Productivity and Wedges: Economic Convergence and the Real Exchange Rate*

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Abstract

This paper explores the convergence in prices in Eastern European countries. While they have had significant convergence in GDP per capita (relative to the EU average) since the 1990s, convergence in real exchange rates for these countries stalled after the EU crisis, and has been flat since then. We estimate the main drivers of real exchange rates and show that a combination of productivity growth (Balassa Samuelson effects) and labor market distortions help explain real exchange rate trends. We develop a structural two-country model that provides a rich decomposition of the long run determinants of the real exchange rate. Simulations based on observed sectoral productivities and labor market wedges show that the model can very accurately account for the historical path of real exchange rates, both before and after the EU crisis.

Keywords: Real Exchange Rates, Convergence, Balassa Samuelson
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1 Introduction

Wealthier countries have higher price levels. This is one of the most robust facts, denoted the 'Penn Effect', that comes out of international comparisons of the prices of goods and services. But despite this broad fact, there are significant departures from price equality, or PPP across countries with similar levels of GDP per capita. Rogoff (1996) noted that the most robust evidence for the Penn effect was in the comparison of developing countries with more developed countries. As countries move from one category to another, they tend to exhibit significant real appreciation, but within categories there exists significant heterogeneity.

Our paper focuses on the question of convergence in prices in the European Union. This is a critical issue for policy makers in the EU. The expectation that a more integrated single market would lead to a greater convergence in income levels across the union should have as its by-product a fall in price differentials between countries. When we focus on the high income countries of western Europe, the evidence for price convergence is quite weak. But perhaps this is not surprising, because GDP per capita differentials among these high income countries have not significantly diminished over the life of the single market. However, one clear fact comes out of a focus on Eastern European countries, particularly those countries that were members of the former Soviet Block. In Figure 1 Panel A we see significant and continuing convergence in GDP per capita since these countries became members of the EU. Although there is a slight downturn at the time of the EU crisis, convergence continues strongly until the end of the sample. Then we would expect there to be an equivalent convergence in national price levels, or in other words, significant real exchange rate appreciation relative to the EU averages. Do we see this? Panel B in Figure 1 shows the real exchange rate for the same set of countries, relative to the EU 27 over the same time sample as Panel A in Figure 1. There we encounter a puzzle. Up until 2009, we see a strong real appreciation, or equivalently, a convergence in prices to the EU average. But after 2008, the real exchange rate is flat, or even slightly falling, despite the continuing convergence in GDP per capita.

This paper is an exploration of the relationship between convergence in real GDP and real exchange rate determination, with a specific focus on Eastern European countries. These countries represent a textbook example of GDP convergence over the last two decades. But as the above Figure shows, the pattern of the real exchange rate does not obviously fit the textbook account of relative price convergence. We explore empirically the determinants of real exchange rates for the countries in Eastern Europe. We then build a simple multi-country two-sector model that can separately disentangle the drivers of GDP and real exchange rates. We use the model as a quantitative tool in order to evaluate the simultaneous convergence of GDP and non-convergence of the real exchange rate. Our results show that a combination of sectoral productivity, labor market wedges, and capital inflows all play an important role in explaining the path of GDP and real exchange rates in Eastern European countries.

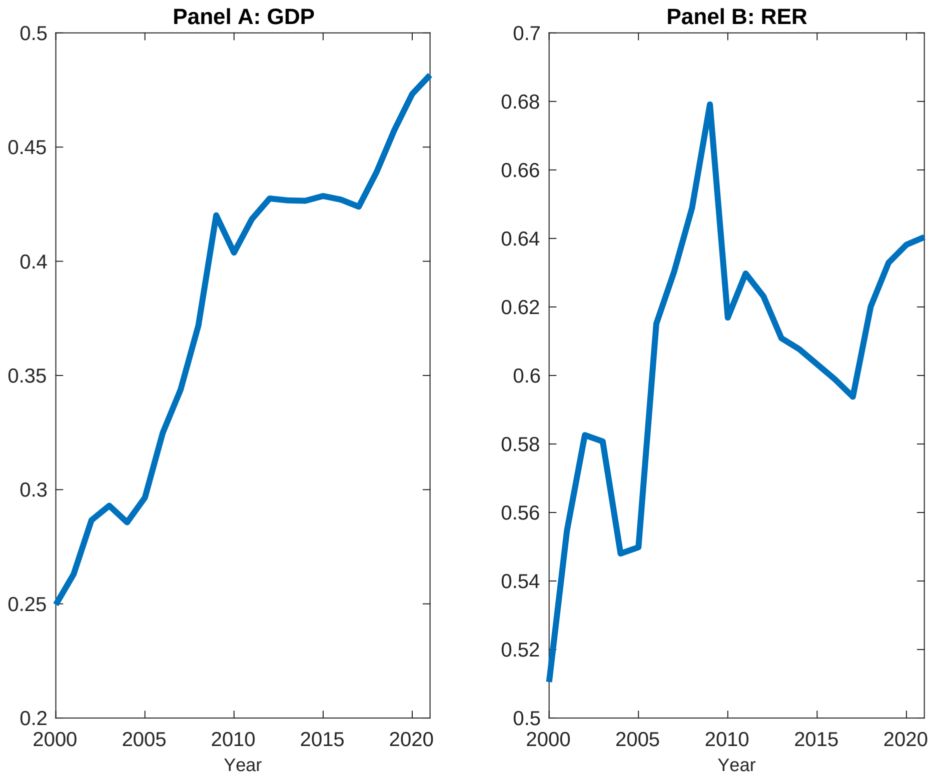

Figure 1: Relative GDP and Real Exchange Rates for Eastern European countries

2 Two country RER model

Here we outline a basic two country model that we will use to interpret the trends in European real exchange rates. Let the countries be Home and Foreign, where we think of Home as being the Eastern European group of countries listed in Section 4 below. In each country there are two sectors, Traded (T) and Non-Traded (NT). Production uses labor with a fixed capital stock in each sector. Since we are focusing on relatively low frequency trends we will assume that prices and wages are fully flexible in both countries.

2.1 Preferences

Utility of Home consumers can be described by the standard CES lifetime utility function:

$$\mathcal{U} = \sum_{t=1}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma} - 1}{1-\sigma} - \Psi_{T,t} \frac{L_{T,t}^{1+\phi}}{1+\phi} - \Psi_{N,t} \frac{L_{N,t}^{1+\phi}}{1+\phi} \right). \tag{1}$$

T, N indicates the sectors Traded and Non-Traded, respectively. σ and ϕ denote the relative risk aversion (inverse of the intertemporal elasticity of substitution) and the inverse of Frisch elasticity, respectively. We assume separately labor supply in each sector, and $\Psi_{j,t}$, $j = T, N$ represents the sectoral labor wedge which will play a role in exchange rate determination.

The preference relationship over traded and non-traded goods is represented by the consumption aggregator:

$$C = \left[\Omega^{\frac{1}{\mu}} C_T^{1-\frac{1}{\mu}} + (1-\Omega)^{\frac{1}{\mu}} C_N^{1-\frac{1}{\mu}}\right]^{\frac{\mu}{\mu-1}}. \tag{2}$$

Ω represents the share of the Traded sector. Within Traded goods, households consume a home and foreign good so that

$$C_T = \left[(1-\gamma)^{\frac{1}{\lambda}} C_{T,H}^{1-\frac{1}{\lambda}} + (1-\gamma)^{\frac{1}{\lambda}} C_{T,F}^{1-\frac{1}{\lambda}}\right]^{\frac{\lambda}{\lambda-1}}.$$

Here, $\gamma = (1 - x(1-n))$, where n is the population share of the Home country, and $0 < x < 1$ allows for some home bias in traded goods preferences. With $x = 1$, there is no home bias. Note that μ represents the elasticity of substitution across sectors, while λ represents the elasticity of substitution across Home and Foreign goods.

Finally, for both home and foreign traded goods, there is a requirement to use distribution services of non-traded goods in order to produce final consumption goods. Hence we have

$$C_{T,H} = \left[v^{\frac{1}{\psi}} I_{T,H}^{1-\frac{1}{\psi}} + (1-v)^{\frac{1}{\psi}} I_{N,H}^{1-\frac{1}{\psi}}\right]^{\frac{\psi}{\psi-1}},$$

$$C_{T,F} = \left[v^{\frac{1}{\psi}} I_{T,F}^{1-\frac{1}{\psi}} + (1-v)^{\frac{1}{\psi}} I_{N,F}^{1-\frac{1}{\psi}}\right]^{\frac{\psi}{\psi-1}}.$$

where $I_{T,H}$ and $I_{N,H}$ refer to the use of traded goods and non-traded goods of the home country in the final consumption of the home traded good $C_{T,H}$. Analogous descriptions apply to the consumption of the foreign traded good $C_{T,F}$. The elasticity of substitution between the 'raw' traded good and non-traded inputs is ψ.

Households in the home country face the following budget constraint:

$$P_t C_t + \frac{B_{t+1}}{1+r_{t+1}} = P_{T,t} C_{T,t} + P_{N,t} C_{N,t} + \frac{B_{t+1}}{1+r_{t+1}} = W_{T,t} L_{T,t} + W_{N,t} L_{N,t} + \Pi_{T,t} + \Pi_{N,t} + B_t, \tag{3}$$

where price indexes are given by

$$P = \left(\Omega P_T^{1-\mu} + (1-\Omega) P_N^{1-\mu}\right)^{\frac{1}{1-\mu}}, \tag{4}$$

$$P_T = \left[\gamma \tilde{P}_{T,H}^{1-\lambda} + (1-\gamma)\, \tilde{P}_{T,F}^{1-\lambda}\right]^{\frac{1}{1-\lambda}}, \tag{5}$$

and

$$\tilde{P}_{T,H} = \left[v P_{T,H}^{1-\psi} + (1-v)\, P_N^{1-\psi}\right]^{\frac{1}{1-\psi}}, \tag{6}$$

$$\tilde{P}_{T,F} = \left[v P_{T,F}^{1-\psi} + (1-v)\, P_N^{1-\psi}\right]^{\frac{1}{1-\psi}}. \tag{7}$$

Households receive income from wages W_N and W_T and profits Π from all sector firms, and consume at the given prices. They can purchase one period 'nominal' international bonds B at price $\frac{1}{1+r_{t+1}}$.[1] γ and v denote share parameters.

Household optimal choices are quite standard, and deliver the solution for the consumption of traded and non-traded goods as

$$C_T = \Omega \left(\frac{P_T}{P}\right)^{-\mu} C, \tag{8}$$

$$C_N = (1-\Omega)\left(\frac{P_N}{P}\right)^{-\mu} C. \tag{9}$$

Given the definition of traded goods, the demand for consumption of home and foreign traded goods is

$$C_{T,H} = \gamma \left(\frac{\tilde{P}_{T,H}}{P_T}\right)^{-\lambda} C_T, \tag{10}$$

$$C_{T,F} = (1-\gamma)\left(\frac{\tilde{P}_{T,F}}{P_T}\right)^{-\lambda} C_T. \tag{11}$$

Likewise, we have the demand for raw traded goods and non-traded distribution services given by:

$$I_{T,H} = vH\left(\frac{P_{T,H}}{\tilde{P}_{T,H}}\right)^{-\psi} C_{T,H}, \tag{12}$$

$$I_{N,H} = (1-v)\left(\frac{P_N}{\tilde{P}_{T,H}}\right)^{-\psi} C_{T,H}, \tag{13}$$

$$I_{T,F} = v\left(\frac{P_{T,F}}{\tilde{P}_{T,F}}\right)^{-\psi} C_{T,F}, \tag{14}$$

$$I_{N,F} = (1-v)\left(\frac{P_N}{\tilde{P}_{T,F}}\right)^{-\psi} C_{T,F}. \tag{15}$$

Equilibrium labor supply conditions are given by

$$\frac{W_T}{P} = \Psi_{T,t} C^{\sigma} L_T^{\phi}, \tag{16}$$

$$\frac{W_N}{P} = \Psi_{N,t} C^{\sigma} L_N^{\phi}. \tag{17}$$

Since our approach to capital flows in the model is described further below in Section 2.6, we abstract from the Euler equation implied by an optimal choice of international bonds.

[1] Although the model is purely real, we define a nominal numeraire below.

2.2 Firms

Assume decreasing returns production functions in each sector with fixed capital. So, $1-\alpha$ is a measure of the labor share. For the home country we have production in traded and non-traded respectively as

$$Y_{T,H} = A_{T,H} L_{T,H}^{1-\alpha},$$

$$Y_{N,H} = A_{N,H} L_{N,H}^{1-\alpha}.$$

Firms in each sector maximize profits given sector-specific wage W_T and W_N. Sectoral wage rates differ due to sector-specific labor disutility in equation (1). First order conditions for the firm are described as:

$$P_{T,H} A_{T,H} (1-\alpha) L_{T,H}^{-\alpha} = W_T, \tag{18}$$

$$P_N (1-\alpha) A_{T,N} L_{N,H}^{-\alpha} = W_N. \tag{19}$$

In addition, assembly firms in the home country purchase home and foreign traded goods, along with home non-traded goods, to produce the traded good for consumption of domestic households.

2.3 Nominal policy

Although prices are flexible and money neutral, it is convenient to assume a monetary rule so that the price index for each country is normalized to unity. Hence we have

$$\left[\Omega P_T^{1-\mu} + (1-\Omega)\, P_N^{1-\mu}\right]^{\frac{1}{1-\mu}} = 1, \tag{20}$$

2.4 Goods market clearing

Goods market clearing in the home and foreign traded good market is described as

$$Y_{T,H} = I_{T,H} + I_{T,H}^{*}, \tag{21}$$

$$Y_{T,F} = I_{T,F} + I_{T,F}^{*}, \tag{22}$$

Note that we label foreign variables with an asterisk where appropriate.

Likewise, market clearing in the non-traded good sector is described as

$$Y_{N,H} = C_N + I_{N,H} + I_{N,F}, \tag{23}$$

$$Y_{N,F} = C_N + I_{N,H} + I_{N,F}. \tag{24}$$

2.5 International price setting

The law of one price holds and therefore

$$P^*_{T,H} = \frac{P_{T,H}}{S}, \tag{25}$$

$$P_{T,F} = SP^*_{T,F}. \tag{26}$$

S refers to the nominal exchange rate.

The real exchange rate, defined as the relative CPI price of the home to foreign country, is then just equal to the inverse of the nominal exchange rate:

$$Q = \frac{P}{SP^*} = \frac{1}{S}. \tag{27}$$

This holds because $P = P^* = 1$ as in equation (20).

2.6 Balance of payments

We can rewrite the Home budget constraint in equation (3) as

$$\begin{aligned} PC &= P_{T,H}Y_{T,H} + P_N Y_{N,H} + B_t - \frac{B_{t+1}}{1+r_{t+1}} \\ &= P_{T,H}Y_{T,H} + P_N Y_{N,H} + \theta P_{T,H} Y_{T,H} \\ &= (1+\theta)\, P_{T,H}Y_{T,H} + P_N Y_{N,H}. \end{aligned}$$

We abstract from the Euler equation derived from the optimal choice of bonds. Rather than solving the intertemporal optimization problem, we assume that there is a capital inflow of amount $\theta P_{T,H} Y_{T,H}$:

$$B_t - \frac{B_{t+1}}{1+r_{t+1}} = \theta P_{T,H} Y_{T,H}. \tag{28}$$

This capital inflow is measured in terms of the domestic traded goods. We remain agnostic about the underlying causes of this capital flow, which could be driven by factors such as transfers, news shocks, foreign direct investment *etc*.

2.7 System of equations

Then, the system of equations consists of equations (5) to (24), and the analogous equations for the Foreign country together with equations (25) to (29).

2.7.1 System of linearized equations

We approximate the system of equations around a symmetric steady state where all relative prices are equal to one, assuming equal country sizes: $n = 1 - n$. These simplifications help in obtaining tractable solutions. Variables with circumflex $\hat{X}$ denote log deviations from the steady state:

$$\hat{X} := \ln(X) - \ln(\bar{X}) \approx \frac{X - \bar{X}}{\bar{X}},$$

where $\bar{X}$ denotes the steady state value. By substituting out several equations, the system of linearized equations consists of 11 equations for 11 endogenous variables $\hat{P}_{T,H}$, $\hat{P}^*_{T,F}$,$\hat{P}_N$, $\hat{P}^*_N$, $\hat{L}_T$, $\hat{L}^*_T$,$\hat{L}_N$, $\hat{L}^*_N$, $\hat{C}$, $\hat{C}^*$, and $\hat{S}$.

labor market clearing: 4 equations

$$\hat{P}_{T,H} + \hat{A}_{T,H} - \alpha \hat{L}_T = \hat{\Psi}_T + \phi \hat{L}_T + \sigma \hat{C},$$

$$\hat{P}^*_{T,F} + \hat{A}_{T,F} - \alpha \hat{L}^*_T = \hat{\Psi}^*_T + \phi \hat{L}^*_T + \sigma \hat{C}^*,$$

$$\hat{P}_N + \hat{A}_{N,H} - \alpha \hat{L}_N = \hat{\Psi}_N + \phi \hat{L}_N + \sigma \hat{C},$$

$$\hat{P}^*_N + \hat{A}_{N,F} - \alpha \hat{L}^*_N = \hat{\Psi}^*_N + \phi \hat{L}^*_N + \sigma \hat{C}^*,$$

Goods market clearing: 4 equations

$$\hat{A}_{T,H} + (1-\alpha)\hat{L}_T = \frac{1}{2}\frac{v\Omega}{1-v\Omega}\left(-\Gamma \hat{P}_{T,H} + \Delta \hat{P}_N + \hat{C}\right) + \frac{1}{2}\frac{v\Omega}{1-v\Omega}\left[-\Gamma\left(\hat{P}_{T,H} - \hat{S}\right) + \Delta \hat{P}^*_N + \hat{C}^*\right],$$

$$\hat{A}_{T,F} + (1-\alpha)\hat{L}^*_T = \frac{1}{2}\frac{v\Omega}{1-v\Omega}\left(-\Gamma \hat{P}^*_{T,F} + \Delta \hat{P}^*_N + \hat{C}^*\right) + \frac{1}{2}\frac{v\Omega}{1-v\Omega}\left[-\Gamma\left(\hat{P}^*_{T,F} + \hat{S}\right) + \Delta \hat{P}_N + \hat{C}\right],$$

$$\hat{A}_{N,H} + (1-\alpha)\hat{L}_N = \hat{C} - \Xi \hat{P}_N,$$

$$\hat{A}_{N,F} + (1-\alpha)\hat{L}^*_N = \hat{C}^* - \Xi \hat{P}^*_N,$$

Prices: 2 equations

$$-\frac{1-\Omega}{\Omega}\hat{P}_N = v\left[\frac{1}{2}\hat{P}_{T,H} + \frac{1}{2}\left(\hat{S} + \hat{P}^*_{T,F}\right)\right] + (1-v)\hat{P}_N$$

$$-\frac{1-\Omega}{\Omega}\hat{P}^*_N = v\left[\frac{1}{2}\hat{P}^*_{T,F} + \frac{1}{2}\left(\hat{P}_{T,H} - \hat{S}\right)\right] + (1-v)\hat{P}^*_N$$

Balance of payments identity: 1 equation

$$-\Gamma \hat{S} + (1-\Gamma)\hat{P}_{T,H} + \frac{1-v\Omega}{v\Omega}\Xi \hat{P}^*_N + \hat{C}^* = (1-\Gamma)\left(\hat{S} + \hat{P}^*_{T,F}\right) + \frac{1-v\Omega}{v\Omega}\Xi \hat{P}_N + \hat{C} - \hat{\theta}. \qquad (29)$$

Note that we define the weighted average of elasticities of substitution as follows:

$$\Gamma := (1-v)\,\psi + v\lambda,$$

$$\Xi := \frac{(1-\Omega)\,v\mu + (1-v)\,\psi}{1-v\Omega},$$

$$\Delta := \frac{(1-v)\,\Omega\psi - (1-v\Omega)\,\lambda + (1-\Omega)\,\mu}{\Omega} = \frac{1-v\Omega}{v\Omega}\,(\Xi - \Gamma)\,.$$

The four equations in “labor market clearing” show that labor demand (LHS), represented by the marginal product of labor, equals labor supply (RHS), which is the marginal disutility of labor multiplied by the marginal utility of consumption. Wages can differ between traded and non-traded production within the same country due to heterogeneous labor wedges. However, these differences do not lead to significant deviations from the outcome under a unified labor market. This is because relative wages are always negatively correlated with relative labor supply.

The first two equations in “Goods market clearing” describe the conditions for traded goods market equilibrium, where the supply (LHS) equals the demand (RHS). The first term on the RHS represents the demand in the producing country, while the second term represents the demand in the counterpart country. Note that $1/2$ indicates the country size, and Γ and $-\Delta$ denote the price elasticities of $\hat{P}_{T,H}$ ($\hat{P}^*_{T,F}$) and $\hat{P}_N$ ($\hat{P}^*_N$), respectively. The last two equations describe the equilibrium conditions for non-traded goods, where supply (LHS) again equals demand (RHS). Here, Ξ denotes the price elasticity of non-traded goods demand with respect to $\hat{P}_N$ ($\hat{P}^*_N$). When simplifying the expressions as shown here, we use the two equations in “Prices” below along with the log-linearized equations for price indices.

The two equations in “Prices” define the theoretical price index for final traded goods, as shown in equation (5). The LHS represents the price of the final traded goods, derived from the CPI definition in equation (4). The CPI index is normalized to unity by the central bank. The first term on the RHS represents the input prices of raw traded goods, while the second term represents the input prices of non-traded services. In our economy, producing final traded goods requires v units of raw traded goods and $(1-v)$ units of non-traded services. Additionally, from these two equations, we can derive the equation for the nominal exchange rate, which is the inverse of the real exchange rate, as shown in equation (31). This equation expresses the nominal exchange rate as a function of the prices of non-traded goods:

$$\hat{S} = \frac{1-v\Omega}{v\Omega}\left(\hat{P}^*_N - \hat{P}_N\right) = -\hat{Q}.$$

The RHS of the “Balance of payments identity” represents the gross exports of the domestic country, while the LHS represents the gross imports.

3 Analytical characterization

This section 3 presents some solutions to the log-linearized system of equations as described in Section 2.7.1.

3.1 Solution of target variables

3.1.1 Real exchange rate

The solution for the real exchange rate is given by

$$
\begin{aligned}
\hat{Q} &= -\frac{1-v\Omega}{v\Omega}\left(\hat{P}_N^* - \hat{P}_N\right) &(30)\\
&= \frac{1-v\Omega}{v\Omega}\frac{\left[(1-\alpha)\sigma + (\alpha+\phi)\right](\Gamma-1)}{\Lambda}\left[(1+\phi)\left(\hat{A}_{T,H} - \hat{A}_{T,F}\right) - (1-\alpha)\left(\hat{\Upsilon}_T - \hat{\Upsilon}_T^*\right)\right]\\
&\quad -\frac{1-v\Omega}{v\Omega}\frac{(1-\alpha)\left[1+\sigma(\Gamma-1)\right] + (\alpha+\phi)\frac{v\Omega}{1-v\Omega}\Gamma}{\Lambda}\left[(1+\phi)\left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) - (1-\alpha)\left(\hat{\Upsilon}_N - \hat{\Upsilon}_N^*\right)\right]\\
&\quad +\frac{\left[(1-\alpha)\sigma + (\alpha+\phi)\right]\left[\frac{1-v\Omega}{v\Omega}(1-\alpha) + (\alpha+\phi)\Gamma\right]}{\Lambda}\hat{\theta}, &(31)
\end{aligned}
$$

where the denominator is defined as

$$
\begin{aligned}
\Lambda &:= \left[(1-\alpha)\sigma + (\alpha+\phi)\right]\left[\frac{1-v\Omega}{v\Omega}(1-\alpha)\left[\Xi + (\Gamma-1)\right] + (\alpha+\phi)\Gamma\Xi\right]\\
&\quad + \left[(1-\alpha)\left[1+\sigma(\Gamma-1)\right] + (\alpha+\phi)\frac{v\Omega}{1-v\Omega}\Gamma\right]\left[(1-\alpha) + (\alpha+\phi)\Xi\right].
\end{aligned}
$$

Whether $\Gamma = (1-v)\psi + v\lambda$ is larger or smaller than unity is a critical determinant of real exchange rate responses. Other parameters, such as σ, do not influence the signs of the responses. Γ represents the price elasticity of the raw traded product in the demand for traded products and is the weighted average of ψ (the elasticity of substitution between raw traded goods and non-traded inputs) and λ (the trade elasticity), with the weight v, which represents the weight for raw traded goods. The trade elasticity, λ, is generally assumed to be significantly larger than unity, while it is plausible to assume that ψ is below unity. But for $v = 0.5$, the parameter value used in our calibrated model below, $\Gamma > 1$ for all values of ψ so long as $\lambda \geq 2$. Consequently, we proceed under the assumption that $\Gamma > 1$. When $\Gamma = (1-v)\psi + v\lambda > 1$, all coefficients in the real exchange rate expression are positive.

Whether Γ is greater than unity is irrelevant in the textbook version of the Balassa-Samuelson model. In contrast to our model, the textbook version assumes that: (1) domestic and foreign goods are perfect substitutes; (2) there is no input requirement for non-traded goods; and (3) wages are identical for workers in both the traded and non-traded sectors. However, it is important to note that relaxing assumption (3) does not lead to significant quantitative deviations from the textbook model. This is because the relative wage is always negatively correlated with the relative labor supply.

The reason that $\Gamma > 1$ matters in our model is as follows. In the standard textbook version of the Balassa-Samuelson model, the prices of traded goods are assumed to be the same across countries. As a result, the real exchange rate is determined by the relative prices of traded and non-traded goods in the domestic and foreign economies. The relative price of non-traded goods versus traded goods is determined by the relative technologies in the production of traded and non-traded goods. Since neither the trade elasticity λ nor the elasticity of substitution ψ between traded and non-traded goods in intermediate goods production are considered, Γ plays no role in the textbook model.

If we relax assumption (1) and assume that domestic and foreign traded goods are imperfect substitutes, the real exchange rate can no longer be expressed solely as a function of the relative technology between traded and non-traded goods. Instead, it becomes a function of both the relative technologies in traded versus non-traded goods and the terms of trade. In this case, whether the trade elasticity is greater than one becomes important. Specifically, in the balance of payments identity, whether net exports increase or decrease in response to improvements in the terms of trade depends on whether the trade elasticity is greater than one. In other words, the direction of the terms of trade's response to macroeconomic conditions depends on whether the trade elasticity exceeds unity.

If we relax assumption (2) further, the real exchange rate is again determined by both the relative technology of traded versus non-traded goods and the terms of trade. However, in this case, the way terms of trade affect net exports is influenced not only by trade elasticity λ, but also by ψ (the elasticity of substitution between traded and non-traded goods in intermediate goods production). This is because the terms of trade affects the relative demand for intermediate traded versus non-traded goods.

This mechanism can be better understood by slightly rewriting the balance of payment identity in equation (29):

$$\left(\hat{C}^* - \hat{C}\right) - \Gamma\hat{S} + (\Gamma - 1)\left(\hat{S} + \hat{P}^*_{T,F} - \hat{P}_{T,H}\right) + \frac{1 - v\Omega}{v\Omega}\Xi\left(\hat{P}^*_N - \hat{P}_N\right) + \hat{\theta} = 0.$$

The effect of the terms of trade on net exports is determined by $\Gamma - 1$, which simplifies to $\lambda - 1$ if there is no input requirement for non-traded goods.

Λ is an increasing function of the elasticities μ, λ, and ψ. It is important to note that μ appears only in the denominator of Λ. Thus, an increase in μ (the elasticity in the trade between tradable and non-tradable goods in final production) reduces the impacts of exogenous variables on the real exchange rate. Specifically, when $\mu = \infty$, the real exchange rate becomes constant.

On the other hand, ψ and λ appear in both the numerator and denominator of Λ, and both affect it positively. Therefore, the way these two elasticities influence the impacts on the real exchange rate is not immediately clear.

Appendix B examines how economic conditions, as represented by the deep parameters, α,ψ and ϕ, influence the real exchange rate's response to the fundamental drivers of the trend when we assume Y:=$\mu = \psi = \lambda > 1$.

Anatomy of real exchange rate dynamics In our calibration, $\Gamma > 1$ and this generally holds under all reasonable calibrations. So, we here aim to understand the determination of the real exchange rate under this condition. We analyze the dynamics of the real exchange rate through three effects: the Balassa-Samuelson effect (the first term), the effect via the Non-Traded sector (the second term), and the effect through capital flows (the third term).

Balassa-Samuelson effect The first term on the second line of (30) captures the Balassa-Samuelson effect. In particular, this is the effect of differential growth in traded goods productivity on the real exchange rate. When the domestic country experiences higher technological progress in the traded goods sector than its foreign counterpart, the real exchange rate is expected to appreciate, since the higher relative growth rate leads to a continual increase in the relative price of non-traded goods. But this is only true when $\Gamma > 1$. In the case of $\Gamma < 1$, the higher growth rate in traded goods productivity causes a downward trend in the country's terms of trade which offsets the rising relative price of non-traded goods to the extent that the aggregate real exchange rate depreciates over time. Conversely, the relative labor wedge in the traded sector, which operates similarly to the relative technology term, has the opposite effect, leading to a depreciation of the real exchange rate. Notice that lower λ and ψ dampens the Balassa-Samuelson effect. This is because this lowers Γ, which represents the price elasticity of the traded product in the demand for traded goods. In addition, as shown in Appendix B, an increase in α,Y and ϕ reduces the magnitude of the Balassa-Samuelson effect.

The Balassa-Samuelson effect is a special case of the more general 'Penn effect', which posits that countries with a higher level of GDP per capita have higher relative price levels. This is consistent with the Balassa-Samuelson effect as described here to the extent that differences in GDP per capita are mainly driven by different productivity in traded goods sectors. [2]

We can get further insight into the Penn effect from the model's linear approximation solution for the movement in relative GDP between the home and foreign country. This is given by

$$\begin{aligned} \hat{C} - \hat{C}^* \quad = \quad & \frac{1+\phi}{\sigma + \alpha(1-\sigma) + \phi}\hat{A}_{N,H} - \frac{1+\phi}{\sigma + \alpha(1-\sigma) + \phi}\hat{A}_{N,F} \\ & - \frac{1-\alpha}{\sigma + \alpha(1-\sigma) + \phi}\hat{\Upsilon}_N + \frac{1-\alpha}{\sigma + \alpha(1-\sigma) + \phi}\hat{\Upsilon}^*_N \\ & + \frac{v\Omega}{1 - v\Omega}\frac{(1-\alpha) + (\alpha+\phi)\,\Xi}{\sigma + \alpha(1-\sigma) + \phi}\hat{Q}. \end{aligned}$$

[2] More generally, Bhagwati () provides a different explanation of the Penn effect arising from balanced growth (e.g. equal growth rates in traded and non-traded goods productivity) but differential factor intensities across sectors. In particular, if the non-traded goods sector is more labor intensive and capital is mobile across countries, then the relative price level of the faster growing country should be rising given labor as a fixed or limited factor. In our model, we don't have capital accumulation so this channel would not be expected to work in the same way. In addition, the illustration in this section assumes equal factor intensities across sectors. But in addition, with uniform growth rates in traded and non-traded goods productivity in our model, the real exchange rate would experience continual depreciation due to declining terms of trade, as can be shown from (31)

Controlling for movements in the non-traded sector productivity and labor wedges in each country, relative GDP and the real exchange rate will move in the same direction, since these will reflect the influence of productivity shocks or labor wedges in the traded goods sector, or capital inflows.

Non-Traded sector In contrast, the second term in (30) implies that if technological progress in the non-traded goods sector is more pronounced in the domestic country than in the foreign country, the real exchange rate tends to depreciate. This is due to the decline in the domestic price level. Additionally, a relatively lower labor wedge in the non-traded sector in the domestic country will lead to an depreciation of the real exchange rate. Together, these factors, alongside the capital flow channel discussed below, mitigate the Penn effect. As illustrated in Appendix B, an increase in α,Υ and ϕ dampens the effect of the non-traded sector channel.

Capital flow The third term indicates that capital inflows typically lead to an appreciation of the real exchange rate by increasing the domestic country's relative consumption. Appendix B demonstrates that an increase in Υ reduces the impact of capital flows, whereas increases in α and ϕ amplify it.

Caution regarding the use of Cobb-Douglas aggregator When the elasticity of substitution between goods is set to unity ($\Upsilon := \psi = \mu = \lambda = 1$), implying that all aggregators are Cobb-Douglas, equation (30) simplifies to

$$\hat{Q} \mid_{\mu=\lambda=\psi=1} = -\frac{1}{2}\left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) + \frac{1-\alpha}{2\,(1+\phi)}\left(\hat{\Upsilon}_N - \hat{\Upsilon}_N^*\right) + \frac{1}{2}\hat{\theta}.$$

A key insight from this specification is that the Balassa-Samuelson effect disappears when all aggregators are Cobb-Douglas. The intuition comes from the fact that a rise in productivity in traded goods leads to a terms of trade deterioration for the affected country which offsets the rise in the relative price of non-traded goods. The wealth effects of the productivity enhancement are then fully shared across countries, so that the relative price of non-traded to traded goods moves equally in each country, leaving the real exchange rate unchanged. This finding highlights a potential pitfall in using the Cobb-Douglas specification in open economies, as it may inadvertently exclude the Balassa-Samuelson effect—one of the most significant channels through which international shocks are transmitted.

3.1.2 Real exchange rate of Non-Traded goods

The real exchange rate of non-traded goods is defined as

$$Q_N := \frac{P_N}{SP_N^*}.$$

By using the solutions in Section A.4, we have a linear exact form:

$$\hat{Q}_N = -\hat{S} - \left(\hat{P}_N^* - \hat{P}_N\right) = -\frac{1}{1-v\Omega}\hat{S} = 2\hat{Q}. \tag{32}$$

The non-Traded goods real exchange rate is proportional to the aggregate real exchange and exhibits more volatile dynamics since $1 - v\Omega < 1$.

3.1.3 Real exchange rate of Traded goods

The real exchange rate of traded goods is defined as

$$Q_T := \frac{P_T}{SP_T^*}.$$

By using the solutions in Section A.4, we have a linear exact form:

$$\hat{Q}_T = -\hat{S} - \left(\hat{P}_T^* - \hat{P}_T\right) = -\hat{S} + \frac{1-\Omega}{\Omega}\left(\hat{P}_N^* - \hat{P}_N\right) = -\frac{1-v}{1-v\Omega}\hat{S} = 2\left(1-v\right)\hat{Q}. \tag{33}$$

The real exchange rate of traded goods is proportional to the aggregate real exchange and it shows less volatile dynamics than the real exchange rate of non-traded goods. In the case where the traded goods consumer bundle does not use non-traded inputs, $\hat{Q}_T$ is constant.

3.1.4 Output of Non-Traded goods

By using the solutions in Section A.4, we have

$$\begin{aligned}
\hat{y}_N &= \left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) + (1-\alpha)\left(\hat{L}_N - \hat{L}_N^*\right) \qquad (34)\\
&= \frac{\frac{1-\alpha}{v\Omega}\left[(1-v\Omega) + v\Omega\sigma\Xi\right](\Gamma-1) + \left(\frac{1-\alpha}{v\Omega} + \frac{\alpha+\phi}{1-v\Omega}\Gamma\right)\Xi}{\Lambda}\left[(1+\phi)\left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) - (1-\alpha)\left(\hat{\Psi}_N - \hat{\Psi}_N^*\right)\right]\\
&\quad + \frac{(1-\alpha)(\Gamma-1)(1-\sigma\Xi)}{\Lambda}\left[(1+\phi)\left(\hat{A}_{T,H} - \hat{A}_{T,F}\right) - (1-\alpha)\left(\hat{\Psi}_T - \hat{\Psi}_T^*\right)\right]\\
&\quad + \frac{(1-\alpha)\left[(1-\alpha) + \frac{v\Omega}{1-v\Omega}(\alpha+\phi)\Gamma\right](1-\sigma\Xi)}{\Lambda}\hat{\theta}.
\end{aligned}$$

Whether $\Gamma = (1-v)\psi + v\lambda$ and/or $\sigma\Xi = \sigma\frac{(1-\Omega)v\mu+(1-v)\psi}{1-v\Omega}$ are larger or smaller than unity is of significant importance. When both Γ and $\sigma\Xi$ are larger than unity, all coefficients are positive. The trade elasticity, λ, is generally assumed to be much larger than unity, making it reasonable to suppose that $\Gamma > 1$.

Ξ represents the price elasticity of the non-traded product in the demand for the non-traded good, and is the weighted average of ψ (the elasticity of substitution between raw traded goods and non-traded inputs) and μ (the elasticity of substitution between traded and non-traded goods in final production), with weights for both ψ and μ given by v and Ω, respectively.

The value of $\sigma\Xi = \sigma\frac{(1-\Omega)v\mu+(1-v)\psi}{1-v\Omega}$ relative to unity affects the direction of the responses to changes in the productivity of traded goods production and to capital inflows. Specifically, the reason why $\sigma\Xi > 1$ is important is that when $0 < \sigma\Xi < 1$, traded and non-traded goods are considered to be Edgeworth complements. In this case, both goods move in the same direction. Conversely, when $\sigma\Xi > 1$, the goods are considered to be Edgeworth substitutes, and in this scenario, they move in opposite directions.

This relationship can be mathematically understood by combining labor market clearing conditions and the goods market clearing condition in the non-traded sector in Section (2.7.1).

In our calibration, $\sigma\Xi > 1$. So, we here aim to understand the determination of the output of non-traded goods under this condition. The output of the non-traded good in the domestic country relative to the foreign country increases when

1. In the non-traded sector, the domestic (foreign) technology improves (declines) or the domestic (foreign) labor wedge decreases (increases),

2. In the traded sector, the domestic (foreign) technology declines (improves) or the domestic (foreign) labor wedge increases (decreases),

3. There are capital outflows to the domestic country.

The first channel is straightforward: efficiency improvements in the domestic country's non-traded sector increase output relative to the foreign country. The second channel operates through the relative demand for traded and non-traded products in the domestic country. Efficiency gains in the traded sector lower the relative price of traded goods, leading to an increase in the production of traded goods when traded and non-traded goods are substitutes. The third channel works via the wealth effects on labor supply. For $\sigma\Xi > 1$, these are strong enough that employment in the non-traded sector falls in response to a capital inflow.

3.1.5 Output of Traded goods

By using the solutions in Section A.4, we have

$$\begin{aligned}
\hat{y}_T &= \left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) + (1-\alpha)\left(\hat{L}_N - \hat{L}_N^*\right) \qquad (35)\\
&= \frac{\Gamma}{1 - v\Omega} \frac{(1-\alpha)\left[v\Omega + (1-v\Omega)\,\sigma\Xi\right] + (\alpha+\phi)\,\Xi}{\Lambda}\left[(1+\phi)\left(\hat{A}_{T,H} - \hat{A}_{T,F}\right) - (1-\alpha)\left(\hat{\Psi}_T - \hat{\Psi}_T^*\right)\right]\\
&\quad + \frac{(1-\alpha)\,\Gamma\,(1-\sigma\Xi)}{\Lambda}\left[(1+\phi)\left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) - (1-\alpha)\left(\hat{\Psi}_N - \hat{\Psi}_N^*\right)\right]\\
&\quad - \frac{(1-\alpha)\,\Gamma}{v\Omega} \frac{\sigma(1-\alpha) + (1-v\Omega)(\alpha+\phi)(1-\sigma\Xi)}{\Lambda}\hat{\theta}
\end{aligned}$$

Similar mechanisms as explained in the previous section are at play in the case of the relative output in Traded goods.

3.1.6 Relative unit labor cost in Non-Traded sector

The relative unit labor cost in the Non-Traded sector is defined as

$$u_N = \frac{\frac{W_N}{A_{N,H} L_N^{1-\alpha} / L_N}}{S \frac{W_N^*}{A_{N,F} \left(L_N^*\right)^{1-\alpha} / L_N^*}}.$$

Using the solutions in Section A.4, we have

$$\hat{u}_N = -\hat{Q}_N = \frac{1}{1 - v\Omega} \hat{Q}. \tag{36}$$

The unit labor cost in the Non-Traded sector moves in the same direction as the real exchange rate of Non-Traded goods. Thus, as shown in equation (30), an increase in the labor wedge in the non-traded (traded) goods sector in the home country increases (reduces) the unit labor cost in the non-traded sector.

3.1.7 Relative unit labor cost of Traded goods

The relative unit labor cost in the traded sector is defined as

$$u_T = \frac{\frac{W_T}{A_{T,H} L_T^{1-\alpha} / L_T}}{S \frac{W_T^*}{A_{T,F} \left(L_T^*\right)^{1-\alpha} / L_T^*}}.$$

Using the solutions in Section A.4, we have

$$\hat{u}_T = \left(\hat{P}_{T,H} - \hat{P}^*_{T,F}\right) - \hat{S},$$

or

$$\begin{aligned}
\hat{u}_T \;=\; & -\frac{(1 - v\Omega)(1-\alpha)(1 - \sigma\Xi)}{v\Omega\Lambda} \left[(1+\phi)\left(\hat{A}_{N,H} - \hat{A}_{N,F}\right) - (1-\alpha)\left(\hat{\Upsilon}_N - \hat{\Upsilon}_N^*\right)\right] \\
& - \frac{(1-\alpha)\left[v\Omega + (1 - v\Omega)\sigma\Xi\right] + (\alpha + \phi)\Xi}{v\Omega\Lambda} \left[(1+\phi)\left(\hat{A}_{T,H} - \hat{A}_{T,F}\right) - (1-\alpha)\left(\hat{\Upsilon}_T - \hat{\Upsilon}_T^*\right)\right] \\
& + \frac{(1-\alpha)\left\{\sigma(1-\alpha) + (\alpha+\phi)\left[(1 - v\Omega) + v\Omega\sigma\Xi\right]\right\}}{v\Omega\Lambda} \hat{\theta}.
\end{aligned} \tag{37}$$

The unit labor cost in the traded sector moves almost in the same direction as the relative output in traded goods. Both labor wedges increase the unit labor cost in the traded sector.

Note that in the regressions below, we only use the aggregate unit labor cost which is the weighted average of equations (36) and (37). Thus, the unit labor cost in the regression represents the aggregate labor wedge.

4 Data

Our data consists of real exchange rates covering all goods, both tradable non-tradable, as well as a number of labor market fundamentals. Our sample of countries are Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovenia, and Slovakia. In most cases we also consider the same variables for the European Union 27 countries group (EU27). Our sample is annual and covers the period 1999-2020.

4.1 Real Exchange Rates

We construct real exchange rates for the sample of Eastern European countries 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 if the country chosen is in the Eurozone this measure does not involve different currencies. The reporting frequency is annual for 1999-2020 and the PLIs are available for 223 "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 the online Appendix Table 14. For each item, the reference price is obtained as a ratio of the domestic price of each good to the EU27 analog and re-expressed in terms of the corresponding EU15 price level for a better comparability for the Eastern European economies case.[3] Hence, the prices are comparable in levels, so that both cross-section and time-series real exchange rate variation can be examined. Our sample contains the 12 Eastern European economies mentioned above. 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.[4] 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 (non-traded) goods. Real exchange rates are measured so that an increase represents an appreciation for the home country.[5]

Relative to other studies that have compared price levels internationally, these data have a number of advantages. They cover the entire consumer basket. For a detailed explanation meant to convey the care taken to make prices comparable see Berka, Devereux and Engel

[3]The EU15 group includes Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Spain, Sweden, Portugal, Finland, and the United Kingdom, and the EU27 Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.

[4]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.

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

(2018). Here we mention only that exhaustive efforts are made at the item priced level to ensure comparability across countries, including to consider that some products are priced at various types of outlets (for example, department stores, supermarkets, specialty outlets) by increasing the sampling of products when their prices across similar outlets show higher variation.

We separate goods into traded and non-traded categories using a criteria by item reported in Table 14 in the (online) Appendix and along the lines followed by Berka et al. (2018) and Crucini et al. (2005) where all goods with a positive trade share are categorized as "traded", and those with a zero trade as "non-traded."

The composition of the consumption baskets differs across goods, countries, and time. To account for this, 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 $\gamma_{i,j,t} = \frac{\exp_{i,j,t}}{\sum_{i=1}^{223} \exp_{i,j,t}}$ 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 country j relative to EU15, we calculate the log of the real exchange rate of country j, $q_{j,t}$, as the expenditure-weighted arithmetic average:

$$q_{j,t} = \sum_{i=1}^{223} \gamma_{i,j,t} p_{i,j,t}$$

Based on these aggregate measures we report some descriptive statistics for a set of variables in Table 1. The table first reports the average log real exchange rate over the sample for each country, denoted $\bar{q}$, as well as the equivalent measures for the traded goods real exchange rate $\bar{q}_T$, the nontraded goods real exchange rate, $\bar{q}_N$, and also the relative price of nontraded goods $\bar{q}_n = \bar{q}_N - \bar{q}_T$. Note that the level data are expressed as proportions of the EU27 average. Thus if an entry is negative in logs it implies that the country's price is below the average.

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

The right panel of Table 1 reports standard deviations of annual real exchange rates. They are range from three to eleven percent for most countries. As we would anticipate, the standard deviation of non-traded real exchange rates exceeds that of the traded real exchange rates. We can also see some of these features in Table 2 where we report summary statistics by variable. We can see that the volatility and average level of the real exchange rate of non-tradables exceeds that of tradables. Similarly, the real exchange rates tend to display a non-trivial autorregressive component, consistent with the trend towards appreciation across the countries in our sample.[6]

Table 1: Country Summary Statistics

Country	$\bar{q}$	$\bar{q}_T$	$\bar{q}_N$	$\bar{q}_n$	$s(q)$	$s(q_T)$	$s(q_N)$	$s(q_n)$
BG	3.96	4.16	3.49	-0.67	0.09	0.09	0.15	0.07
CY*	4.49	4.60	4.35	-0.25	0.03	0.03	0.04	0.05
CZ	4.16	4.30	3.91	-0.38	0.11	0.10	0.16	0.08
EE*	4.26	4.38	4.04	-0.34	0.10	0.09	0.12	0.05
HU	4.14	4.29	3.87	-0.42	0.07	0.07	0.09	0.04
LT*	4.18	4.30	3.76	-0.54	0.08	0.09	0.10	0.09
LV*	4.22	4.36	3.95	-0.41	0.09	0.10	0.12	0.08
MT*	4.39	4.53	4.21	-0.32	0.03	0.04	0.06	0.07
PL	4.10	4.23	3.81	-0.42	0.06	0.06	0.09	0.07
RO	3.98	4.16	3.55	-0.61	0.10	0.11	0.11	0.07
SI*	4.36	4.45	4.20	-0.25	0.04	0.04	0.06	0.04
SK*	4.18	4.31	3.91	-0.39	0.18	0.15	0.27	0.14
	$\bar{a}_T$	$\bar{a}_N$	$\bar{a}_{TN}$	$\overline{rulc}$	$s(a_T)$	$s(a_N)$	$s(a_{TN})$	$s(rulc)$
BG	-2.13	-0.51	-1.62	-2.19	0.11	0.21	0.11	0.22
CY*	-0.57	0.19	-0.76	-0.50	0.06	0.04	0.05	0.11
CZ	-0.50	-0.54	0.05	-0.96	0.19	0.04	0.18	0.25
EE*	-0.94	-0.06	-0.88	-1.20	0.18	0.23	0.08	0.32
HU	-0.47	-0.38	-0.08	-1.24	0.11	0.05	0.11	0.15
LT*	-1.21	-0.85	-0.36	-1.44	0.20	0.20	0.07	0.24
LV*	-0.93	-0.30	-0.63	-1.69	0.24	0.21	0.05	0.23
MT*	-0.81	-0.40	-0.41	-0.39	0.05	0.10	0.13	0.21
PL	-0.62	-0.35	-0.27	-1.38	0.13	0.16	0.08	0.11
RO	-1.31	-0.51	-0.81	-2.70	0.25	0.21	0.10	0.19
SI*	-0.45	-0.26	-0.19	-0.45	0.10	0.05	0.08	0.07
SK*	-0.39	-0.17	-0.22	-1.12	0.28	0.12	0.18	0.39

Notes: All real exchange rate variables (q, q_T, q_N, q_n) are home country values relative to EU15 average. q is the expenditure-weighted log real exchange rate (an increase is an appreciation). q_T (q_N) is the real exchange rate for traded (nontraded) goods only, both relative to EU15 average. $q_n \equiv q_N - q_T$. $s(\cdot)$ denotes standard deviation. a_T (a_N) is a logarithm of traded (nontraded) labor productivity of the home country relative to EU27. Traded is an aggregate of one-digit sector's labor productivities aggregated using sectoral gross outputs as weights. $a_{TN} \equiv a_T - a_N$. $rulc$ is a logarithm of relative unit labor costs the home country relative to the EU27 average. The balanced sample period is 1999-2020.
* Countries joining the Eurozone at some point in our sample.

[6]Note that these are standard deviations of logs, rather than log differences.

Table 2: Variable Summary Statistics

	q	q_T	q_N	q_n	a_T	a_N	a_{TN}	$rulc$
$mean(std_i(\cdot))$	0.08	0.08	0.11	0.07	0.16	0.14	0.10	0.21
$std(mean_i(\cdot))$	0.16	0.14	0.26	0.13	0.50	0.26	0.46	0.69
$AR(1)$	0.81	0.81	0.81	0.80	0.86	0.82	0.63	0.94

Notes: All real exchange rate variables (q, q_T, q_N, qn) are expressed as home country relative to EU15. q is the expenditure-weighted log real exchange rate (an increase is an appreciation). q_T (q_N) is the real exchange rate for traded (nontraded) goods only, both relative to EU15 average (an increase is an appreciation). $q_n \equiv q_N - q_T . a_T$ (a_N) is a logarithm of traded (nontraded) labor productivity in the home country relative to EU27. 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 each home country relative to EU27. The balanced sample period is 1999-2020. The top row reports average time series standard deviation $(\text{std}_i(\cdot)$, where i indexes countries) and the second row standard deviation of average real exchange rates $(\text{mean}_i(\cdot)$, where i indexes countries). The bottom row reports the autocorrelation coefficient from a fixed-effects panel AR(1) regression.

Figure 2 displays some properties of the aggregate real exchange rates in our Eastern European sample. We can see that there is a substantial convergence towards the mean in the whole sample for all levels of aggregation (all goods, traded, non-traded); furthermore we see that the relative price of non-tradables, shown in panel D, shows a noticeable stability in most countries, which reflects either a substantial comovement between the traded and non-traded components of the real exchange rate (RER), or even a convergence of these variables.

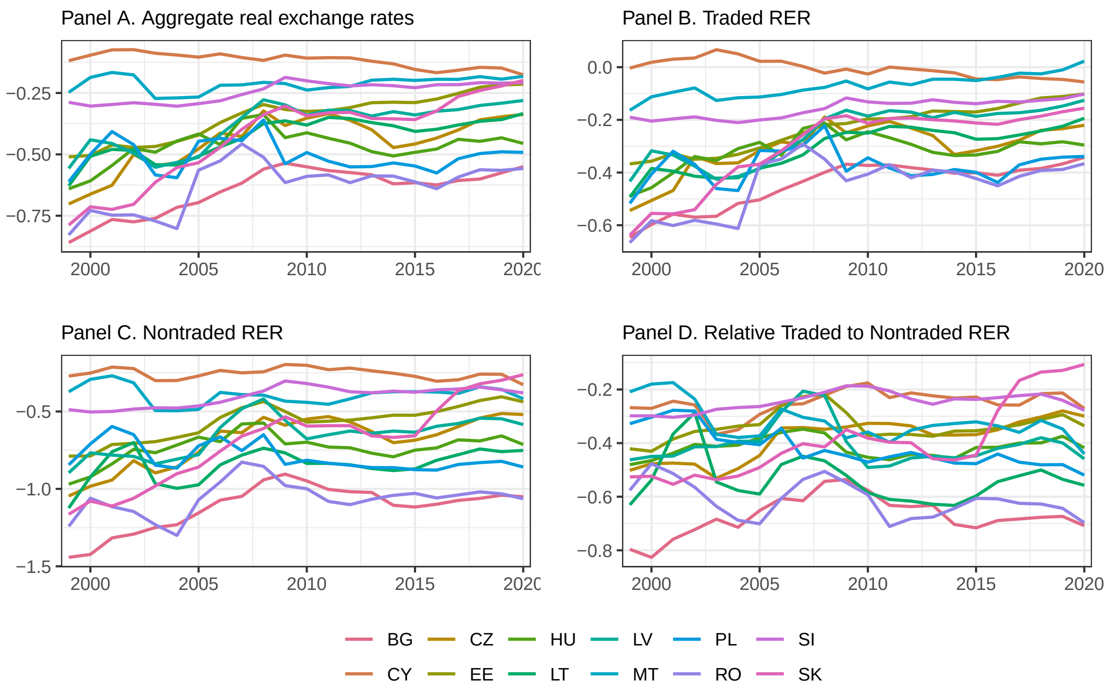

Figure 2: Real Exchange Rates

4.2 Productivity and Unit labor Costs Data

We wish to associate the real exchange rate data with supply-side indicators that are suggested by the theoretical discussion above. For the latter we consider labor productivity data for the whole economy and at the sectoral level.[7] Similarly, we consider labor market conditions to account for the possibility that the real exchange rates are influenced by factors beside productivity. These are accounted for by including the unit labor costs.

We obtain indexes of real labor productivity per hour from Eurostat at the sectoral level for the single-letter NACE Rev. 2 classification. We proceed to adjust these indexes by the sectoral output level relative to the EU25 analog. To do this adjustment, we multiply each labor productivity sectoral index by the corresponding sectoral output per-hour worked from the 1997 Productivity Level Database reported by the Groningen Growth and Development Centre (GGDC) and along the lines of Berka et al. (2018) where, importantly, we adjust the levels to be expressed in terms of the EU25 sectoral output rather than the US levels as in the official data release. Once we have sectoral level adjusted indexes, we aggregate these into tradable and non-tradable broader-sector categories, using a weighted average of the tradable and non-tradable sectors with weights approximated by the sectoral contribution to the total economy value added obtained from the 2023 Productivity Level Database reported by the GGDC (see Inklaar, Marapin and Gräler, 2023, for details). For this calculation, we adapt the sectoral mapping into tradable and non-tradable sectors from Berka et al. (2018) into the single letter NACE Rev. 2 sectoral classification that are considered in the Eurostat, and GGDC datasets. Table 3 shows the sectors considered and their tradability categorization we use.

At the same time, we compute a measure of relative labor productivity in the tradable sector with respect to the non-tradable one, and express this ratio, in relative terms with respect to the analog quantity for the EU27 group. This variable can be obtained based on the relative real labor productivity of each type of aggregate (tradable, non-tradable) with respect to EU27 as follows:

$$RLprod = \frac{\frac{realLabProd_{T,it}}{realLabProd_{T,EUt}}}{\frac{realLabProd_{N,it}}{realLabProd_{N,EUt}}} = \frac{\frac{realLabProd_{T,it}}{realLabProd_{N,it}}}{\frac{realLabProd_{T,EUt}}{realLabProd_{N,EUt}}}$$

In addition we consider a measure of real relative unit labor costs which we compute based on Nominal Unit labor Cost data in euros from Eurostat at the sectoral level, divided by the Producer Price Index data (PPI) of each economy which we obtain from the IMF-IFS database (and complement for the EU27 group using the industry PPI from 2018 to 2020 from Eurostat). After obtaining such real labor unit costs per hour, we divide it in each case by the same measure for the EU27 group which gives us the real relative unit labor costs per sector.

Tables 1 (lower panel) and 2 report descriptive statistics for traded and non-traded labor productivity in the same form as reported for the real exchange rate data. In general we see that the traded labor productivity tends to be more volatile than the non-traded one. We also

[7] One might want to consider TFP data directly instead of factor-specific productivity data as in Berka et al. (2018). However, in contrast to the Western Europe case, this data is not available for our sample of Eastern European countries. Thus, we use the labor productivity indexes sectoral data from Eurostat.

illustrate the properties for these variables across time in Figure 3. We can see in Panel C that there is substantial variation of the unit labor costs over time which justifies the inclusion of these costs as a separate determinant for the real exchange rate.

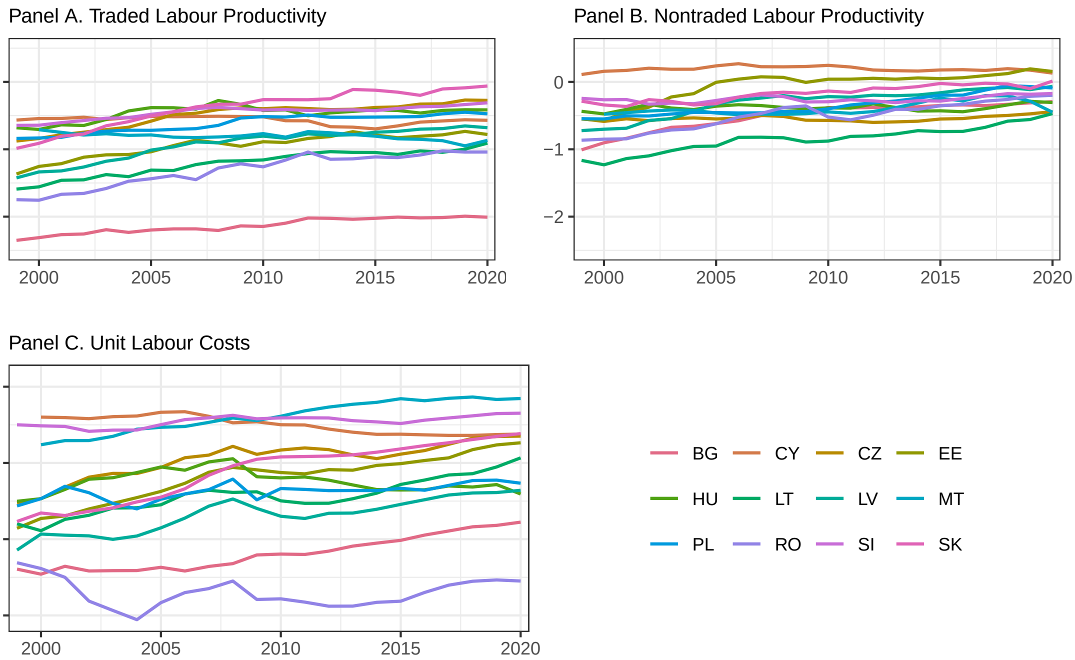

Figure 3: labor productivity by sectors and unit labor costs

Table 3: Sectoral Classification and Tradability

NACE Rev. 2 Sector Letter	Sector Name	Tradability
A	Agriculture, forestry and fishing	T
B	Mining and quarrying	T
C	Manufacturing	T
D	Electricity, gas, steam and air conditioning supply	N
E	Water supply; sewerage, waste management and remediation activities	N
F	Construction	N
G	Wholesale and retail trade	T
H	Transportation and storage	N
I	Accommodation and food service activities	N
J	Information and communication	N
K	Financial and insurance activities	N
M	Professional, scientific and technical activities	N
N	Administrative and support service activities	N
R	Arts, entertainment and recreation	N
S	Other service activities	N
B-E	Industry (except construction)	T
G-I	Wholesale and retail trade, transport, accommodation and food services	N
M-N	Professional, scientific. services	N
R-U	Arts, entertainment, recreation, and other services	N

Notes: T and N refer to the tradable and non-tradable sectoral classification.

We can also summarize the relative productivities and unit labor costs by sectors. To this end, we consider population-weighted averages across the countries in our sample and illustrate the associated Eastern European region indicators over time in Figures 5 and 4. We can see that the comovement between sectoral productivities and the substantial unit labor costs variation over time we highlighted before is also visible at the regional level for both tradable (T) and non-tradable sectors (N).

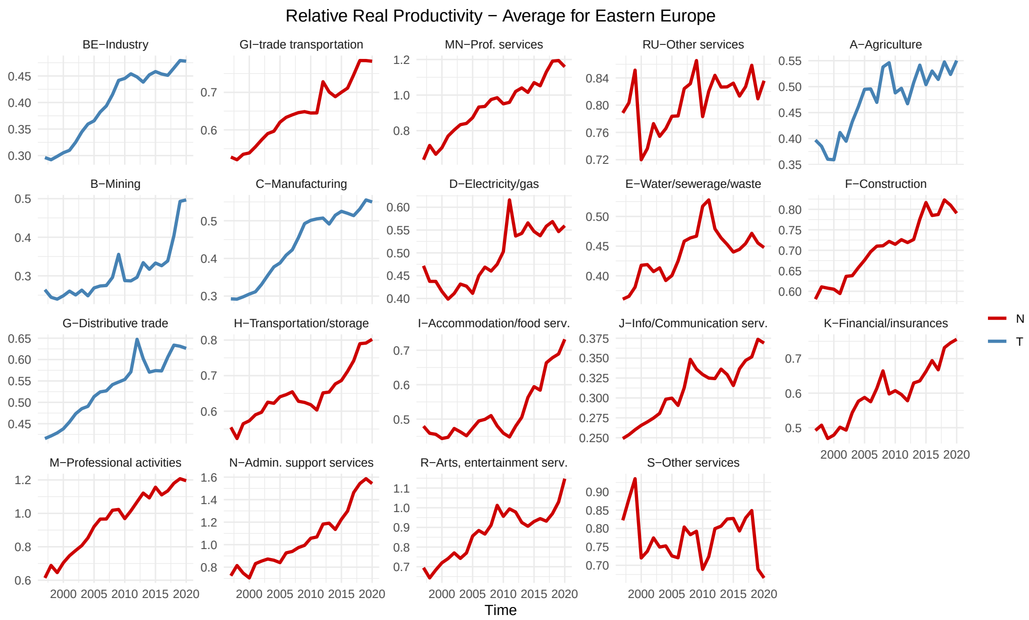

Figure 4: Average Relative Real labor Productivity for Eastern Europe (12 countries).

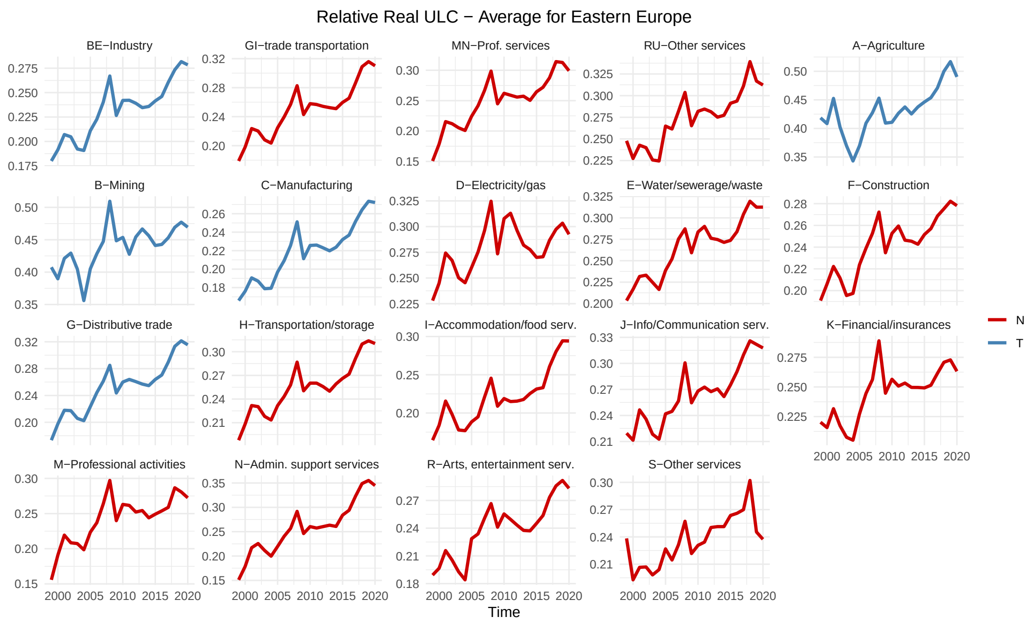

Figure 5: Average Relative Real Unit labor Cost for Eastern Europe (12 countries).

5 Real Exchange Rate regressions

Based on our data described above, here we summarize a set of estimations to explore the relationship between real exchange rates at different levels of aggregation and the relative sectoral productivities and the labor cost dynamics.

Estimations with productivity for tradable and non-tradable sectors

We present an empirical setup in which the real exchange rate (RER) is dependent on the relative labor productivity of the tradable and non-tradable sectors, as well as the real labor unit cost (relative to the EU). We consider versions of the regression where the relative (traded to non-traded) labor productivity enters as a single variable ($RLprod$), then one in which we consider the real labor productivity of tradable and non-tradable sectors as separate variables (relative to EU27), and a final estimation where we consider the separate productivities, and the relative unit labor costs ($RULC$).

Our data consists on a panel with annual frequency and country level observations (computed from sectoral data). We report panel estimations with fixed and random effects. All standard errors are computed using a panel corrected standard errors clustering method following Beck and Katz (1995). We also report the result of the Hausman test (HT) for the random effects regression (rejection of the null implies no difference between the Fixed effects and Random effects estimations, interpreted as a weak preference for the Fixed effects model).

We report estimations for the real exchange rate for all goods, a second group of estimates for the real exchange rate of tradable goods, and a final for non-tradable goods. For interpretations, it is also useful to remember that the RER is defined in a way that an increase indicates a real appreciation.

The regression specifications are described as follows:

$$\log RER^j_{it} = \alpha_0 + \beta_1 \log \overbrace{\left(\frac{\frac{realLabProd_{T,it}}{realLabProd_{N,it}}}{\frac{realLabProd_{T,EUt}}{realLabProd_{N,EUt}}} \right)}^{RLprod} + \beta_2 \log \overbrace{\left(\frac{RealULC_{it}}{RealULC_{EUt}} \right)}^{RULC} + \epsilon_{ti},$$

$$\log RER^j_{it} = \alpha_0 + \beta_1 \log Lprod_{T,it} + \beta_2 \log Lprod_{N,it} + \beta_3 \log RULC_{it} + \epsilon_{ti}, \quad \text{for } j = \{All, T, N\},$$

where in the first type of regression $RLprod$ denotes the real labor productivity of the tradable sector relative to the non-tradable one expressed itself in relative terms with respect to the same quantity for the EU. Similarly, $RULC$ is the real unit labor cost of each country relative to the same measure in the EU. As for the second type of panel, $Lprod_T$ and $Lprod_N$ denote respectively the real labor productivity of the tradable and non-tradable sectors with respect to the analog quantity for the EU.

As implied by equations (30), (32) and (33) in Section 3 above, we note that the presumptive sign on both β_1 and β_2 in the first regression is positive. A rise in traded relative to non-traded goods productivity as well as a rise in the labor wedge and/or the terms of trade —both of which enter into the relative unit labor cost, should be associated with a real exchange rate appreciation. Likewise, for the same reasons, in the second regression, we expect that β_1 and β_3 to be positive, while β_2 to be negative.

We note that the estimated coefficients are the largest for RERN and they are similar for RER and RERT. This result is consistent with the theoretical prediction from equations (30), (32) and (33).

In evaluating the empirical results, it is important to consider the following two points. (1) The primitives in the model are the labor wedges for the Traded and Non-Traded sectors. Ideally, estimation should be conducted using exogenous variables, with these labor wedges included as explanatory variables. However, since these variables are unavailable, we use unit labor cost as a proxy that combines the labor wedges. (2) Unit labor cost is not a primitive; rather, it is expressed as a function of technology and the labor wedge. As a result, the use of relative unit labor cost in the estimation may introduce multicollinearity, which could lead to estimated parameters whose signs may not fully align with the theoretically consistent ones as assumed above.

Table 4 shows the results for regressions for the real exchange of all goods (as dependent variable). Similarly, in the tables 5 and 6 we report the results for the real exchange of traded and non-traded goods. The coefficients on traded and non-traded productivity have the right sign, and the former is significant. At the same time, it is important to include the relative unit cost variable which is also significant in all cases. As we will see, this specification is an initial point that can be subject to improvements by considering the inclusion of additional variables as we show below.

Table 4: Model for the RER (all goods)

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.281****	**0.198****	—	—	**0.207*****	0.093	—	—
	(0.13)	(0.08)			(0.08)	(0.04)		
$Lprod_T$	—	—	**0.397*****	**0.296*****	—	—	**0.325*****	**0.202*****
			(0.07)	(0.06)			(0.06)	(0.05)
$Lprod_N$	—	—	0.005	-0.063	—	—	0.062	0.023
			(0.08)	(0.07)			(0.07)	(0.07)
$RULC$	—	**0.298*****	—	**0.188*****	—	**0.266*****	—	**0.175*****
		(0.04)		(0.04)				(0.04)
$R^2(adj.)$	0.23	0.63	0.61	0.71	0.26	0.62	0.6	0.69
N	263	262	263	262	263	262	263	262
HT					not reject	reject	reject	reject

Notes: Dependant variable: log real exchange rate (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

Table 5: Model for the RER of Traded goods

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.245***	**0.168****	—	—	**0.171****	0.063	—	—
	(0.13)	(0.08)			(0.07)	(0.04)		
$Lprod_T$	—	—	**0.36*****	**0.28*****	—	—	**0.295*****	**0.19*****
			(0.06)	(0.05)			(0.05)	(0.05)
$Lprod_N$	—	—	0.041	-0.012	—	—	0.092	0.064
			(0.06)	(0.06)			(0.06)	(0.06)
$RULC$	—	**0.276*****	—	**0.149*****	—	**0.241*****	—	**0.139*****
		(0.04)		(0.04)				(0.03)
$R^2(adj.)$	0.23	0.61	0.65	0.71	0.26	0.59	0.63	0.69
N	263	262	263	262	263	262	263	262
HT					not reject	reject	reject	reject

Notes: Dependant variable: log real exchange rate for traded goods (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log of an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

Table 6: Model for the RER of Non-traded goods

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.359****	**0.248****	—	—	**0.308*****	0.14	—	—
	(0.17)	(0.12)			(0.12)	(0.06)		
$Lprod_T$	—	—	**0.49*****	**0.321*****	—	—	**0.41*****	**0.19****
			(0.13)	(0.12)			(0.1)	(0.09)
$Lprod_N$	—	—	-0.033	-0.147	—	—	0.048	0.001
			(0.15)	(0.13)			(0.12)	(0.11)
$RULC$	—	**0.4*****	—	**0.317*****	—	**0.375*****	—	**0.292*****
		(0.07)		(0.08)				(0.06)
$R^2(adj.)$	0.19	0.54	0.43	0.56	0.23	0.57	0.46	0.61
N	263	262	263	262	263	262	263	262
HT					not reject	reject	reject	reject

Notes: Dependant variable: log real exchange rate for non-traded goods (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log of an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

Additional Explanatory Variables

We consider specifications with additional controls, namely fiscal indicators (relative government expenditure and deficit), and financial indicators (relative long-run interest rates). The full set of regressions is shown in the appendix. Here we report a summarized output of the models where the financial conditions are introduced in the model and an interaction with a Global Financial Crisis dummy is included which generates an improvement in the significance of the sectoral productivity indicators. As shown in equations (30), (32), and (33), capital inflows increase the real exchange rate. Here, this interaction term of relative long-run interest rates and the Global Financial Crisis dummy is expected to have a negative coefficient, as it represents capital outflows for Eastern European countries.

The results are shown in Table 7 for the real exchange rate of all goods, and in tables 8 and 9 for the real exchange rate of traded and non-traded goods.

In this case, after including additional economic variables as controls the results indicate not only the right signs for the relative sectoral productivities and labor unit costs, but their significance. In addition, the financial conditions, measured either via the long-run interest rate spread vis-a-vis the Euro area (EU27) or the interaction of the spread with a Global Financial Crisis dummy becomes significant in the panels for the real exchange rate of traded and non-traded goods.

Table 7: Model for the RER (all goods)

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.189*****	**0.192*****	—	—	0.068	**0.08***	—	—
	(0.05)	(0.05)			(0.05)	(0.05)		
$Lprod_T$	—	—	**0.186*****	**0.19*****	—	—	**0.095***	**0.107***
			(0.07)	(0.06)			(0.06)	(0.06)
$Lprod_N$	—	—	**-0.193*****	**-0.195*****	—	—	-0.05	-0.067
			(0.07)	(0.07)			(0.07)	(0.07)
$RULC$	**0.283*****	**0.284*****	**0.286*****	**0.286*****	**0.246*****	**0.25*****	**0.232*****	**0.238*****
	(0.04)	(0.03)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)
LR	0.0016	0.0039	0.0016	0.0039	0.0019	0.0039	0.0019	0.0040
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
$LR \times GFC$	—	-0.0048	—	-0.0048	—	-0.0042	—	-0.0043
		(0.003)		(0.003)		(0.003)		(0.003)
$R^2(adj.)$	0.63	0.64	0.63	0.64	0.9	0.9	0.9	0.89
N	214	214	214	214	214	214	214	214
HT					reject	reject	reject	reject

Notes: Dependant variable: log real exchange rate (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log of an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. LR is a spread between the real long-run (10-year) bonds rate of each country relative to EU (EU19). The rates are made real by subtracting CPI inflation. GFC is a dummy variable taking the value of 1 for the years 2007-2009. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

Table 8: Model for the RER of Traded goods

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.136*****	**0.137*****	—	—	0.042	0.052	—	—
	(0.05)	(0.05)			(0.04)	(0.04)		
$Lprod_T$	—	—	**0.158*****	**0.159*****	—	—	**0.084***	**0.095***
			(0.06)	(0.06)			(0.05)	(0.05)
$Lprod_N$	—	—	-0.1	-0.101	—	—	0.004	-0.009
			(0.07)	(0.07)			(0.06)	(0.06)
$RULC$	**0.267*****	**0.268*****	**0.242*****	**0.242*****	**0.233*****	**0.237*****	**0.202*****	**0.207*****
	(0.03)	(0.03)	(0.05)	(0.05)	(0.03)	(0.03)	(0.04)	(0.04)
LR	**0.0030***	0.0040	**0.0030***	0.0041	**0.0033***	0.0040	**0.0032***	0.0041
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
$LR \times GFC$	—	-0.0020	—	-0.0021	—	-0.0015	—	-0.0017
		(0.003)		(0.003)		(0.003)		(0.003)
$R^2(adj.)$	0.64	0.64	0.64	0.64	0.91	0.9	0.91	0.9
N	214	214	214	214	214	214	214	214
HT					reject	reject	reject	reject

Notes: Dependant variable: log real exchange rate for traded goods (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log of an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. LR is a spread between the real long-run (10-year) bonds rate of each country relative to EU (EU19). The rates are made real by subtracting CPI inflation. GFC is a dummy variable taking the value of 1 for the years 2007-2009. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

Table 9: Model for the RER of Non-traded goods

	Fixed effects				Random effects			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
$RLprod$	**0.269****	**0.277*****	—	—	0.124	**0.138***	—	—
	(0.11)	(0.1)			(0.08)	(0.08)		
$Lprod_T$	—	—	0.197	**0.207***	—	—	0.096	0.107
			(0.12)	(0.12)			(0.09)	(0.09)
$Lprod_N$	—	—	**-0.387*****	**-0.393*****	—	—	-0.135	-0.152
			(0.14)	(0.14)			(0.11)	(0.11)
$RULC$	**0.356*****	**0.359*****	**0.441*****	**0.442*****	**0.332*****	**0.335*****	**0.344*****	**0.349*****
	(0.07)	(0.07)	(0.1)	(0.09)	(0.06)	(0.06)	(0.07)	(0.07)
LR	-0.0010	0.0048	-0.0010	0.0046	-0.0004	0.0051	-0.0003	0.0051
	(0.003)	(0.005)	(0.003)	(0.005)	(0.003)	(0.005)	(0.003)	(0.005)
$LR \times GFC$	—	**-0.0117****	—	**-0.0114****	—	**-0.0112****	—	**-0.0111****
		(0.005)		(0.005)		(0.005)		(0.005)
$R^2(adj.)$	0.47	0.48	0.48	0.49	0.78	0.78	0.79	0.79
N	214	214	214	214	214	214	214	214
HT					reject	reject	reject	reject

Notes: Dependent variable: log real exchange rate for non-traded goods (expenditure-weighted) expressed as the country i price level relative to EU15 (an increase is an appreciation). $RLprod_i$ is the log of the traded labor productivity relative to nontraded sector for country i ($realLabProd_{T,i,t}/realLabProd_{N,i,t}$) made itself relative with respect to EU15. $Lprod_T$ is the log of an aggregation of one-letter sectoral labor productivity of traded sectors using sectoral outputs as weights. $Lprod_N$ is an analog measure for nontraded sectors. $RULC_{it}$ is the log of an aggregation of sectoral level (single letter NACE rev. 2) nominal compensation of employees per hour worked for a country i as a ratio to the Producer Price Index and expressed relative to EU27. The nominal ULC involved in the calculations are sourced in euros for all countries. LR is a spread between the real long-run (10-year) bonds rate of each country relative to EU (EU19). The rates are made real by subtracting CPI inflation. GFC is a dummy variable taking the value of 1 for the years 2007-2009. The data sample period is 1999-2020. 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 (exept 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). Standard errors are in parenthesis. The estimate of the constant is not reported. Rejection of the null in the Hausman test (HT) implies a statistical difference between the FE and RE, viewed as a preference for FE.

6 Quantitative evaluation of the model

We now return to the theoretical model to explore the degree to which the model can account for the historical evolution of the real exchange rate, GDP and other macro aggregates in the Eastern European data. The model is extremely sparse - there are just two countries and two sectors in each country. There are no trade or financial frictions, and except for measures of the labor wedge, as described in Section 2 above, there are no other distortions. Preferences are homothetic, so differential income elasticities play no role in the baseline model. Thus, the exercise here should be seen as an exploration of the ability of a minimally parameterized general equilibrium model to account for the joint behaviour of real exchange rates and GDP in the region.

Our simulation strategy is to take the observed labor productivities by sector as in the data, for both regions, and use these as an input in the model. We then compare the model solution with the data for the full sample years. The measure of success of the model is represented by the degree to which the simulated model can fit the data, both in levels and changes over the sample years. We conduct this comparison for aggregate and sectoral real exchange rates, aggregate and sectoral GDP, and for the measure of relative unit labor cost, which represented an important explanatory variable in our above empirical estimates.

Table (10) reports the minimal calibration used for the model. All parameters and elasticities are identical across countries except for the labor wedge in traded goods as described below. The share of produced tradable goods in the retail traded goods consumption aggregate (for both home and foreign goods) is set at $v = 0.3$, following Burstein et al. (2003). Ω is set so that the share of the Traded goods share becomes 0.5 as is consistent with the data. The population share of Western Europe is set at $n = 0.78$, to match the data or relative population size. The elasticity terms λ, ψ,$and \mu$ are taken from Berka et al. (2018).

To come close to matching the data, it is important to take a stand on the size of the sectoral labor wedges. Our regression estimates indicate that sectoral labor productivity alone is insufficient to account for the movement in real exchange rates in the Eastern European data. The importance of the relative unit labor cost in the regressions suggests the need to allow for differential labor wedges across regions with the calibration. In reality, it is likely that there have been substantial labor market distortions in Eastern Europe, unrelated to measures of labor productivity. In order to allow for these distortions, we calibrate the labor wedge in the traded good sector in the home country so as to match the model solution for the relative unit labor cost in the initial period. In the baseline solution, this parameter is then kept constant for all years in the sample. Given this matching of the initial simulated RULC series with the data, we can then see how close the simulated series of real exchange rates and GDPs match those of the data.

Table 10: Model Calibration

	Parameter
$n = 0.78$	Size of Western European countries
$\Omega = 0.75$	Weight on traded goods
$v = 0.5$	Share of wholesale traded good in C_T
$\lambda = 8$	Elasticity of substitution between H and F retail traded goods
$\mu = 0.25$	Elasticity of substitution between traded good and retail service
$\psi = 0.7$	Elasticity of substitution between traded and non-traded good
$\sigma = 2$	Inverse elasticity of inter-temporal substitution
$\phi = 1$	Inverse Frisch elasticity of labor supply
$\alpha = \frac{1}{3}$	labor share (1 minus)

Impulse responses Figure (6) reports the theoretical impulse responses to shocks to the four key exogenous variables in the model. A rise in traded goods productivity leads to a rise in GDP and an exchange rate appreciation. A shock to non-traded goods productivity has a positive effect on GDP also but leads to a real exchange rate depreciation. A rise in Ψ_T, the home labor wedge in the traded sector, leads to a fall in GDP and a real exchange rate depreciation. A capital inflow θ leads to a simultaneous rise in GDP and a real exchange rate depreciation also.

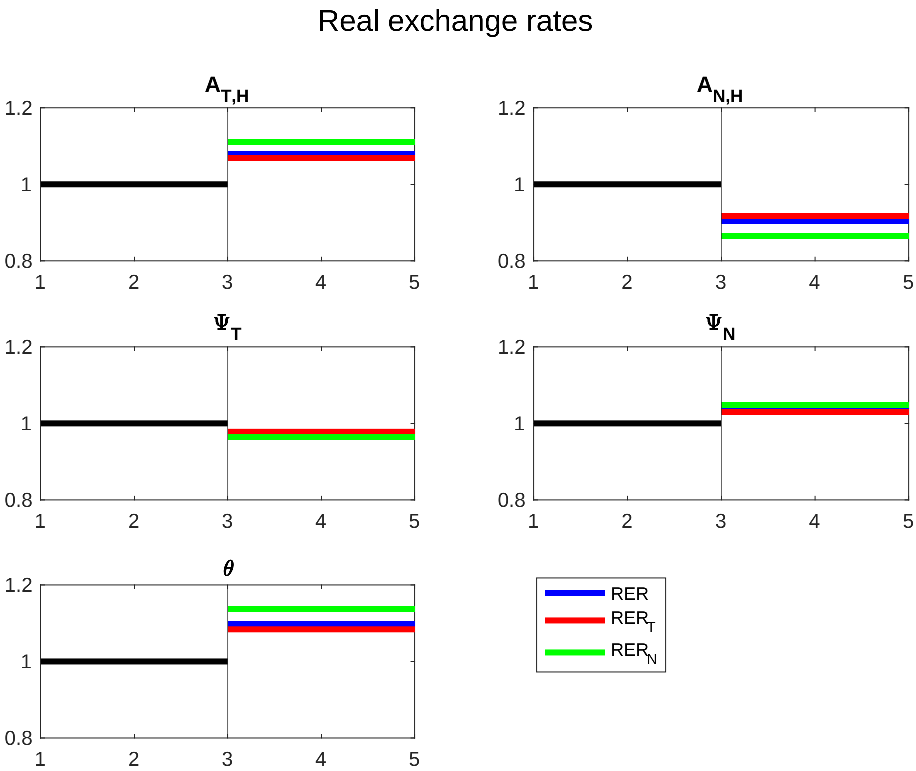

Figure 6: Response of Real Exchange Rate to shocks

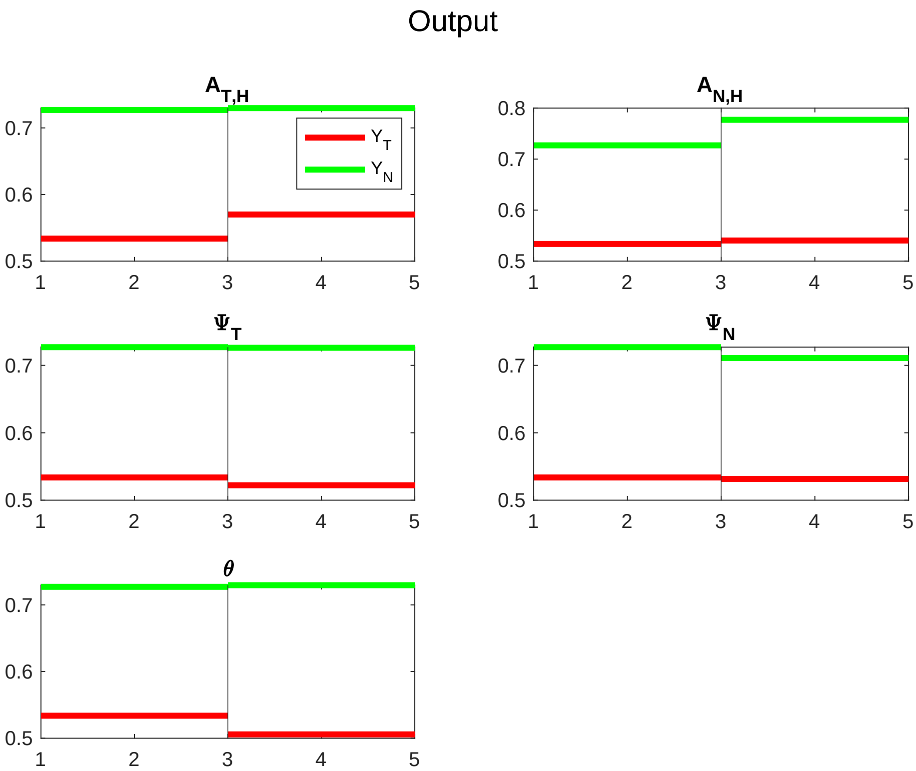

Figure 7: Response of output to shocks

Model Simulation We now simulate the model using the measured sectoral labor productivity series as proxies for $A_{T,H}$ and $A_{N,H}$ in the model. The model is solved period by period. In the baseline version of the model with assume $\theta = 0$, so there are no transfers from the foreign to the home country.

Figure (8) shows the results for the baseline case. The top left panel displays the data for labor productivity in the traded and non-traded sectors for Eastern Europe. Note that the scale in all panels in the Figure are the same, in each case indicating that the variable is measured relative to the EU27. For instance, the GDP panel shows that GDP per capita for Eastern Europe began at approximately 25 percent of the EU27 average. The simulated model matches closely the levels of aggregate and sectoral GDP as well as the overall real exchange rate and the sectoral real exchange rates. In the second from left top panel, we see that the model is surprisingly successful in matching the rapid rise in the real exchange rate and GDP at the beginning of the sample, and the subsequent leveling off in the real exchange rate (with some fluctuations) despite the continuing convergence in GDP. The key feature involved seems to be the rapid recovery in non-traded goods productivity after the GFC and EU crisis, relative to the relatively smooth growth in traded good productivity.

While Figure (8) assumes a constant labor wedge which is set to match the initial observed labor wedge. We explore an alternative hypothesis, by allowing for a time varying labor wedge. We take our direction from Berka and Devereux (2013), who show that among both Western European and Eastern European countries, the path of GDP alone explains a substantial share of the trends in relative real exchange rates in European countries. Accordingly, we set the path of the traded goods labor wedge so as to match the value of aggregate relative GDP over the sample. Figure (9)) illustrates the sample simulation results for the real exchange rate, the sectoral GDP and real exchange rates, and the relative unit labor costs. We see that adjusted in this way, the simulations obtain a significantly closer match to the sample data. While aggregate GDP is matched by construction, sectoral GDPs follow the data closely. In addition, the real exchange rate inferred from this simulation is almost identical to the historical sample path. Figure (11) (left hand panel) plots the inferred path of the traded good labor wedge underlying this simulation. We see that the wedge starts at a considerably elevated level, before dropping sharply in the early 2000's, and then fluctuating around a relative stable value thereafter. The fact that an addition of the inferred labor wedge improves the simulation fit of the model real exchange rate dovetails well with the regression estimates in Section 5 above, which suggest that the dynamics of the labor wedge (as part of the drivers of RULC) play a significant role in the real exchange rate trends in Eastern Europe.

As a final exercise we ask to what the degree the labor wedge alone can explain the real exchange rate movement over the sample. To this end, Figure (10) sets the relative sectoral productivity constant at their mean levels, and again sets the traded goods labor wedge so as to match the movement in relative GDP (in Figure (11 right hand panel). Here we see that the model still matches the average real exchange rates quite well, but misses out on the dynamics. The implied real exchange rate is too low in the early part of the sample, since the sample mean productivity in the traded goods sector is lower than that in the non-traded goods sector, and then the real exchange rate is too high in the later part of the sample, since the continuing convergence of relative GDP drives a greater than warranted real appreciation, without taking account of the fact that traded goods and non-traded goods productivity display equal growth rates after the GFC.

Figure 8: Model with observed productivities in traded and non-traded sectors

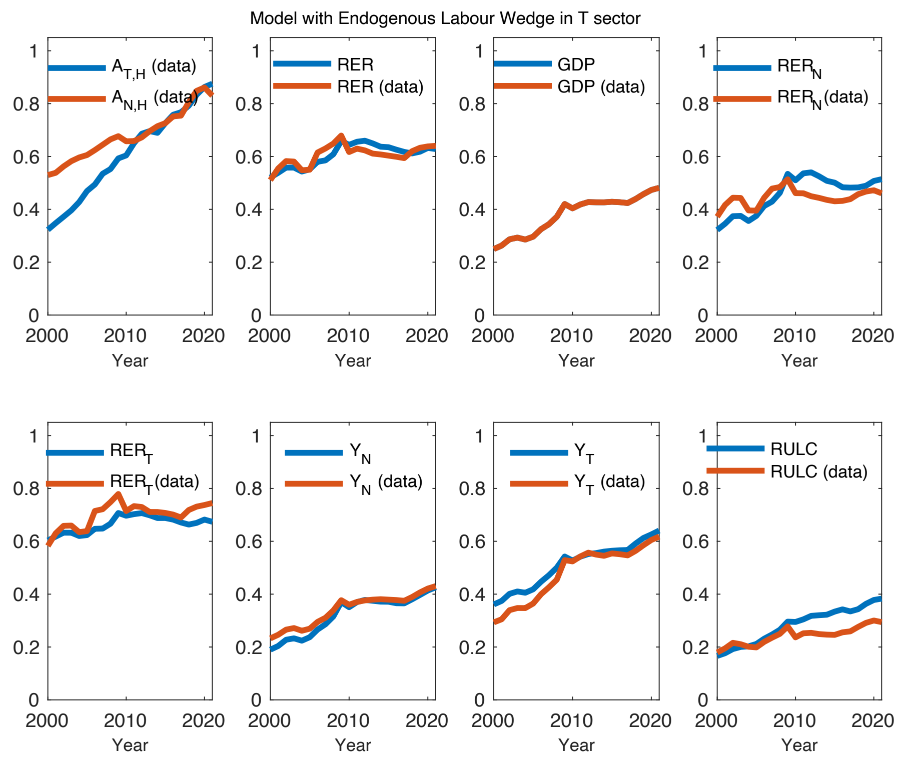

Figure 9: Model with observed productivities in traded and non-traded sectors and an endogenous traded sector wedge

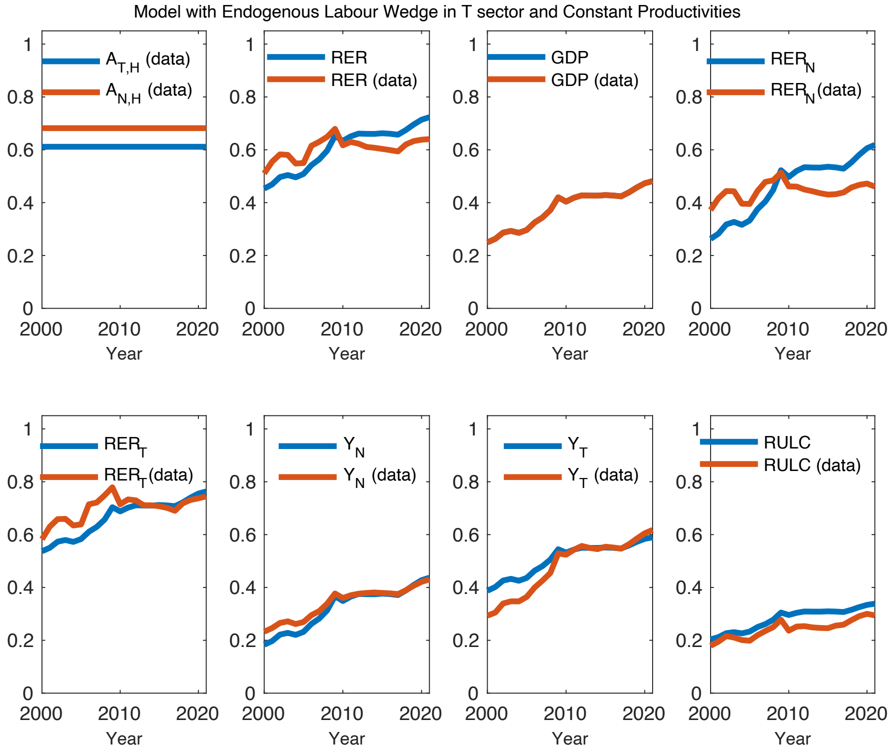

Figure 10: Model with constant productivities in traded and non-traded sectors and an endogenous traded sector wedge

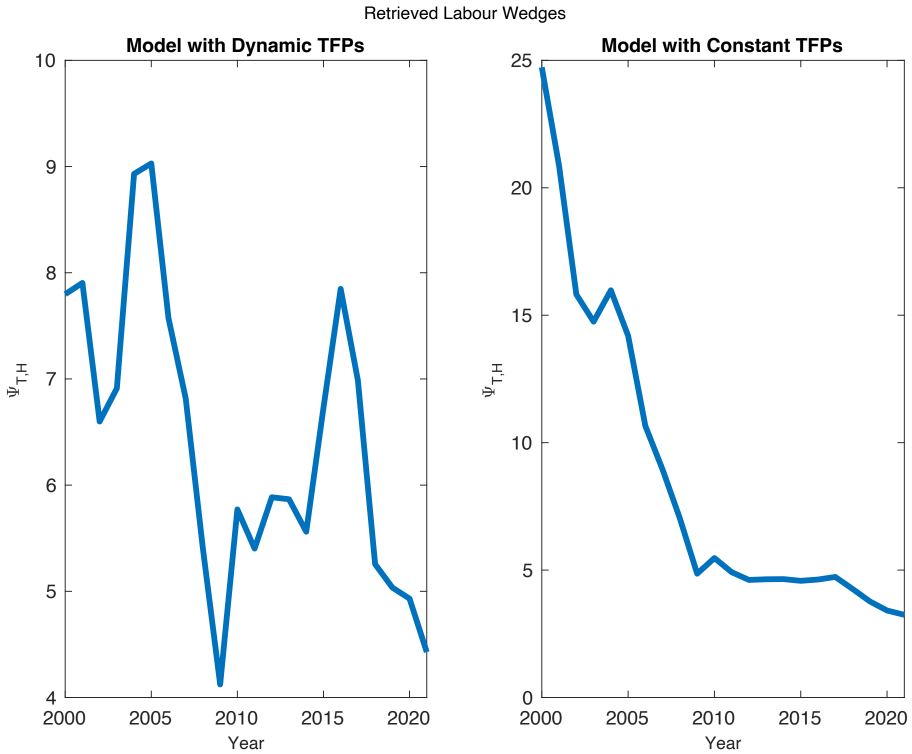

Figure 11: Retrieved labor wedges in traded sectors associated to models that target GDP

7 Conclusions

A large literature in international macroeconoimcs has focused on the understanding of high frequency movements in real and nominal exchange rates. A common conclusion from these studies is that it is hard to establish the relevance of fundamental based models of exchange rates, particularly among floating exchange rate countries. In the longer run, we expect to see real exchange rate appreciation in fast growing countries, consistent with the 'Penn Effect'. But evidence supporting the Penn effect is mixed. This paper focuses on longer run determinants of real exchange rates, and focuses on real exchange rate movements between countries of Eastern Europe relative to the EU as a whole. Some of these countries are pegged to the euro, while most others maintain stable exchange rates vis a vis the euro. We find support for the Penn effect, and the more specific Balassa Samuelson version of this relationship. But as documented in the introduction, there is a puzzle regarding the lack of convergence in the real exchange rate after the GFC. Our premilinary evidence suggests that movements in the labor wedge may explain this. Our model simulations provide encouraging support for this hypothesis.