# For Online Publication
# Real Exchange Rates and Sectoral Productivity in the Eurozone
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## Data Appendix

### *A1. Construction of the panel of sectoral TFP levels across Europe*

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

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

#### 1997 TFP levels

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

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

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

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

sectoral TFP as:

$$\text{(A1)}\quad \ln A_{i,j} \equiv \ln TFP^{SO}_{i,j} = \ln \frac{Q^{SO}_{i,j}}{Q^{SO}_{i,US}} - \hat{\nu}_K \ln \frac{Q^{K}_{i,j}}{Q^{K}_{i,US}} - \hat{\nu}_L \ln \frac{Q^{L}_{i,j}}{Q^{L}_{i,US}} - \hat{\nu}_{II} \ln \frac{Q^{II}_{i,j}}{Q^{II}_{i,US}}$$

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

## TFP time series

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

$$\begin{aligned}\Delta \ln Y_{it} \quad = \quad & \bar{\nu}^X_{it}\bar{\omega}^E_{it}\Delta \ln X^E_{it} + \bar{\nu}^X_{it}\bar{\omega}^M_{it}\Delta \ln X^M_{it} + \bar{\nu}^X_{it}\bar{\omega}^S_{it}\Delta \ln X^S_{it} \\ & + \bar{\nu}^K_{it}\bar{\omega}^{ICT}_{it}\Delta \ln K^{ICT}_{it} + \bar{\nu}^K_{it}\bar{\omega}^N_{it}\Delta \ln K^N_{it} \\ & + \bar{\nu}^L_{it}\Delta \ln LC_{it} + \bar{\nu}^L_{it}\Delta \ln H_{it} + \Delta \ln B^Y_{it}\end{aligned} \tag{A2}$$

where $Y$ is output, $K$ is an index of capital service flows, $L$ is an index of labor service flows, $X$ is an index of intermediate inputs, $H$ is hours worked, $LC$ is labor

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

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

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

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

## Construction of the TFP level sectoral panel dataset

The construction of TFP level sectoral panel dataset proceeds in four steps. First, the sectors in the 1997 cross-section dataset are matched to the sectors in the TFP growth-rate dataset. Second, a level TFP series is constructed for each sector and country. Third, the TFP level is expressed relative to EU12 average, to match the construction of the real exchange rate dataset [49]. Fourth, the sectors are aggregated into traded and non-traded aggregates using sectoral output data.

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

$$C_{ijt} = \frac{A_{ij} B_{ijt}}{B_{i,US,t}} \tag{A3}$$

and similarly for the EU15 aggregate:

$$C_{i,EU12,t} = \frac{A_{i,EU12} B_{i,EU12,t}}{B_{i,US,t}} \tag{A4}$$

The TFP level index is expressed vis-a-vis EU12. It is the ratio of (A3) and (A4):

$$TFP_{ijt} = \frac{C_{ijt}}{C_{i,EU12,t}} = \frac{A_{ij} B_{ijt}}{A_{i,EU12} B_{i,EU12,t}} \tag{A5}$$

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

$$TFP_{T,j,t} = \frac{\sum_{i \in T} \gamma_{ij,T} C_{ijt}}{\frac{1}{12} \sum_{j \in EU12} (\sum_{i \in T} \gamma_{i,j,T} C_{i,j,t})} \tag{A6}$$

$$TFP_{N,j,t} = \frac{\sum_{i \in N} \gamma_{ij,N} C_{ijt}}{\frac{1}{12} \sum_{j \in EU12} (\sum_{i \in N} \gamma_{i,j,N} C_{i,j,t})} \tag{A7}$$

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

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

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

Consequently, the relative productivity measure in traded to non-traded sectors is constructed as a ratio of (A6) and (A7). In our empirical analysis we always work with the logarithms of these constructed productivity measures.

### *A2. Real Exchange Rates*

We use a dataset on price levels from the Eurostat-OECD PPP Programme[50]. The dataset covers most European countries over the 1995-2009 period. The data are annual Price Level Indices, or PLI's. They give the price of the good category at a given time and for a given country, relative to the price in the reference country. The reference country is the EU 15 area[51]. PLI's are available for 146 consumer expenditure headings on goods and services. These are listed in Table A1. At any point of time $t$, PLI for good $i$ in country $j$ tells us how much more (or less) expensive good $i$ is in country $j$ than in the EU15.

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

### *A3. Gross wages*

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

[50]Methodological manuals describing the dataset are available at: `http://ec.europa.eu/eurostat/en/web/products-manuals-and-guidelines/-/KS-RA-12-023` and `https://unstats.un.org/unsd/EconStatKB/KnowledgebaseArticle10220.aspx`

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

**Table A1. Comparative properties of relative Unit Labor Costs**

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

### *A4. Unit Labor Costs*

Database: OECD.Stat, Unit labour costs : Annual indicators
Series name: ULC_ANN
Sector: Total Economy
Measure: Level, ratio, or national currency
Link: `http://stats.oecd.org/Index.aspx?DataSetCode=ULC_ANN`

Relative Unit Labor Costs are expressed as EU17 average (as provided by OECD.Stat) relative to country $i$.

Table A2 establishes that unit labor costs are positively correlated with two measures of labor market regulations. AUTH represents a summary measure of the authority of unions in wage setting, and CENT is a measure of national and sectoral centralization of wage bargaining. Both are obtained from the Amsterdam Institute of Advanced Study of Labour's Database on Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts in 51 countries between 1960 and 2014 (see: `http://www.uva-aias.net/en/ictwss`). In addition, as discussed in Section 2 of the paper, unit labor costs are positively correlated with a measure of the terms of trade derived from the Penn World Tables. This supports the derivation of equation (13) as a specification for real exchange rate determination.

Table A2. Comparative properties of relative Unit Labor Costs

Correlations with RULC

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

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

### *A5. Hours worked*

Database: OECD Eurostat, Average annual hours actually worked per worker, according to National Accounts concept. The concept used is the total number of hours worked over the year divided by the average number of people in employment. The variable used is the difference between log of the EU15 average and log of a specific country in our dataset. Series names: ANHRS for 1950-2015
Indicator: Series selected for Employment status: Total Employment
Link: `https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS`

### *A6. Construction of the labor wedge*

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

An alternative measure (Method 2) of labour wedge uses the first-order condi-

tion (17) instead:

$$\chi^* - \chi = \text{RULC} + \gamma\kappa(a_F^* - a_H) + (1 - \gamma\kappa)(a_N^* - a_N) - \psi(\ell^* - \ell) \tag{A8}$$

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

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

Table A3. Comparative properties of Labor wedge estimates

Correlations with Labor wedge

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

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

### *A7. Government consumption as fraction of GDP*

Database: OECD - Annual National Accounts
Subject: Government deficit/surplus, revenue, expenditure and main aggregates
Measure: GP3P: Final consumption expenditure, Millions euro, Current prices
Link: `http://stats.oecd.org/Index.aspx?DatasetCode=SNA_TABLE12`
Subject: Main aggregates, Gross Domestic Product
Measure: B1_GE: Gross domestic product (expenditure approach), Millions euro, Current prices
Link: `http://stats.oecd.org/Index.aspx?DatasetCode=SNA_TABLE1`

### *A8. Surplus of the government budget*

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

*A9. Long run real interest rate*

Database: OECD - Key Short-term Economic Indicators
Subject: Long-term interest rates, annual data
Measure: Level
Link: `http://stats.oecd.org/index.aspx?DatasetCode=KEI`
Subject: Consumer prices, all items
Measure: Growth over pervious period
Link: `http://stats.oecd.org/index.aspx?DatasetCode=KEI`

## Model simulations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### *B1. The role of measurement error in the the regression of $q$ on $q_n$.*

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

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

$$q = (1 - \gamma\kappa)(p_N^* - p_N) + \gamma(1 - \kappa)(u^* - u) \tag{B1}$$

In addition, using the same conditions, we have

$$q_n = (p_N^* - p_T^* - (p_N - p_T)) = \kappa(p_N^* - p_N) - (1 - \kappa)(u^* - u) \tag{B2}$$

Using (B2) in (B1) we arrive at the 'true' relationship between $q$ and $q_n$ given by:

$$q = \frac{(1 - \gamma\kappa)}{\kappa} q_n + \frac{(1 - \kappa)}{\kappa}(u^* - u) \tag{B3}$$

Hence, using (B2) and (B3), our estimate of the slope coefficient in the regression of $q$ on $q_n$ will be

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

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

## Further discussion of Eurostat data procedures

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

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

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

"Faced with such an array [.. of goods within each basic heading ...], selecting a subset of products for a basic heading that can be priced over a number of countries is clearly going to be difficult, much more difficult than it is to select

the products to be priced at the elementary level of a consumer price index (CPI) within a single country. There, within broad guiding parameters, the selection can be left to the price collector whose choice may differ from outlet to outlet providing it does not change over time. This initiative cannot be allowed to price collectors collecting prices for Eurostat and OECD comparisons because they are spatial comparisons."

Regarding the 'representativeness' of prices that are surveyed:

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

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

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

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

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

"The issue of heterogeneity raised earlier is partly eased by the way basic headings are defined in the Eurostat-OECD expenditure classification. Definitions list the products covered by the basic headings. For example, 'other bakery products' include 'crispbread, rusks, toasted bread, biscuits, gingerbread, wafers, waffles, crumpets, muffins, croissants, cakes, tarts, pies, quiches and pizzas'. The lists are not exhaustive, but they are sufficiently extensive to allow the more heterogeneous basic headings to be subdivided into smaller and more homogeneous product groups. Breaking a basic heading down into a more manageable frame-

work facilitates both product selection and coverage. In anticipation of this, the lists for the more heterogeneous basic headings arrange products in sets. For example, the list for the basic headings covering clothing identifies four sets or subgroups:

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

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

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

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

- selecting the outlets that are to be visited by price collectors and contacting the outlets selected to explain why they are to be visited;
- preparing pricing materials and other documentation for price collectors (product specifications, survey guidelines, price reporting forms, outlet codes and co-ordinates, schedule of visits, identification and letters of introduction, etc.), including the translation of product specifications and survey guidelines into the national language if necessary;

- identifying which specifications on the final group product list are to be priced and, in the case of generic specifications, which brands are to be priced (if these tasks are not left for the price collectors to do themselves);

- holding a meeting with price collectors to clarify the pricing and supporting materials prepared and issues such as how many items per basic heading, how many prices per item, etc.

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

On outlet selection:

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

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

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

cent) and specifications that are brandless (20 per cent). Assuming a level of precision of 10 per cent, which is both reasonable and acceptable, application of $[t^2CV^2/SE^2]$ gives sample sizes of around 5 for brand specific specifications, of around 10 for well-known brand specifications and between 15 to 20 for brandless specifications." The prices are usually collected in the capital city (for most countries). Consequently, countries need to provide a "spatial adjustment factor" that helps to convert those prices to the "national average price". There is a temporal adjustment to get an annual price uses CPI monthly data. This is done with "temporal adjustment factors", extracted from CPI: "Participating countries extract the temporal adjustment factors from their CPI data base. COICOP38 is the classification underlying the CPIs of most participating countries. And, as explained in Chapter 3, it is as well the classification underlying the breakdown of individual consumption expenditure by households in the Eurostat-OECD classification of final expenditure on GDP. The correspondence between CPI sub-indices and basic headings is therefore generally high. But when there is no exact match, participating countries are expected to select a sub-index, or an aggregation of subindices, that closely approximates the basic heading in question. CPI sub-indices are usually more detailed than basic headings and often they can be aggregated specifically for a basic heading."

## Table A4. Sectors in the GGDC 1997 TFP level database

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

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

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

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

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

**Table A6. Sectoral concordance**

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

Adding aggregate demand variables to the real exchange rate regression

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

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

regression, traded TFP is marginally significant while non-traded TFP is not significant. The random effects regression selects the same demand-side variables as the fixed-effects regression, with similar coefficients. All our baseline repressors remain highly significant and have the predicted signs. In the light of these sensitivity results, we conclude that the inclusion of demand-side variables does not alter the results of our analysis. Importantly, unit labour costs do not appear to proxy for the effects of demand-side variables.

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

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

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

## Results using Terms of Trade

**Table A8. RER - TFP regression with Terms of Trade**

| | Pool | Fixed effects | Random effects | Cross-section |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| $TFP_T$ | **0.43**$^{***}$ | 0.04 | **0.14**$^{***}$ | **0.54**$^{***}$ |
| | (0.033) | (0.06) | (0.05) | (0.04) |
| $TFP_N$ | **-0.25**$^{***}$ | -0.02 | -0.12 | -0.22 |
| | (0.046) | (0.12) | (0.09) | (0.13) |
| $TOT$ | **1.68**$^{***}$ | **1.64**$^{***}$ | **1.72**$^{***}$ | **1.41**$^{***}$ |
| | (0.088) | (0.15) | (0.13) | (0.31) |
| $\overline{R}^2$ | 0.83 | 0.94 | 0.65 | 0.90 |
| N | 117 | 117 | 117 | 9 |
| HT | – | reject | – | – |

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

## Results using Labor Wedge Method 2

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

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

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

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

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

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

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

**Table A11a: Time Series Regressions**

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

**Table A11b: Cross Section Regressions**

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

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

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

**Table A12a. Time Series Regression Results**

| | Sticky price A | Sticky price B | Flexible price | Data |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Traded TFP | 0.184 | 0.193 | 0.216 | 0.18 |
| | (0.082,0.281) | (0.119,0.264) | (0.188,0.244) | |
| Nontraded TFP | -0.236 | -0.224 | -0.216 | -0.36 |
| | (-0.411,-0.052) | (-0.358,-0.094) | (-0.264,-0.188) | |
| RULC | 0.429 | 0.517 | 0.693 | 0.46 |
| | (0.374,0.484) | (0.471,0.563) | (0.653,0.713) | |

**Table A12b. Cross Section Regression Results**

| | Sticky price A | Sticky price B | Flexible price | Data |
|---|---|---|---|---|
| | 5 | 6 | 7 | 8 |
| Traded TFP | 0.376 | 0.379 | 0.389 | 0.93 |
| | (0.275,0.533) | (0.276,0.535) | (0.282,0.540) | |
| Nontraded TFP | -0.373 | -0.377 | -0.380 | -0.27 |
| | (-0.503,-0.258) | (-0.509,-0.256) | (-0.512,-0.256) | |
| RULC | 0.514 | 0.525 | 0.539 | 0.43 |
| | (0.392,0.652) | (0.397,0.670) | (0.399,0.687) | |

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

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

**Table A13a. Time Series Regression Results**

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

**Table A13b. Cross Section Regression Results**

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

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

### Fit of the model

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

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

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

$$q_F(i,t) =$$

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

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

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

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

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

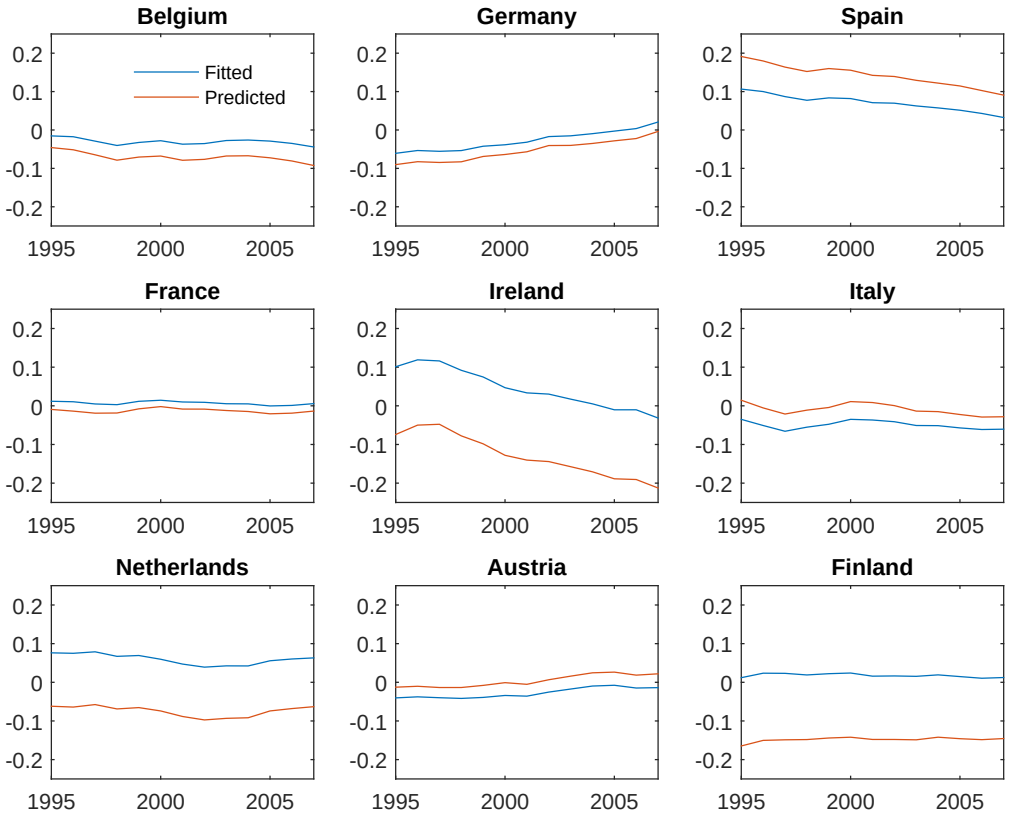
$$q_P(i,t) =$$

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

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

Figure G1 below plots the fitted values $q_F(i,t)$ and the predicted values $q_P(i,t)$ on the same axes for all countries in our sample. We can see that the model matches the average level as well as the temporal movement of real exchange rates very closely for a number of countries, including Germany, France, Italy and Austria. Even in the countries where model gap is exceeds 5 percentage points on average, the temporal movement in the model match remarkably to the predicted movements in the real exchange rates from our estimations.

FIGURE G1. PREDICTED REAL EXCHANGE RATES: PREDICTED AND FITTED VALUES



## Model solution with firm-side labor wedge

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

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

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

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

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

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

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

$$q = (1 - \gamma\kappa)(p_F^* - p_H + (a_F^* - a_H) - (a_N^* - a_N)) \tag{H1}$$

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

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

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

$$\text{RULC} = p_F^* - p_H - (\zeta^* - \zeta) + (1 - \gamma\kappa)(a_F^* - a_H) - (1 - \gamma\kappa)(a_N^* - a_N) \tag{H2}$$

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

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

Now substituting (H2) into (H1) we

(H3)

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

Equation (H3) shows that the original regression specification in equation (13) of the text is misspecified in the model where the labor wedge is driven by variation in the firm's markup rather than variation coming from the household side of the labor market. Intuitively, in the model with a household supply side labor wedge, RULC fully reflects movements in the terms of trade, conditional on productivity, because the labor wedge leads to movements in wage rates, which feed into prices and the terms of trade. But with the product market labor wedge, movements in the labor wedge may affect the terms of trade independently of changes in RULC. Hence, movements in RULC and productivity do not provide a complete description of movements in the real exchange rate.

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

$$\begin{aligned}
\text{RULC} &= \frac{\beta_0}{D}(a_F^* - a_H) - \frac{\beta_1}{D}(a_N^* - a_N) + \frac{\sigma}{D}(\chi^* - \chi) - \frac{D-\sigma}{D}(\zeta^* - \zeta) \qquad \text{(H4)} \\
q &= \frac{1}{D}\left[\sigma\psi\gamma\kappa^2(\lambda-1)(1-\gamma\kappa)\right](a_F^* - a_H) \qquad \text{(H5)} \\
&\quad -\frac{1}{D}(1-\gamma\kappa)\left[\sigma(1+\psi+\psi\gamma\kappa^2(\lambda-1))\right](a_N^* - a_N) + \frac{\sigma}{D}(1-\gamma\kappa)(\chi^* + \zeta^* - \chi - \zeta)
\end{aligned}$$

where the coefficients are as defined in the text. From (H5) we see that the firm's markup labor wedge generates a real exchange rate appreciation, and has an impact exactly equivalent to the household labor wedge. This is because both wedges lead to an identical terms of trade appreciation. However, the impact of the product market wedge on RULC is quite different, and is in fact negative, as opposed to the positive impact of the labor market wedge (Note that from the definition of $D$ in the text, $D - \sigma > 0$). The intuition for this is that the elasticity of the terms of trade with respect to the product market wedge is less than unity. Then, looking at equation (H2), the direct negative effect of $\zeta^* - \zeta$ on RULC is greater than the indirect positive effect coming through terms of trade appreciation.

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

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

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