03	0.10	−0.08	−0.02	0.19	0.10	0.10	0.04	0.07	0.03	0.05	0.03
NET	−0.13	−0.23	0.09	−0.03	−0.57	−0.29	0.02	0.03	0.05	0.04	0.19	0.06
AUS	0.05	−0.01	0.06	−0.11	−0.34	−0.07	0.06	0.02	0.04	0.04	0.10	0.02
FIN	−0.20	−0.16	−0.05	−0.01	−0.31	−0.16	0.08	0.04	0.05	0.01	0.07	0.05

Notes: 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). $q_n \equiv q_N - q_T$. $s(\cdot)$ 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 one-digit sector's TFP levels aggregated using sectoral gross outputs as weights. $a_{TN} \equiv a_T - a_N$. *rulc* is a logarithm of relative unit labour costs of EU17 relative to home country. lw_A and lw_B are our two measures of labor wedges, as described in online Appendix A.7. The balanced sample period is 1995–2007.

that the standard deviation of nontraded real exchange rates exceeds that of the traded real exchange rates. We find this to be true for eight of the nine 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 (RER). The second panel reports the cross-country dispersion in aggregate and sectoral real exchange rates. The high-income non-eurozone economies (group Float) 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]

[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 downward (toward appreciation) over the sample.

Table 2—Standard Deviation and Serial Correlation

	mean(std$_i$ (·))				std(mean$_i$(·))				AR (1)
Variable	All	EZ	Float	East	All	EZ	Float	East	EZ
q	0.058	0.032	0.060	0.081	0.345	0.114	0.099	0.206	0.669
q_T	0.052	0.028	0.049	0.076	0.254	0.088	0.106	0.166	0.597
q_N	0.076	0.042	0.077	0.106	0.493	0.159	0.117	0.292	0.716
q_n	0.041	0.029	0.043	0.052	0.259	0.105	0.122	0.138	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	0.078	0.049	0.081	0.112	0.123	0.105	0.168	0.093	1.009

Notes: All real exchange rate variables (q, q_T, q_N, qn) 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). $q_n \equiv q_N - q_T$. a_T (a_N) is a logarithm of traded (nontraded) TFP of EU12 relative to home country. Traded is an aggregate of one-digit sector's TFP levels aggregated using sectoral gross outputs as weights. *rulc* is a logarithm of relative unit labor costs of EU17 relative to home country. 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.

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 PLIs for the eurozone as a whole. If PPP held at the goods level, this would be zero all the time. The 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, tell 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 second, there is substantial movement over time in relative positions.

B. *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 Centre (GGDC) 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

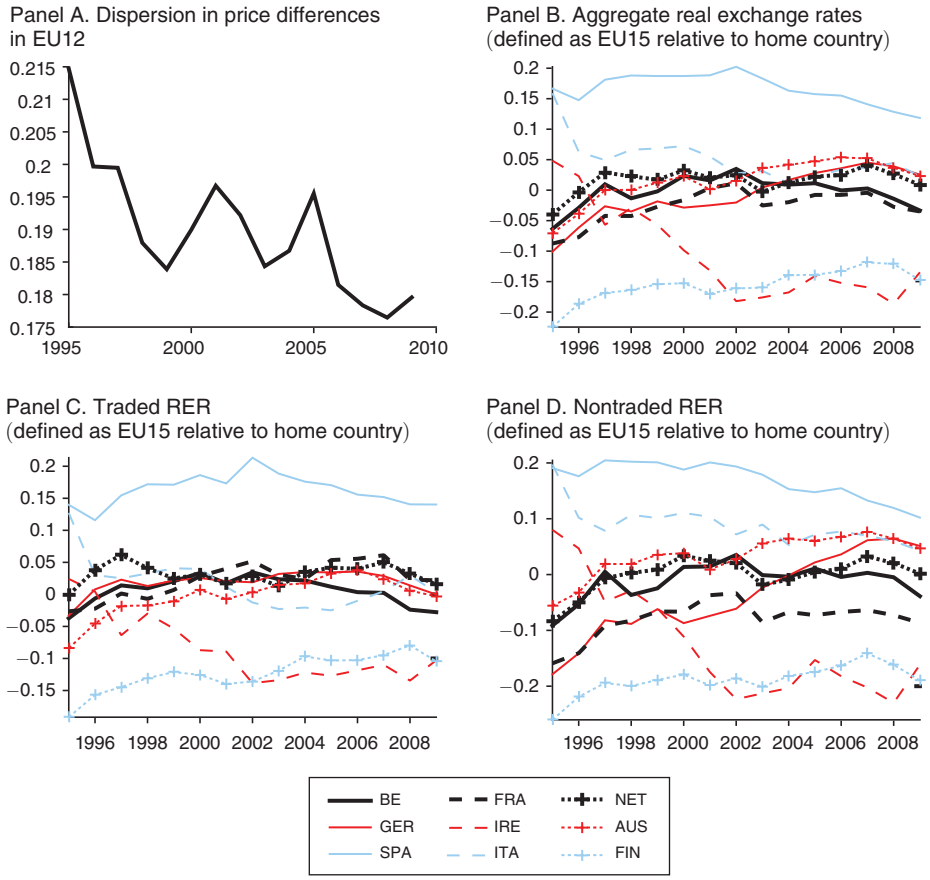

FIGURE 1. PROPERTIES OF REAL EXCHANGE RATES

series of TFP for traded and nontraded 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 online Appendix A.

Tables 1 and 2 report descriptive statistics for traded and nontraded 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 nontraded 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

[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 important, the new index data are reported in ISIC Revision 4, which makes it more difficult to construct a concordance mapping to the 1997 cross section vis-á-vis the US. Furthermore, this new dataset has several missing observations for the US, requiring imputation of data. We use the 1995–2007 panel.

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 I. 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 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 both labor and product markets of many European countries are characterized by various regulatory and other nonmarket 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, online Appendix A.A6 shows that relative unit labor costs display a high positive correlation with a number of measures of labor and product market distortions in the eurozone.

Figure 2 illustrates the properties of traded and nontraded 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.

Panel C of Figure 2 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.

C. *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.

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

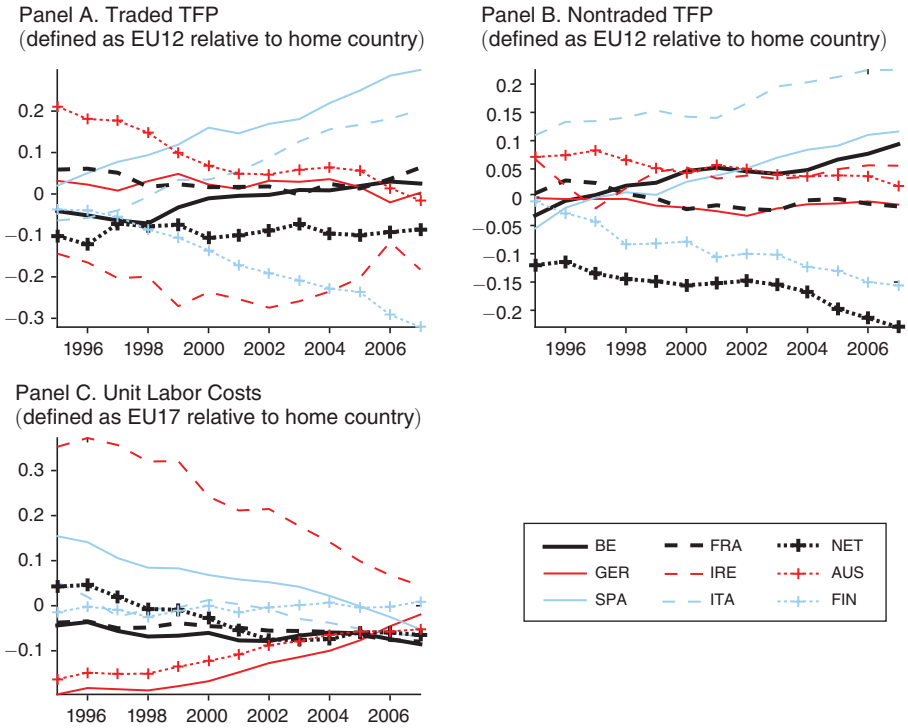

FIGURE 2. PROPERTIES OF TOTAL FACTOR PRODUCTIVITY AND UNIT LABOR COSTS

We present four different approaches to handling the data. In the first, we pool the data and estimate a simple ordinary least squares (OLS) 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. 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 nontraded 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. Panel A of Table 3 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

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

Table 3—Price Regressions

Panel A. Regression of q on q_n	Pool	FE	RE	XS
	(1)	(2)	(3)	(4)
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	—

Panel B. Regression of q_T on q_n	Pool	FE	RE	XS
	(5)	(6)	(7)	(8)
q_n	0.26	0.11	0.12	0.27
	(0.057)	(0.076)	(0.07)	(0.24)
$\overline{R}^2$	0.10	0.89	0.02	0.03
N	180	180	180	12
HT	—	—	not reject	—

Panel C. Regression of q on q_T	Pool	FE	RE	XS
	(9)	(10)	(11)	(12)
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	—

Notes: 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 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. 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 five percent in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

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 nontraded goods prices and aggregate real exchange rates (e.g., Engel 1999).

Panel B of Table 3 explores the relationship between the traded goods real exchange rate and the relative price of nontraded 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.

Panel C 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 nontraded 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

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)	(0.12)
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)	(0.18)
RULC	—	—	0.43	—	—	0.46	—	—	0.46	—	—	0.43
			(0.079)			(0.072)			(0.077)			(0.11)
$\overline{R}^2$	0.25	0.41	0.57	0.84	0.85	0.90	−0.007	0.02	0.32	0.28	0.62	0.7
N	117	117	117	117	117	117	117	117	117	9	9	9
HT	—	—	—	—	—	—	reject	reject	reject			

Notes: 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 nontraded sector in EU12 ($\log(TFP_{T,EU12,t}/TFP_{N,EU12,t})$) relative to country *i*. $TFP_{T,i,t}$ is an aggregation of one-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 EU17 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. 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.

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. Nontraded TFP also takes on the correct sign under all four approaches, and is significant at the five 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 nontraded 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 nontraded 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 regressions. 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—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)			(0.027)			(0.038)
$\overline{R}^2$	0.25	0.41	0.57	0.84	0.85	0.90	−0.007	0.025	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			

Notes: 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 nontraded sector in EU12 $(\log(TFP_{T,EU12,t}/TFP_{N,EU12,t}))$relative to country i. $TFP_{T,i,t}$ is aggregation of one-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 $(*** \; LW_A = -0.33a_T + 2.33a_N + 2.8rulc)$, and is a linear combination of productivity in each sector and relative unit labor costs as described in Table 5. LW in EU17 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. 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 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 labor 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 Tables 4 and 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 nontraded) 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, nontraded 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.

[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.

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. In the data, estimates of labor wedge shocks covary negatively with traded goods productivity shocks and positively with nontraded goods productivity shock on average. 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. Online 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 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.

III. Model Determined Real Exchange Rates

We now return to a more detailed quantitative analysis of the properties of the model of Section I. 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.

A. *Model Calibration*

Table 6 lists the calibration values. For the 9 countries used in our complete sample, the average expenditure share on nontraded goods in the PLI dataset on consumer goods is 49.9 percent, 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 $\kappa = 0.6$ ($1 - \kappa$ is the share of distribution services in traded goods consumption.). We assume a common value of κ for both Home and

[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 online Appendix A.A6.

Table 6—Calibration

Households			
Share of C on traded goods	γ	0.5	
Share of wholesale traded goods in C_T	κ	0.6	
EOS. between H and F retail traded goods	λ	8	Corsetti et al. (2010)
EOS. between traded good and retail service	ϕ	0.25	
EOS. 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)

Foreign goods consumption in both countries. These parameter values together imply that (given other parameter settings) the overall share of nontraded 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, Dedola, and Leduc (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 nontraded 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 1.[37] The parameter σ, the coefficient of relative risk aversion, is set to equal to 2, a standard consensus estimate used in DSGE modeling. 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 distribution service, ϕ is set to 0.25.[38]

[36] Corsetti, Dedola, and Leduc (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.

[38] Corsetti, Dedola, and Leduc (2010) set this equal to 0. 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.

The elasticity of substitution between traded and nontraded 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, is 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. Online 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 0, 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 0, 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 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.

We create moments for traded and nontraded 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 I. 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 online 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 I, we have somewhat less confidence in this specification for the labor wedge given the difficulty of comparing hours data across countries.

[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.

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 nontraded) as well as labor wedge shocks follow first-order autoregressions given by

$$a_{Y,t} - \overline{a}_Y = \rho_Y(a_{Y,t-1} - \overline{a}_Y) + u_{Y,t}, \tag{18}$$

where $Y \in \{a_N, a_T, \chi\}$, $a_{Y,t}$ and $\overline{a}_Y$ for each of the nine countries are calculated from our data, and ρ_Y is directly estimated. 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. Online Appendix F describes how we translate the moments of the annual data into quarterly data for the model. In particular, ρ_Y is computed by taking the quartic root from an AR(1) estimate on the annual data. The variance covariance matrix over $u_{Y,t}$ is estimated based on the assumption that $u_{Y,t}$ 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 (a concatenation of $u_{a_T,t}$, $u_{a_N,t}$, and $u_{\chi,t}$) in the data across countries, and across the measures of the exogenous variables (traded productivity, nontraded productivity and the labor wedge), using the 27 by 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. Panel A 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, 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.

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

B. *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 discussion of real

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

Table 7—Properties of TFP and Labor Wedge Shocks

Panel A. Cross-sectional properties of relative TFP and labor wedge shocks				Panel B. Time-series properties of relative TFP and labor wedge shocks						
	Mean values				AR(1) coefficients			Standard deviations		
	$\bar{a}_T$	$\bar{a}_N$	$\overline{LW}$		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

Notes: Panel A reports, for each country, the sample average level of the of TFP and labor wedge as described by online Appendix A1 and A7. Panel B 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 nine countries.

Table 8—Properties of Model Real Exchange Rates

	Sticky price A (1)	Sticky price B (2)	Flexible price (3)	Data (4)
STD (Time series)	0.049	0.051	0.054	0.033
	(0.039, 0.060)	(0.041, 0.062)	(0.045, 0.066)	
STD (Cross section)	0.138	0.138	0.140	0.113
	(0.086, 0.227)	(0.087, 0.228)	(0.089, 0.230)	
Serial Correlation	0.768	0.739	0.673	0.670
	(0.689, 0.843)	(0.653, 0.820)	(0.578, 0.759)	

Notes: Results in the data column are from Table 3. Other columns report regressions with simulated data (500 simulations of the DGP, as described in online 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. Ninety percent confidence intervals are reported in the parentheses. Sticky price A assumes a 10 percent price adjustment per quarter, B assumes a 20 percent price adjustment per quarter.

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]

[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 II, with supporting estimates given in online 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.

Table 9—Model Price Regressions

	Panel A. Time-series regressions				Panel B. Cross-section regressions			
	Sticky price A (1)	Sticky price B (2)	Flexible price (3)	Data (4)	Sticky price A (5)	Sticky price B (6)	Flexible price (7)	Data (8)
Regression of q on q_n	1.193 (1.166, 1.245)	1.193 (1.166, 1.245)	1.192 (1.168, 1.241)	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 (0.646, 0.761)	0.685 (0.646, 0.759)	0.89
Regression of q on q_T	1.750 (1.680, 1.867)	1.751 (1.682, 1.870)	1.752 (1.685, 1.868)	1.08	1.726 (1.636, 1.857)	1.727 (1.636, 1.859)	1.729 (1.636, 1.861)	1.20

Notes: 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 online 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. Ninety percent confidence intervals are reported in the parentheses. The calibration in column Sticky price A assumes a 10 percent price adjustment per quarter. Sticky price B assumes a 20 percent price adjustment per quarter.

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, Kehoe, and McGrattan (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 nontraded distribution services contains a component that is not accurately measured by observed prices of nontraded 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 downward due to classical measurement error. This point is established more formally in online Appendix F. However, the results of Tables 3 and 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 nontraded goods in driving real exchange rate variation in these eurozone countries.

Table 10—Model Regressions with *RULC*

	Panel A. Time-series regression results				Panel B. Cross-section regression results			
	Sticky price A (1)	Sticky price B (2)	Flexible price (3)	Data (4)	Sticky price A (5)	Sticky price B (6)	Flexible price (7)	Data (8)
Traded TFP	0.176 (0.067, 0.302)	0.186 (0.104, 0.283)	0.205 (0.171, 0.253)	0.18	0.281 (0.074, 0.534)	0.283 (0.078, 0.532)	0.288 (0.090, 0.546)	0.93
Nontraded TFP	−0.227 (−0.412, −0.028)	−0.212 (−0.362, −0.076)	−0.208 (−0.287, −0.166)	−0.36	−0.491 (−0.763, −0.286)	−0.491 (−0.770, −0.293)	−0.505 (−0.790, −0.303)	−0.27
RULC	0.438 (0.367, 0.500)	0.521 (0.456, 0.573)	0.687 (0.607, 0.716)	0.46	0.453 (0.333, 0.539)	0.455 (0.337, 0.543)	0.460 (0.333, 0.551)	0.43

Notes: Results in the data column are from Table 4. Other columns report regressions with simulated data (500 simulations of the DGP, as described in online 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. Ninety percent confidence intervals are reported in the parentheses. Sticky price A assumes a 10 percent price adjustment per quarter, B assumes a 20 percent price adjustment per quarter.

Table 9 also shows the results comparable with panel C of Table 3, 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 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 4 and 5. 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.

Panel A of Table 10 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 1 percent rise in traded goods productivity leads to an 0.18 percent appreciation of the real exchange rate. A 1 percent rise in nontraded goods productivity leads to a 0.36 percent depreciation of the real exchange rate. On the other hand a 1 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 1 percent rise in traded goods productivity leads to a 0.18 percent appreciation, a 1 percent rise in nontraded good productivity leads to a 0.23 percent real exchange rate depreciation,

Table 11—Model Regressions with Labor Wedge

	Panel A. Time-series regression results				Panel B. Cross-section regression results			
	Sticky price A (1)	Sticky price B (2)	Flexible price (3)	Data (4)	Sticky price A (5)	Sticky price B (6)	Flexible price (7)	Data (8)
Traded TFP	0.173 (−0.054, 0.408)	0.200 (−0.026, 0.438)	0.264 (0.044, 0.503)	0.24	0.171 (−0.180, 0.393)	0.175 (−0.177, 0.403)	0.179 (−0.178, 0.416)	0.98
Nontraded TFP	−0.642 (−0.939, −0.340)	−0.690 (−0.983, −0.399)	−0.798 (−1.078, −0.521)	−0.75	−0.585 (−0.957, −0.088)	−0.592 (−0.973, −0.088)	−0.604 (−0.996, −0.086)	−0.62
Labor wedge	0.084 (0.013, 0.249)	0.089 (0.013, 0.263)	0.097 (0.015, 0.283)	0.17	0.199 (0.070, 0.341)	0.199 (0.070, 0.342)	0.200 (0.070, 0.344)	0.15

Notes: Results in the data column are from Table 5. Other columns report regressions with simulated data (500 simulations of the DGP, as described in online 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. Ninety percent confidence intervals are reported in parentheses. Sticky price A assumes a 10 percent price adjustment per quarter, B assumes a 20 percent price adjustment per quarter.

and a 1 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.

Panel B of Table 10 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 indicate that a country with a nontraded goods productivity 1 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 1 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 one-half of that found in the data.

Table 11 reports the results where we replace *RULC* with the measure of the labor wedge from (16). Panel A 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. Panel B 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 nontraded 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 panel A of Tables 10 and 11, 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 nontraded 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 nontraded 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 favor 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 behavior of eurozone real exchange rates. Moreover, both model and data offer strong support for an amended form of the traditional Balassa-Samuelson approach to real exchange rates. In Tables 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 nontraded 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, online Appendix F, Table A13 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.

IV. Conclusions

Real exchange rates in the eurozone closely reflect differences in the relative prices of nontraded to traded goods across countries, and in turn differences in the relative productivity levels in the traded versus nontraded sectors, as well as variations in unit

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

Table 12—Model Regressions with TFP Only

	Panel A. Time-series regression results				Panel B. Cross-section regression results			
	Sticky price A (1)	Sticky price B (2)	Flexible price (3)	Data (4)	Sticky price A (5)	Sticky price B (6)	Flexible price (7)	Data (8)
Labor wedge: Method 1								
Traded TFP	0.175 (−0.145, 0.464)	0.202 (−0.121, 0.508)	0.264 (−0.074, 0.576)	0.00	−0.074 (−0.715, 0.394)	−0.070 (−0.714, 0.396)	−0.060 (−0.717, 0.402)	0.67
Nontraded TFP	−0.618 (−1.087, −0.194)	−0.676 (−1.151, −0.249)	−0.781 (−1.270, −0.341)	−0.36	−0.038 (−0.481, 0.767)	−0.043 (−0.485, 0.756)	−0.049 (−0.488, 0.736)	0.05
	Panel C. Time-series regression results				Panel D. Cross-section regression results			
Labor wedge: Method 2								
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

Notes: 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. Ninety percent confidence intervals are reported in parentheses. Sticky price A assumes a 10 percent price adjustment per quarter, B assumes a 20 percent price adjustment per quarter.

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 nontraded 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, and that monetary and financial factors

must play a role: "existing models based on real shocks cannot account for short-term exchange rate volatility" (Rogoff 1996, 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 US, 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. Online 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-Grohé 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.

REFERENCES

Altissimo, Filippo, Evaggelia Georgiou, Teresa Sastre, Maria Teresa Valderrama, Gabriel Sterne, Marc Stocker, Mark Weth, Karl Whelan, and Alpo Willman. 2005. "Wealth And Asset Price Effects On Economic Activity." European Central Bank Occasional Paper 29.

Baxter, Marianne, and Anthony Landry. 2012. "IKEA: Product, Pricing, and Pass-Through." Federal Reserve Bank of Dallas Globalization Institute Working Paper 132.

▶ **Beck, Nathaniel, and Johanthan N. Katz.** 1995. "What to do (and not to do) with Time-Series Cross-Section Data." *American Political Science Review* 89 (3): 634-47.

▶ **Benigno, Gianluca, and Christoph Thoenissen.** 2008. "Consumption and Real Exchange Rates with Incomplete Financial Markets and Non-Traded Goods." *Journal of International Money and Finance* 27 (6): 926–48.

▶ **Bergin, Paul R., Reuven Glick, and Alan M. Taylor.** 2006. "Productivity, Tradability, and the Long-Run Price Puzzle." *Journal of Monetary Economics* 53 (8): 2041–66.

▶ **Berka, Martin, and Michael B. Devereux.** 2013. "Trends in European Real Exchange Rates." *Economic Policy* 28 (74): 193–242.

Berka, Martin, Michael B. Devereux, and Charles Engel. 2018. "Real Exchange Rates and Sectoral Productivity in the Eurozone: Dataset." *American Economic Review.* https://doi.org/10.1257/aer.20151045.

▶ **Betts, Caroline M., and Timothy J. Kehoe.** 2006. "U.S. Real Exchange Rate Fluctuations and Relative Price Fluctuations." *Journal of Monetary Economics* 53 (7): 1297–1326.

▶ **Bils, Mark, and Peter J. Klenow.** 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy* 112 (5): 947–85.

Bils, Mark, Peter J. Klenow, and Benjamin A. Malin. 2014. "Resurrecting the Role of the Product Market Wedge in Recessions." National Bureau of Economic Research Working Paper 20555.

▶ **Bordo, Michael D., Ehsan U. Choudhri, Giorgio Fazio, and Ronald MacDonald.** 2017. "The Real Exchange Rate in the Long Run: Balassa-Samuelson Effects Reconsidered." *Journal of International Money and Finance* 75: 69–92.

▶ **Burstein, Ariel, Martin Eichenbaum, and Sergio Rebelo.** 2005. "Large Devaluations and the Real Exchange Rate." *Journal of Political Economy* 113 (4): 742–84.

▶ **Burstein, Ariel T., Joao C. Neves, and Sergio Rebelo.** 2003. "Distribution Costs and Real Exchange Rate Dynamics during Exchange-Rate-Based Stabilizations." *Journal of Monetary Economics* 50 (6): 1189–1214.

▶ **Canzoneri, Matthew B., Robert E. Cumby, and Behzad Diba.** 1996. "Relative Labor Productivity and the Real Exchange Rate in the Long Run: Evidence for a Panel of OECD Countries." *Journal of International Economics* 47 (2): 245–66.

▶ **Cavallo, Alberto, Brent Neiman, and Roberto Rigobon.** 2014. "Currency Unions, Product Introductions, and the Real Exchange Rate." *Quarterly Journal Economics* 129 (2): 529–95.

▶ **Chari, V. V., Patrick J. Kehoe, and Ellen R. McGrattan.** 2002. "Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates?" *Review of Economic Studies* 69 (3): 533–63.

▶ **Chari, V. V., Patrick J. Kehoe, and Ellen R. McGrattan.** 2007. "Business Cycle Accounting." *Econometrica* 75 (3): 781–836.

▶ **Chen, Lein-Lein, Seungmook Choi, and John Devereux.** 2015. "Explaining Price Level Differences: New Evidence on the Balassa-Samuelson Effect." *Southern Economic Journal* 82 (1): 81–99.

Chinn, Menzie, and Louis Johnston. 1996. "Real Exchange Rate Levels, Productivity and Demand Shocks: Evidence from a Panel of 14 Countries." National Bureau of Economic Research Working Paper 5709.

▶ **Chong, Yangping, Òscar Jordà, and Alan M. Taylor.** 2012. "The Harrod-Balassa-Samuelson Hypothesis: Real Exchange Rates and Their Long-Run Equilibrium." *International Economic Review* 53 (2): 609–34.

▶ **Choudri, Ehsan U., and Lawrence L. Schembri.** 2014. "Productivity, Commodity Prices and the Real Exchange Rate: The Long-Run Behavior of the Canada–US Exchange Rate." *International Review of Economics & Finance* 29: 537–51.

▶ **Cole, Harold L., and Lee E. Ohanian.** 2004. "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis." *Journal of Political Economy* 112 (4): 779–816.

Corsetti, Giancarlo, Luca Dedola, and Sylvain Leduc. 2010. "Optimal Monetary Policy in Open Economies." In *Handbook of Monetary Economics*, Volume 3, edited by Benjamin M. Friedman and Michael Woodford, 861–933. New York: Elsevier.

▶ **Crucini, Mario J., and Mototsugu Shintani.** 2008. "Persistence in Law of One Price Deviations: Evidence from Microdata." *Journal of Monetary Economics* 55 (3): 629–44.

Dadush, Uri, and Bennet Stancil. 2011. "Is the Euro Rescue Succeeding?" *VOX EU*, February 6, 2011. https://voxeu.org/article/euro-rescue-succeeding (accessed January 26, 2017).

▶ **De Gregorio, José, Alberto Giovannini, and Holger C. Wolf.** 1994. "International Evidence on Tradables and Nontradables Inflation." *European Economic Review* 38 (6): 1225–44.

▶ **Devereux, Michael B.** 1999. "Real Exchange Rate Trends and Growth: A Model of East Asia." *Review of International Economics* 7 (3): 509–21.

Devereux, Michael B., and Viktoria V. Hnatkovska. 2013. "Borders and Nominal Exchange Rates in Risk-Sharing." Centre for Applied Macroeconomic Analysis Working Paper 2013-37.

▶ **Duarte, Margarida, and Alexander L. Wolman.** 2008. "Fiscal Policy and Regional Inflation in a Currency Union." *Journal of International Economics* 74 (2): 384–401.

▶ **Engel, Charles.** 1999. "Accounting for US Real Exchange Rate Changes." *Journal of Political Economy* 130 (3): 507–38.

▶ **Engel, Charles, and John H. Rogers.** 2004. "European Product Market Integration after the Euro." *Economic Policy* 19 (39): 349–84.

European Commission. 2015. "The Euro Plus Pact: How Integration into the EU Framework Can Give New Momentum for Structural Reforms in the Euro Area." *European Political Strategy Centre Strategic Notes* 3 (accessed February 10, 2017).

Eurostat and OECD. 2012. *EUROSTAT-OECD Methodological Manual on Purchasing Power Parities*. Luxembourg: Publications Office of the European Union.

Felipe, Jesus, and Utsav Kumar. 2011. "Unit Labor Costs in the Eurozone: The Competitiveness Debate Again." Levy Economics Institute Working Paper 651.

Fitzgerald, Doireann. 2003. "Terms-of-Trade Effects, Interdependence and Cross-Country Differences in Price Levels." Unpublished.

▶**Galí, Jordi, Mark Gertler, and J. David López-Salido.** 2007. "Markups, Gaps and the Welfare Costs of Business Fluctuations." *Review of Economics and Statistics* 89 (1): 44–59.

▶**Goldberg, Linda, S., and José Manuel Campa.** 2010. "The Sensitivity of the CPI to Exchange Rates: Distribution Margins, Imported Inputs, and Trade Exposure." *Review of Economics and Statistics* 92 (2): 392–407.

▶**Gopinath, Gita, Pierre-Olivier Gourinchas, Chang-Tai Hsieh, and Nicolas Li.** 2011. "International Prices, Costs, and Markup Differences." *American Economic Review* 101 (6): 2450–86.

Gubler, Matthias, and Christoph Sax. 2011. "The Balassa-Samuelson Effect Reversed: New Evidence from OECD Countries." University of Basel Center of Business and Economics (WWZ) Discussion Paper 2011/09.

▶**Hall, Robert E.** 1997. "Macroeconomic Fluctuations and the Allocation of Time." *Journal of Labor Economics* 15 (1): S223–50.

▶**Haskel, Jonathan, and Holger Wolf.** 2001. "The Law of One Price: A Case Study." *Scandinavian Journal of Economics* 103 (4): 545–58.

▶**Honohan, Patrick, and Philip R. Lane.** 2003. "Divergent Inflation Rates under EMU." *Economic Policy* 18 (37): 357–94.

▶**Hsieh, Chang-Tai, and Peter J. Klenow.** 2007. "Relative Prices and Relative Prosperity." *American Economic Review* 97 (3): 562–85.

Inklaar, Robert, and Marcel P. Timmer. 2008. "GGDC Productivity Level Database: International Comparisons of Output, Inputs and Productivity at the Industry Level." University of Groningen Growth and Development Centre Discussion Paper GD-104.

Itskhoki, Oleg, and Dmitry Mukhin. 2016. "Exchange Rate Disconnect in General Equilibrium." Unpublished.

▶**Karabarbounis, Loukas.** 2014b. "Home Production, Labor Wedges, and International Business Cycles." *Journal of Monetary Economics* 64: 68–84.

▶**Karabarbounis, Loukas.** 2014a. "The Labor Wedge: MRS vs. MPN." *Review of Economic Dynamics* 17 (2): 206–23.

▶**Kim, Soyoung, and Nouriel Roubini.** 2008. "Twin Deficit or Twin Divergence? Fiscal Policy, Current Account, and Real Exchange Rate in the U.S." *Journal of International Economics* 74 (2): 362–83.

▶**Lee, Jaewoo, and Man-Keung Tang.** 2007. "Does Productivity Growth Appreciate the Real Exchange Rate?" *Review of International Economics* 15 (1): 164–87.

▶**Lothian, James R., and Mark P. Taylor.** 2008. "Real Exchange Rates over the Past Two Centuries: How Important Is the Harrod-Balassa-Samuelson Effect?" *Economic Journal* 118 (532): 1742–63.

▶**MacDonald, Ronald, and Luca Antonio Ricci.** 2005. "The Real Exchange Rate and the Balassa-Samuelson Effect: The Role of the Distribution Sector." *Pacific Economic Review* 10 (1): 29–48.

Mendoza, Enrique G. 2005. "Real Exchange Rate Volatility and the Price of Nontradable Goods in Economies Prone to Sudden Stops." *Economía* 6 (1): 103–48.

▶**Mussa, Michael.** 1986. "Nominal and Real Exchange Rate Regimes and the Behavior of Real Exchange Rates: Evidence and Implications." *Carnegie-Rochester Conference Series on Public Policy* 25: 117–214.

Peeters, Marga, and Ard den Reijer. 2012. "Apart from the Fiscal Compact: On Competitiveness, Nominal Wages and Labour Productivity." *VOX EU*, January 3, 2012. https://voxeu.org/article/wages-and-productivity-eurozone (accessed October 7, 2017).

▶**Peeters, Marga, and Ard den Reijer.** 2014. "Coordination versus Flexibility in Wage Formation: A Focus on the Nominal Wage Impact of Productivity in Germany, Greece, Ireland, Portugal, Spain and the United States." *Applied Economics* 46 (7): 698–714.

Rogoff, Kenneth. 1996. "The Purchasing Power Parity Puzzle." *Journal of Economic Literature* 34 (2): 647–68.

▶**Schmitt-Grohé, Stephanie, and Martín Uribe.** 2016. "Downward Nominal Wage Rigidity, Currency Pegs, and Involuntary Unemployment." *Journal of Political Economy* 124 (5): 1466–1514.

▶**Shimer, Robert.** 2009. "Convergence in Macroeconomics: The Labor Wedge." *American Economic Journal: Macroeconomics* 1 (1): 280–97.

▶**Steinsson, Jón.** 2008. "The Dynamic Behavior of Real Exchange Rates in Sticky Price Models." *American Economic Review* 98 (1): 519–33.

Tica, Josip, and Ivo Družic. 2006. "The Harrod-Balassa-Samuelson Effect: A Survey of Empirical Evidence." University of Zagreb EFZG Working Paper 06-7/686.