World Technology Shocks and the Real Euro-Dollar Exchange Rate

Kyriacos Lambrias†

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Abstract

We analyse annual data on US productivity, Euro Area - US productivity differentials and the real euro-dollar exchange rate to extract information on a structural permanent world technology shock using a Structural Vector Autoregression (SVAR) approach with long-run restrictions. The main result is as follows: permanent shocks to world technology are the dominant source of fluctuations in US productivity growth as well as productivity differentials across the regions. Moreover, they significantly account for real exchange rate variations despite not being the dominant source of movements; a result that holds true under many different specifications and assumptions. This goes against other findings in the empirical exchange rates literature where "real" factors fail to play an important role in explaining real exchange rate movements and provides support to theoretical models that render an important role to real variables.

Keywords: Euro-Dollar Real Exchange Rate, Technology Shocks, Structural VAR.

CEL Classification: C32, E32, F41

† Toulouse School of Economics, Universite de Toulouse 1 - Sciences Sociales, Manufacture des Tabacs, 31042 Toulouse - Cedex, France. Email: kyriacos.lambrias@univ-tlse1.fr.

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1 Introduction

How important are common world-wide technology shocks in explaining fluctuations in real exchange rates and productivity? The aim of this paper is to address this issue in the context of the euro-dollar rate, using a Structural VAR (SVAR) approach with long-run restrictions.

The empirical literature on real exchange rates (RER) has long sought to identify those shocks that are the primal source behind their movements. In a seminal paper, Clarida and Gali (2004) use long-run restrictions à la Blanchard and Quah (1989) to identify relative supply, demand and monetary shocks and check their contributions to movements in four major currencies against the US dollar. They find that supply shocks have in general a very small effect on real exchange rates - less than 10% of the long-run variance. On the other hand, shocks to demand appear to be the most influential factor for exchange rate movements; so much that for horizons greater than 4 quarters the remaining variance of the log level of the real exchange rate that is not attributed to nominal shocks[1], "virtually all is attributed to demand shocks and virtually none is attributed to supply shocks" [2] . Farrant and Peersman (2006) effectively repeat Clarida and Gali (1994) exercise using data for the Euro Area (EA), UK, Japan and Canada versus the US but use sign restrictions as their identification method. They conclude that the important role of demand shocks in explaining RER movements is significantly reduced and nominal shocks appear to be much more relevant. Further, despite that the effect of real shocks is found to be significantly higher - ranging between 14-26% - yet they fail to be the prominent source of real exchange rate fluctuations. V. Lewis (2006) identifies economy-wide and sectoral *productivity* shocks in a structural analysis of the real euro-dollar rate with sign restrictions and finds that each of these shocks accounts for approximately 10% of its long-run variance. However, his results still suggest that demand and nominal shocks are the most influential even at long horizons. In contrast, Lastrapes (1992) finds an important contribution of "real" shocks to exchange rate movements and Meese and Rogoff (1988) find no evidence that models that specify the importance of sticky prices and monetary disturbances can adequately explain swings in

[1] Under their specifications, nominal shocks represent unpredicted changes in supply or demand for real money balances. Demand shocks, on the other hand, are unexpected changes to aggregate demand.

[2] Clarida and Gali (1994), p.35.

the real exchange rate; and consequently "one must seriously consider the possibility that real shocks play a major role".

Nevertheless, these papers have one thing in common: they emphasise on *country-specific supply shocks*; thus ignoring the effects of *common* shocks - where by common we mean a common stochastic-trend component of labour productivity shared by all economies involved - and the distinction between (labour) supply shocks and permanent changes in *technology*[3]. Hence, our contribution in this paper is twofold: first we check the importance of the commonality of world technology shocks on the euro-dollar real exchange rate and on productivity, and second we claim that we identify a *technology* shock that can permanently change productivity; rather than shocks that can permanently change the level of output or labour input but not both[4]. Shapiro and Watson (1988) distinguish between the effects of permanent technology shocks and permanent shocks to the labour input and find that the latter are more important in explaining output and labour movements at all frequencies. Rabanal et al (2008) explain that Total Factor Productivities (TFP) that are cointegrated with a cointegrating vector $(1 - 1)$ is a sufficient condition for a balanced growth path in a two-country world. In simulating a DSGE model with cointegrated TFP they show that they can match the observed real exchange rate volatility relative to output when conventional International Real Business Cycle (IRBC) models with stationary TFP processes do not. Moreover, Dupaigne and Feve (2009) show that in a VAR system estimated from aggregate G-7 data, aggregate employment *increases* in response to a world technology shock; thus casting doubts on Gali's (1999) famous result that employment decreases in the short-run after such an impulse. This is because "the labour productivity of the G-7 countries do cointegrate and display a single stochastic trend, interpreted as a non-stationary world technology shock"[5]. Also, this way of identifying *permanent* technology shocks - i.e. by using cointegrated productivities - is more immune to country-specific *stationary* disturbances. We use cointegrated productivities as a tool in identifying the permanent world technology shock. To the extent that permanent world technology shocks are large in magnitude, and to the extend that technology is used differently across countries, they will have effects on

[3]An exception is V. Lewis who claims to identify productivity (i.e. technology) shocks. However, using output in the VAR estimation blurs the identification of these shocks (Gali (1999)). This issue is explained in more detail in the next section.

[4]See Gali (1999).

[5]Dupaigne and Feve (2009)

macroeconomic variables at business cycle frequencies. Finally, our emphasis on common permanent changes in technology meets a vast literature seeking to identify common factors in IRBC (see for example Canova et al (2007), Kose et al (2003), Stock and Watson (2005))[6].

The paper that is more similar to ours is Ahmed et al (1993) in so far that they identify and quantify the effects of a world supply shock (among other shocks) using long-run restrictions in a SVAR system for the US and a five-nation OECD aggregate; but they do not check for technology shocks. Variance decomposition results show that the dominant shock for real exchange rate fluctuations is the demand shock, in line with Clarida and Gali (1994). The world supply shock explains 10.7% of the implied variability at one-quarter and 11.8% at 32-quarters horizon but country-specific shocks appear to matter more in the long-run (16.9%). Similarly, own-country supply shocks are more relevant in explaining output movements (66.8%) than common disturbances are (19.4%).

We estimate a SVAR model with US productivity growth, EA-US productivity differentials and the euro-dollar exchange rate using annual data from Upenn World Tables for the period 1970-2004. We extract information about three types of structural disturbances, but we are able to properly identify only one of them, namely a permanent world technology shock. Identification is achieved using the approach pioneered by Blanchard and Quah (1989) and employed by Shapiro and Watson (1988), Bayoumi and Eichengreen (1992), Ahmed et al (1993) and others. An important advantage of this approach is that we do not have to impose any restrictions on the dynamics. Rather, we use long-run restrictions which are in general less controversial (Ahmed et al (1993)); even though their empirical validity has often been questioned (Farrant and Perrsman (2006)).

From our analysis we derive two major conclusions. First, the world technology shock is extremely influential in explaining variations in US productivity growth ($84 - 87\%$), and less in explaining differences in labour productivity across the Atlantic ($53 - 57\%$). This is in line to various models of IRBC that find that common factors and real factors are very important for movements at business cycle frequencies. Second, despite that the

[6]Typically, factor models do not give any indications on what these factors are leaving one hungry for economic insights. However, Crucini et al (2008) find that "...productivity is the main driving variable for the common component of the business cycles among the G-7"; it explains around 47% of the common factor.

world technology shock fails to be a dominant source of real-exchange rate fluctuations, its contribution is still significant standing at 10.2% on impact and 21.8% in the long-run. Checks for robustness lead us to the conclusion that permanent innovations in technology can explain up to 40% of real exchange rate movements; numbers that in general stand above those found in the literature. Our results suggest that technology in particular and real factors in general can be very influential to exchange rate fluctuations at all horizons thus providing support to classical RBC models were real factors play a dominant role.

The next section describes the Blanchard and Quah (1989) methodology employed and our identifying restrictions. Section III discusses data and stationarity issues and Section IV provides the results. Section V concludes.

2 Methodology

In this section we describe the Blanchard and Quah (1989) approach and how it can be fitted to our case. We impose - and confirm using statistical tests - that the log of US productivity (X_t^{US}) is non-stationary in levels but stationary in first differences, whereas the other two variables of our system - log of EA-US productivity differentials ($X_t^{EA} - X_t^{US}$) and the log of the real euro-dollar exchange rate (q_t) are stationary processes. We assume that there are three types of disturbances in the economy, and our main identifying restriction is that only the "world technology shock" can have a permanent effect on the level of productivity. Similarly to Gali (1999), other shocks are allowed to permanently affect the level of output or employment but *not* both; making a technology shock distinguishable from any other shock that can have similar effects. The reader should also notice that since we impose that productivity differentials and the real exchange rate are stationary, no shock can permanently change their level. This blurs the identification of the other two shocks. The fact that we impose no restriction on the dynamics of the variables does not allow for an a priori determination of their origin. What we know about these shocks is that their either "non-technology shocks" (e.g. temporary supply shocks, demand shocks or nominal shocks) or they are "transitory technology shocks"[7]. The distinction between world permanent productivity and country-specific stationary productivity disturbances is

[7]The fact that we assume cointegrated productivities implies that any country-specific technology shock is necessarily transitory.

also found in Dupaigne and Feve (2009). However, Gali (1999) claims that "it is hard to understand how shocks to technology could be transitory, an observation which seems to conform with the failure to detect a significant transitory component in measures of Total factor productivity". In any case, the main aim of this exercise is to identify and qualify the effects of a world productivity shock and our identification restriction achieves that.

Letting $Y = (\Delta X_t^{US}, X_t^{EA} - X_t^{US}, q_t)'$ be the vector of endogenous variables and $\varepsilon = (\varepsilon_t, v_t^1, v_t^2)'$ be the vector of the world technology shock and two other unidentified shocks; then under standard regularity conditions each variable can be uniquely represented as an infinite distributed lag of these disturbances:

$$Y_t = A_0\varepsilon_t + A_1\varepsilon_{t-1} + A_2\varepsilon_{t-2} + ... \tag{1}$$

A_0 is the matrix of contemporaneous effects of the shocks on the endogenous variables, and thereafter $A_i \forall i \geq 1$ represent the effects at subsequent lags. The assumption that the shocks are uncorrelated implies that the variance-covariance matrix is diagonal, hence the assumption that $var(\varepsilon) = I_3$ is a simple normalisation. Our restriction that only the world technology shock can have a permanent effect on productivity implies that the second and third elements of the first rows of the sequence of A_i matrices sum up to zero:

$$\sum_{i=0}^{\infty} \alpha_{12i} = 0 \tag{2}$$

$$\sum_{i=0}^{\infty} \alpha_{13i} = 0 \tag{3}$$

For full identification, we need the long-run matrix to be lower-triangular. Thus, we need to impose a further restriction that the third element of the second row of the series of matrices A_i also sum to zero. Note that this restriction has no economic meaning since by stationarity of the differentials series; no shock can have a permanent effect.

$$\sum_{i=0}^{\infty} \alpha_{23i} = 0 \tag{4}$$

We show now how this structural representation can be retrieved from the data. Since Y follows a stationary process, it has a Wald decomposition:

$$
\begin{aligned}
Y_t &= e_t + B_1 e_{t-1} + B_2 e_{t-2} + ... \\
var(e) &= \Sigma
\end{aligned}
\tag{5}
$$

e_t represents the vector of reduced-form innovations. To convert equation (5) to the fundamental equation (1), we need to transform the innovations e_t into the structural shocks ε_t. Let the relation between the structural and the reduced-form innovations be linear, such that $e_t = C\varepsilon_t$ for some non-singular 3×3 matrix C. Comparing equations (1) and (5), we see that $A_0 = C$ and $A_1 = B_1 C$, $A_2 = B_2 C$ and so on, i.e. $A(L) = B(L)C$. Thus, knowledge of A_0 allows us to extract the structural shocks ε_t from the reduced-form innovations e_t and subsequently all A_j.

Is A_0 identified? A_0 has nine elements, thus we need nine restrictions to fully identify them. One can obtain six, using the relationship between the variance of the structural innovations (by assumption, the identity matrix) and the estimated reduced form variance as follows:

$$
var(e) = \Sigma \Rightarrow var(A_0 \varepsilon_t) = A_0 A_0^{'} = \Sigma \tag{6}
$$

The last three restrictions come from our identification restriction of a lower-triangular long-run matrix and hence from equations (2) - (4). This means that the matrix $(\sum_{i=0}^{\infty} B_i) A_0$ is lower triangular. Thus we can recover the structural system $A_1, A_2...$ and the world technology shock.

3 Data and Stationarity

Our sample consists of annual data from Upenn World Tables (PWT 6.3), for the period 1970-2004. The merit of using Upenn data is that they are homogeneous for all countries. Typically, studies using SVAR use quarterly data but using data on annual frequency has its own advantages. Since the workhorse of our model, i.e. that productivities are $(1 - 1)'$ cointegrated, is expected to hold true in the long-run or even at the steady state; lower frequency data might be better to look at. As Strauss (1996) puts it, simple "time disaggregation" from years to higher frequency is not likely to reveal long-run relationships. A similar argument holds for the real exchange rate. Stationarity of the real exchange rate

in levels is derived from purchasing power parity (PPP) which is a long-run relationship, hence annual data are more appropriate[8]. Finally, as Giannone et al (2008) point out, quarterly data for Europe are not very trustworthy and are only harmonised after 1991.

We define EA as the eleven countries that first joined the monetary union, and are those countries used in the Are-Wide-Model developed by Fagan et al (2001). These are Belgium, Germany, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Austria, Portugal and Finland. We constructed a productivity series for the EA by adding up Real GDP in 1996 International Dollars (code: RGDPL2) and divided by aggregate employment. RGDPL2 series from the Upenn World Tables is a measure of GDP per capita; thus we multiplied by population (code: POP) to obtain Real GDP in levels for each country. Thereafter, we summed up all the countries' entries to get a measure of EA Real GDP. For employment we use the employment index in the AWM. To transform quarterly AWM-data to annual we simply took the Q4 value for each year.

To estimate the real exchange rate we used values for the nominal rate of the "synthetic euro" from Datastream, whereas as a proxy of the price level we used data on consumer price indices. For the Euro Area data come from the AWM of the ECB - transformed from quarterly to annual frequency by simple averaging. For the US we used the annual consumer price index[9] available on the Bureau of Labour Statistics web-site. Note that the exchange rate is the value of one dollar in terms of the common European currency - thus an increase represents real euro depreciation. More details on the construction of the euro-dollar real exchange rate are found in the appendix. All variables are presented and analysed in log-levels, and hence first differences represent growth-rates. Graphs of all the series are presented in the end of the paper (Appendix I).

According to our specification, productivity in EA and US should be non-stationary integrated one processes who are mutually cointegrated. Graphs of the natural logarithm of both series are presented in Appendix I and both series exhibit an upward trend. For each series we conducted four different types of stationarity tests: the Augmented Dickey-Fuller test (ADF), the Philips-Perron test (PP), the Dickey-Fuller GLS test (DF-GLS) and the Kwiatkowski-Philips-Schmidt-Shin test (KPSS); the results of which are presented in the Appendix II. The null-hypothesis that the euro-area productivity has a unit root cannot

[8]Strauss, J. (1996).

[9]US City Average, non-seasonally adjusted.

be rejected by any of the first three tests mentioned above, with high p-values. However, the KPSS test rejects the null hypothesis of *stationarity* at 5% level but not at 1%. The results for the corresponding US series provide even more solid evidence for the existence of a unit root. The above, together with strong rejection of the unit-root once the series are differenced (not reported) support that the series are indeed $I(1)$.

The evidence on productivity differentials is less clear cut[10]. The ADF and PP tests reject the null hypothesis at 5% level, with a p-value equal to 3%. The cannot reject the null at any level and finally; the KPSS test accepts the null hypothesis of stationarity at 5% level. More importantly, Johansen Trace and Max Eigenvalue tests provide evidence for the existence of a single cointegrating vector at 5% level, and the null hypothesis that $\beta = (1 - 1)$ cannot be rejected with a high p-value. (see Appendix III). With that, our assertion of cointegrated productivities across the two regions gains strong statistical support.

Finally, we provide tests for the stationarity of the real exchange rate for the period 1970-2004. Whether the real exchange rate is a stationary process or not is not a conclusive issue in the empirical literature; and to some extent neither in the theoretical one. Intuitively, the real exchange rate should be stationary by virtue of the PPP[11]. Consequently, any test checking for unit roots in real exchange rates is equivalently a test for the empirical validity of the PPP; which it is known to be a rather contentious issue. Froot and Rogoff (1994) analyse a number of studies that empirically test real exchange rates as unit-root processes and conclude that "the most important overall lesson has been that the exchange rate appears stationary over sufficiently long horizons". Second, it seems that the null hypothesis of a unit-root is more difficult to reject in the post Bretton Woods period of floating - and rather volatile - exchange rates rather than under fixed exchange rate regimes[12]. There can

[10] According to Hamilton (1994), when the cointegrating vector is known the by far best method of checking for cointegration is to construct a series using the implied cointegrating relationship and check that series for stationarity.

[11] Note also the relation with our assertion of cointegrated productivities at a balanced growth path: if the only permanent shocks to technology are international and common in nature, then at the steady state marginal productivity of labour will be the same, wages will be the same and prices will be the same across countries.

[12] Lothian and Taylor (1994) when using only post Bretton-Woods data cannot reject the null hypothesis of a random walk for any real exchange rate series used, but that is "easily rejected"

also be theoretical reasons why deviations from PPP might be long and persistent, with the most prominent one being the Balassa-Samuelson effect (attributed to Balassa (1964) and Samuelson (1964)), especially in the short-run when the economy is prone to frictions[13]. Nevertheless, in our model we impose PPP in the long-run and that no shock can have permanent effect on the real exchange rate; with official tests giving mixed evidence to the latter. Even thought PP and KPSS provide evidence against stationarity at any level of confidence; the null hypothesis of a unit root is strongly rejected under the most powerful test - DF-GLS. Finally, the ADF test rejects the null hypothesis of a unit root at 10%.

Overall, stationarity results do allow us to construct a SVAR system as outlined in the previous section. The following section provides the results of this analysis.

4 Results from SVAR

In this section we analyse the Impulse Response Functions (IRFs) and the variance decompositions of the three variables in our system. We estimated a $VAR(1)$ model in reduced-form as chosen by both Akaike and Scwartz Information Criteria.

As explained above, our identification restriction asserts that only the world technology shock can permanently change US productivity. We name the other two shocks simply as shock 1 and shock 2, or "other shocks". Figure 1 presents the accumulated IRFs of US productivity growth to one standard deviation shocks. Since productivity growth is a stationary variable, no shock can have a permanent effect, thus accumulated responses demonstrate permanent changes in the level[14]. The level of US productivity increases in response to a permanent innovation in world technology, and follows a hump-shaped behaviour: initially it increases by 1.2%, reaches a peak after three-four years (1.5%) only to decrease thereafter and restore itself to its new long-run value at a level 1% higher than before the shock. Ahmed et al (1993) find that output peaks 30-quarters after a supply shock, i.e. seven-and-a-half years. The difference of our results to Ahmed et al (1993) cast doubts on whether the authors identify a world supply shock, a world technology shock or some strange mixture of both. Since the authors use output (growth) as one of

when the entire sample is used (100+ years).

[13]See for example a model developed by Rogoff (1992)

[14]Blanchard and Quah (1989).

their endogenous variables, then they cannot clearly distinguish between permanent labour supply shocks or technology shocks; since both can have permanent effects on the level of output[15]. Figure 2 provides the IRFs of the other two variables. The world technology shock is primarily felt in the American economy, since on impact the differentials series initially decreases by 1.2% before it reverts back to its long run (constant) level. Since the differentials series' IRF is almost a mirror image of the impact response of US productivity, one can conclude that the technology shock starts at the US and "spreads" to the EA with time[16]. This is of course detrimental to our assertion of a *"world"* technology shock; but one should not forget that in our case commonality stems from a common trend in the productivity series, one that the long-run leaves the two regions with the same level of productivity by virtue of cointegration. Indeed, as time goes by the response of the level of EA productivity increases, and a century later both series (EA and US level of productivity) increase by the same rate - 1.0%.

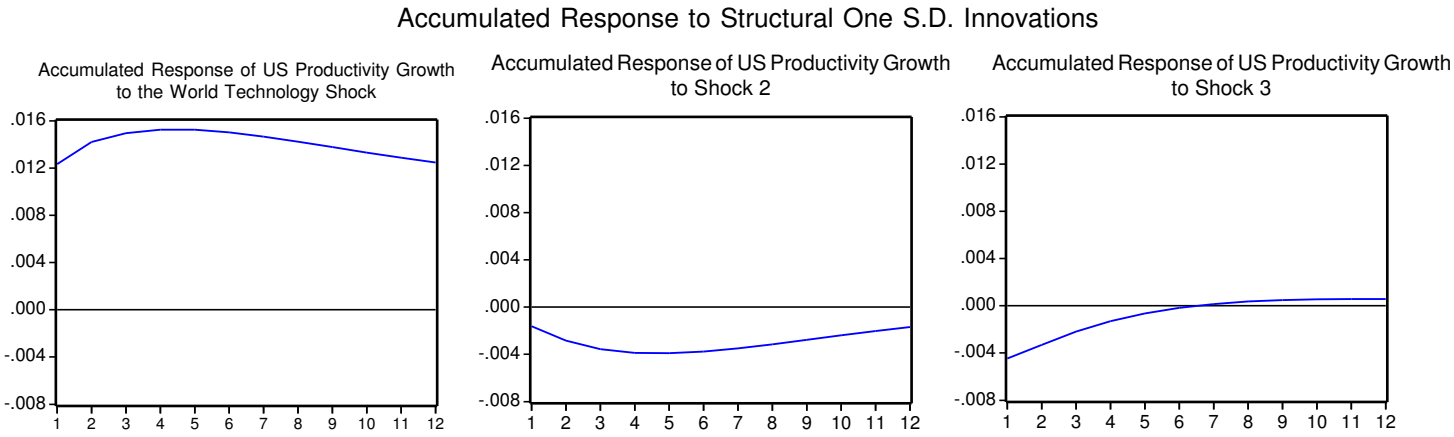

Figure 1: Accumulated IRFs of US Productivity Growth to Structural One Standard Deviation Innovations

Finally, we observe a Balassa-Samuelson effect in the real exchange rate since temporarily higher productivity in the US causes a real euro depreciation - even though the exchange rate goes slightly negative before mean-reverting to its long-run value. Alquist and Chinn (2002) find that "a one percentage point in the US-EA productivity differential results in a

[15]Gali (1999).

[16]IRFs of EA productivity in levels (not shown) confirm the latter.

five percentage point appreciation of the dollar"[17]. Interestingly, IRFs here imply a similar result where a 1.2% decrease in the EA-US differential (periods one and two) causes the euro to hit its lower value (higher in the graph) at 4.3% lower than its equilibrium level two years following the impulse.

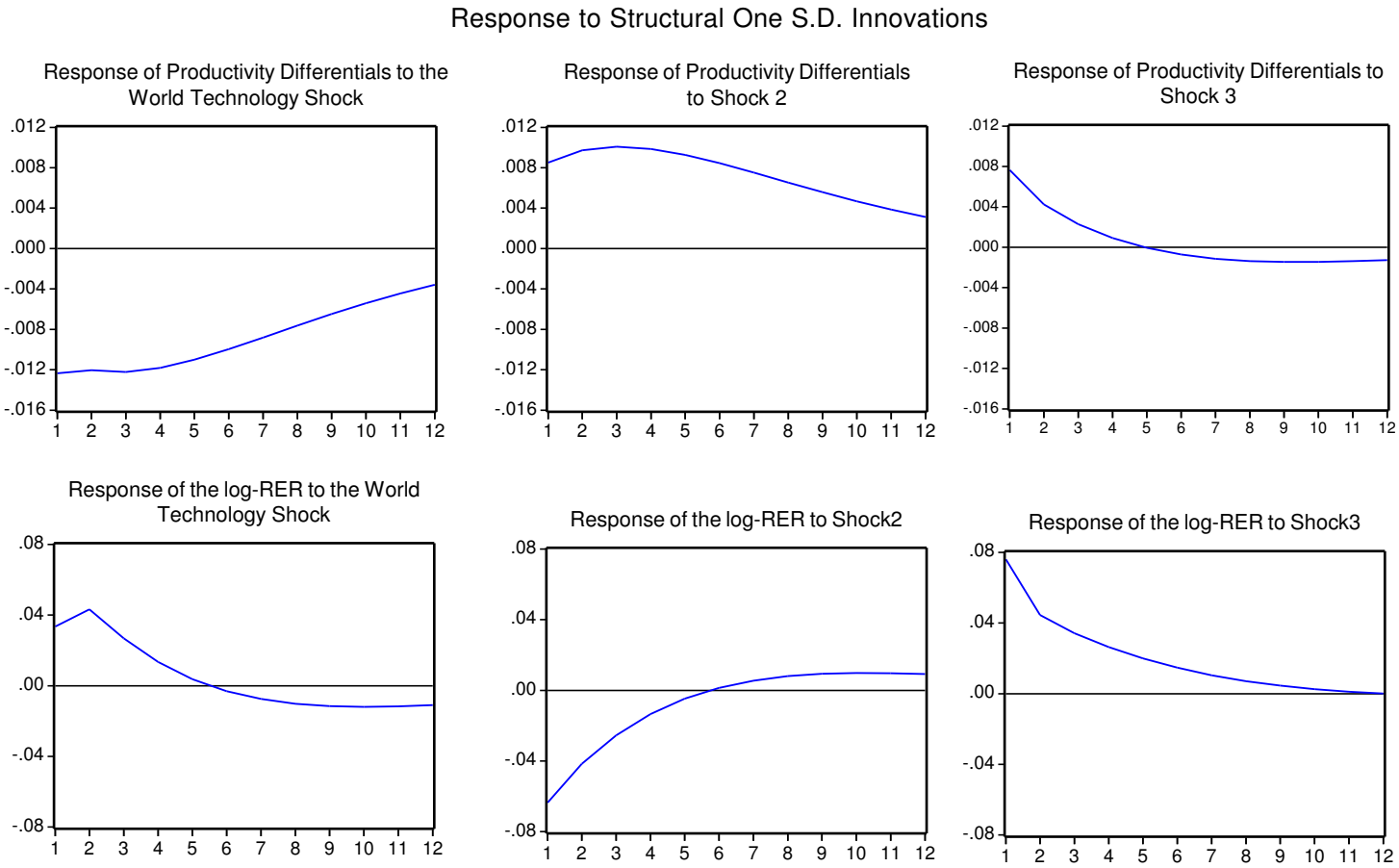

Figure 2: IRFs of log Productivity Differentials and the log of the Real Exchange Rate to Structural One Standard Deviation Innovations

We now move on to the analysis of the influence of the shocks to the variability of the underlying economic aggregates, which are reported in Table 1. The biggest portion of the variability in the US productivity series is explained by the permanent world productivity shock; 87.1% in the short run and 84.1% at longer horizons. This is in sharp-contrast to

[17]Schnatz et al (2003) find this number to be lower at 1.5-2.0%.

the minor importance Gali (1999) assigns to technology shocks in explaining US business cycles fluctuations, where non-technology shocks "are seen to have had a dominant role in postwar US fluctuations". Note that even though we did not properly identify the other two structural innovations in our system, they definitely do meet Gali's assertion of "non-technology shocks" - since in Gali (1999) all technology shocks are permanent. With that in mind, both of these shocks together explain only 13-16% of fluctuations in US productivity. Also, in V. Lewis (2006) despite that the domestic "economy-wide productivity shock" is the dominant in explaining movements in output, it is far below our estimated value (43.8%)[18]. Ahmed et al (1993) find a low contribution of the world supply shock in explaining output growth (19.4%) even though the overall effect of real shocks - world supply shock, domestic and foreign shocks to labour input - explain all together 90.9% of its long-run movements[19]. Furthermore, the world technology shock explains more than half of the varation in productivity differences across the Atlantic at all horizons; contributing 53.9% on impact and around 57% in the long-run. The significance of the common technology innovation in explaining variations in productivity is in line with IRBC models that find significant contribution of the common factor to business cycle fluctuations (Canova et al (2007), Kose et al (2003), Stock and Watson (2005)).

Moving on to the relative importance of the shocks to the real euro-dollar rate, we observe that common innovations in technology can explain 10.2% of the one-year variance in the forecast-error, 20.8% at 12 years and 21.8% in the very long-run (100 years). Compared to Clarida and Gali (1994) this effect is much larger, since they find that the supply shock explains only 1.6% of the variability in the level of the Deutche Mark (DM)-dollar exchange rate and 10.4% of its growth at 20 quarters (5 years) horizon. However, Farrant and Peersman (2005) find this number closer to our estimation - between 14-26% - whereas Ahmed et al (1993) show that the world supply shock explains 10.7% at one-quarter and 11.8% of the long-run variation in relative prices; thus significantly lower than ours but the domestic and foreign labour input shock explain together an additional 18.3%. Finally, V. Lewis (2006) who identifies economy-wide and sectoral *productivity* shocks finds that

[18]Even if why add to this the contribution of sectoral productivity shocks (31.1%) the overall effect of productivity stands at 74.9%.

[19]The reader should note that all these studies refer to the long-run effects on *output* whereas we check the effect on productivity.

Table 1: Variance Decomposition of the Endogenous Variables

Percentage of the Variance of US Productivity Growth due to:		
Years	World Technology Shock	Other Shocks
1	87.1	12.9
2	86.0	14.0
5	84.6	15.4
12	84.2	15.8
∞	84.1	15.9

Percentage of the Variance of log EA-US Productivity Differentials due to:		
Years	World Technology Shock	Other Shocks
1	53.9	46.1
2	55.1	44.9
5	57.0	43.0
12	56.9	43.1
∞	56.8	43.2

Percentage of the Variance of log Real Exchange Rate due to:		
Years	World Technology Shock	Other Shocks
1	10.2	89.8
2	18.1	81.9
5	19.0	81.0
12	20.8	79.2
∞	21.8	78.2

in one-year horizon their effect stands at 4% and 12% respectively; and 10% each in ten years. Obviously, the residual variability, which constitutes the biggest portion of the real euro-dollar rate (around 80%), is explained by shocks which can be either real or nominal, but definitely cannot change productivity permanently.

Overall, our results suggest that if we are indeed identifying a "pure" technology shock, despite it being the primal source of productivity movements in US as well as productivity differentials in the two regions; it fails to be the primal source of real exchange rate variations. However, the effect is in no case negligible since technology shocks account for more than one-fifth of the long-run euro-dollar real exchange rate variability. In general, this number stands higher than those found in similar studies in the literature, where real shocks explain between 10%-15%.

The latter might suggest two things. First, that real factors are indeed a significant - albeit not the dominant - source of real exchange rate movements providing more support on classical RBC models that emphasise the role of real variables for business cycles fluctuations. Second, it can also imply that our method of identifying a permanent technology shock provides more information about the nature of real shocks. That means that it might indeed be the case that supply shocks are heavily "contaminated" by shocks other than technology and as a result their potential effect on macroeconomic variables at business cycle frequencies is reduced.

5 Robustness

In this section we evaluate the robustness of our results to different modifications. In particular, we check the sensitivity to changing the first variable of the system to the EA productivity growth, to adding another endogenous variable in the system and to the definition of price and hence the real exchange rate, From now on, whenever the "benchmark case" is referred, we imply the SVAR system analysed in the previous section.

5.1 EA Productivity Growth

In this first robustness test, we check whether our results change when we include EA productivity growth instead of US as the first variable. If we are indeed identifying a

common productivity shock the results should not be altered dramatically - at least not in the long-run. Also, Fernald (2007) shows that impulse responses in VAR systems with long-run restrictions can be quite sensitive to low-frequency correlations that need not be causal. Thus, to the extend that non-causal low-frequency correlations between the two growth series and the exchange rate are different, we might expect to get different results. If, however, this statistical feature with no economic value does not influence much the impulses (and hence the contributions to variance) the results should not be very different under the two specifications.

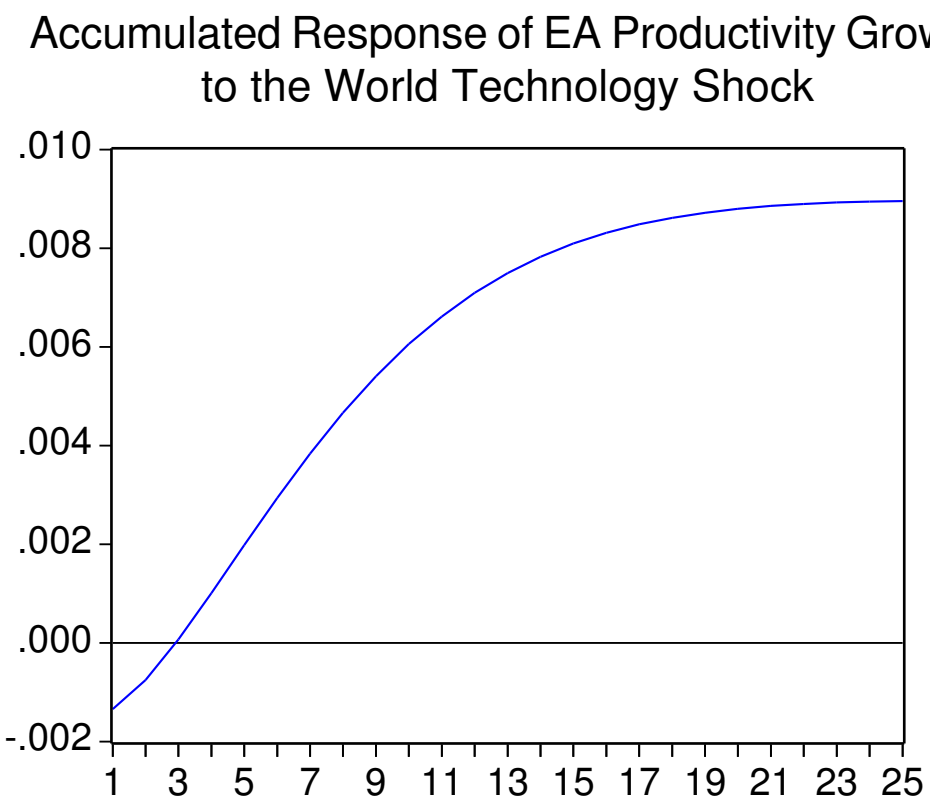

Figure 3: Accumulated IRF of EA Productivity Growth to Structural One Standard Deviation Innovations to World Productivity

Indeed, we observe some differences in the response of the EA and US productivity. Strangely, he effect of a world technology shock to EA productivity is on impact negative, albeit very small -0.1% (figure 3). Thereafter, the series increases monotonically untill it is restored to its new long-run level approximately 0.9% higher than before the shock.

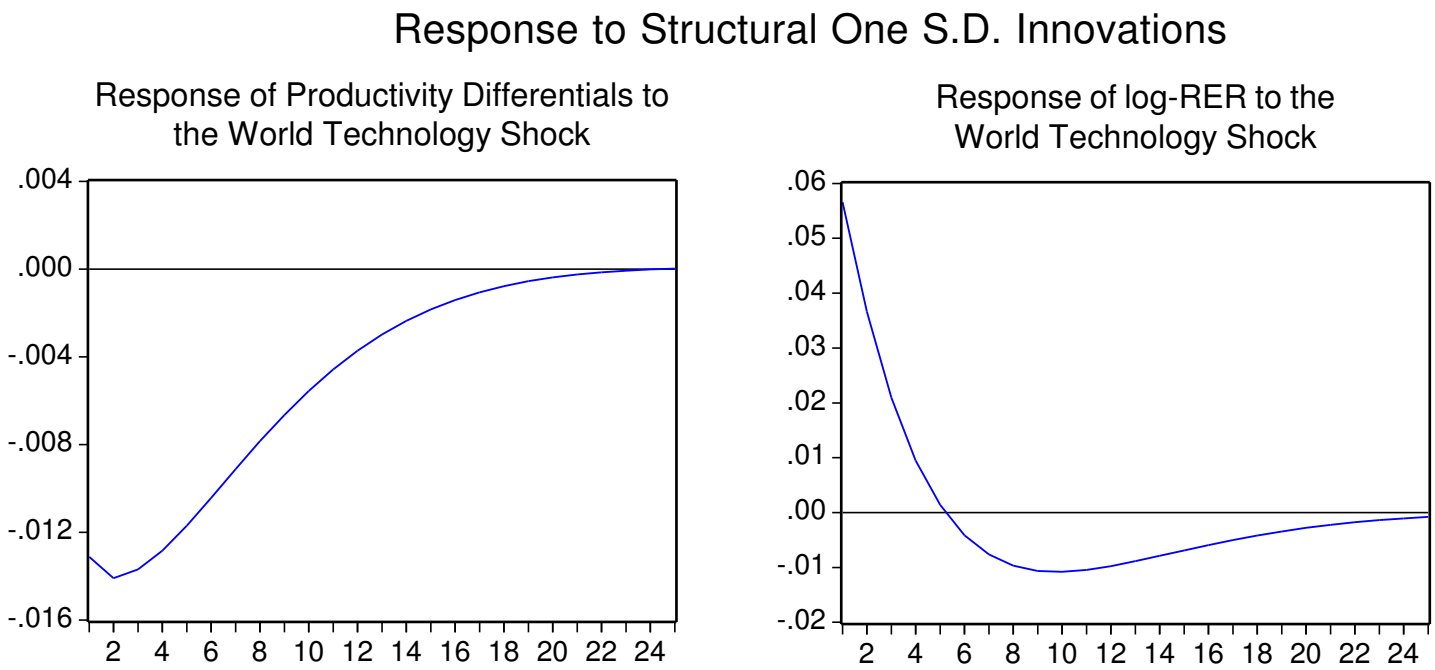

Figure 4:

Accordingly, the response of the differentials series is now -1.3%. Interestingly, the response of the real exchange rate is now higher at 5.6% higher on impact and the peak is reached immediately (figure 4); whereas in the benchmark case the lowest value for the euro is reached one year after at approximately 4% below its pre-shock level.

Table 2 provides a summary of results on variance decompositions under different attempts. For this case - Panel B of the table - we observe that a very low proportion of the variability in EA-productivity growth is explained by the world technology shock, at 11.4% in the long-run. Instead, the dominant shock is Shock 2 contributing 70.6%. The contribution of the world technology shock to the long-run variability of the differentials series is a bit higher than in the benchmark case around 63% at all horizons. On a more positive tone, contributions to the long-run variability of the real exchange rate are almost the same - see panel A of table 2 under specification 1. However at short horizons this is not the case. In one-year horizon, the world technology shock is the dominant one contributing 27.2% and 25.2% in the second year following the shock. The discrepancy in the contribution to short-run variations raises the first warning flags, even-though the results

Table 2: Variance Decomposition Under Different Specifications

Panel A: Percentage of the Variance of the Real Exchange Rate due to the World Technology Shock

Specification	1	2	5	12
1. EA Growth	27.2	25.2	21.4	22.3
2. Four Variables	12.1	16.6	13.9	16.0
3. Four Variables-VAR(2)	22.1	36.3	42.9	41.8
4. Price of GDP RER	33.0	35.9	36.7	36.1

Panel B: Contribution of the World Technology Shock to other selected Variables

Variable	1	2	5	12
EA productivity Growth	2.9	3.4	6.7	11.4
US productivity Growth under 4 variables	75.7	71.5	71.1	70.7
US productivity Growth under 4 variables VAR2	93.7	59.4	52.8	51.0
Interest Rate differentials	19.4	21.9	21.6	21.7
Interest Rate differentials - VAR(2)	0.8	0.9	2.5	2.9

with regard to long-run variability so far remain robust. With that in mind, we thereafter check the stability of our results to a 4-variables SVAR system.

5.2 Four Variables

We include the "short-term interest rates differential" as an additional variable to our initial specification since this can possibly capture differences in monetary policy behaviour across the two regions. Clarida and Gali (1994), Farrant and Peersmann (2006), Eichenbaum and Evans (1995) have shown that monetary policy shocks are very influential to real exchange rate movements. Further, interest rate differentials have a theoretical appeal in exchange rate determination[20]

We consider short-term interest rate differentials between US and Germany, instead of using some aggregate measure for Europe. The reason for doing so is twofold. First, common monetary policy for Europe does not exist before 1999, thus if we want to capture relative monetary policy shocks some aggregate measure of the interest rate would not make much sense. Second, Germany has always been a dominant country for fighting inflation in Europe. Clarida et al (1998) document "strong influence of the Bundesbank on monetary arrangements" within France, Italy and England. Also, it seems that these countries were following very closely German monetary policy even before the "hard ERM" period between $1990 - 92$[21].

Following Eichanbaum and Evans (1995) and Faust and Rogers (2003) we proxy the short term interest rates using the "Federal Reserve Overnight Effective Rate" for US and the "Money Market Frankfurt Banks Overnight Rate" for Germany; both at annual frequency[22]. The differentials series is stationary[23] and is included in levels in our system; not in logs. Note also that we use Germany-US thus an increase in the series represents a contractionary monetary policy shock in the EA. We also check with a lower frequency measure of the short term interest rates across the Atlantic namely the equivalent to the 3-Months rates to the above; again both transformed at annual frequency. Results (not reported) are not significantly different. Finally, we carried out our estimation using two-lags

[20] Frankel J. (2008)

[21] Clarida et al (1998)

[22] Our indicator for Germany is a bit different than these authors

[23] DF-GLS rejects unit root at 5% level.

in the reduced-form VAR as instructed by the Akaike Criteria.

Figure 5 presents the response functions of the interest rate differential and the log-level real exchange rate to the shocks; for the sake of brevity we omit the dynamic responses of the other two variables. Overall, the responses maintain the same sign but we observe differences in the magnitude when compared to the initial specification. US productivity growth responds positively to a one-standard deviation shock in world technology, but the response is slightly lower than the benchmark case. Similarly, the response of the differentials series preserves the negative sign (i.e. US productivity is increased by more).

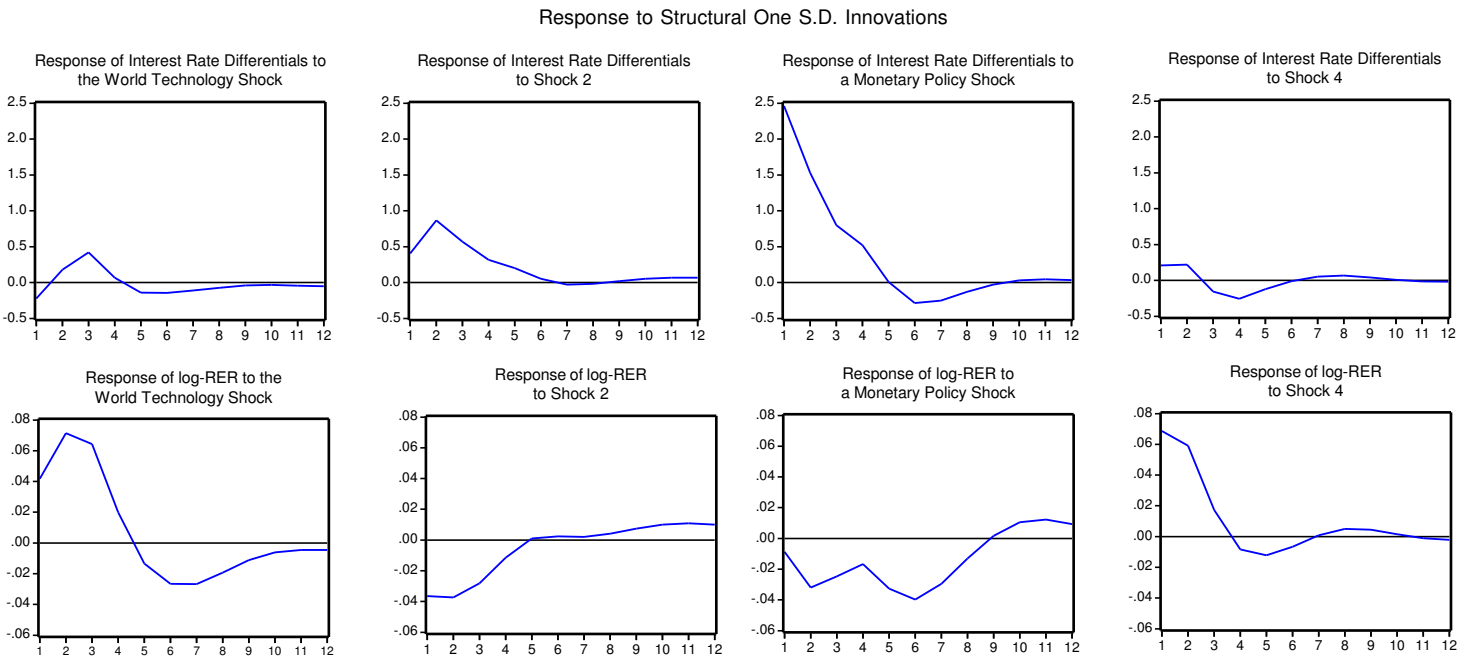

Figure 5: IRFs of Interest Rate Differentials and RER to Structural One Standard Deviation Innovations

Finally, the interest rate differential decreases in response to the world technology shock by a significant amount a bit more than 20 basis points. This difference is interesting, since both central banks are considered as "inflation hawks" and conduct monetary policy in a very similar manner especially for the period under consideration[24]. However, this would be consistent to the conventional wisdom that Bundesbank is more aggressive and reacts

[24]Clarida et al. (1998).

more to price changes than to output. A world productivity shock creates a boom in both countries, but of course the central bank that assigns more weight to output stabilization would increase interest rates by more. If indeed the Fed cares more about output than Bundesbank does, it increases the Fed rate by more and the differential series drops. Another possible reason for the latter is the fact that the world productivity shock is felt more in the US in the initial periods. Thus, output increases by more in US than in Germany and naturally the monetary authorities respond more aggressively. Nevertheless, Clarida et al (1998) find that the Fed is actually more responsive to inflation and less to output than Bundesbank is, contrary to this conventional wisdom. Also, it is puzzling that the interest rate difference *increases* in the years following the shock and peaks in period 3 where the differential stands at 42 basis points, this time higher for Germany. Again, a possible explanation can be Bundesbanks' aggressive reaction as the shock starts affecting Europe but a change in sign and the magnitude of this response are hard to justify.

The effects of a world technology shock in explaining movements in real exchange rates are amplified compared to the benchmark case (see Table 2 - Panel A under specification 4) by significant amounts at all horizons. On impact,the contribution to real exchange rate movements is increased significantly, at 22.1% compared to 10.2% initially found. The effect of a world technology shock increases with the horizon and at twelve years it reaches as high as 41.8% approximately twice as much as initially estimated. This is the highest contribution of the shock to long-run real exchange rate movements estimated in this paper. Even though a higher contribution of the technology shock can be a good thing if one believes that technology shocks are important, such big differences are bad for robustness of our results and can suggest that more is needed to the VAR to properly disentangle the effect of a common technology shock. Indeed, when we perform the same SVAR estimation with one lag - as chosen by the Schwartz Criterion this time - the contribution to variance appears to be significantly lower (see Table 2 - Panel A under specification 3) and at 12-years horizon it can explain 16.0%, which is lower than the 21% found in the benchmark specification. This sensitivity of the lag structure is of course bad for robustness of the results, but one should not forget that wherever the true contibution of permanent technology shocks to real exchange rate variability stands - between 16% to 42% - it is in general much higher than the effect of supply shocks estimated in other studies.

Concerning other variables, the effect of the shock on US productivity growth appears

to be lower by 10-12%. Similarly, the effect on the productivity differentials across the Atlantic is lower in this case. Finally, productivity shocks play little role in the determination of policy rates for both Germany and US; validating the perception that the monetary authorities of these nations are mostly inflation hawks (see Panel B, Table 2). However, under a VAR(1) system the latter is not true since it shows that around 20% of any discrepancy in monetary policy followed by the two countries is explained by permanent technology disturbances.

5.3 Different Measure for the exchange rate

In this section, we retain the exact same specifications for the first two endogenous variables of our system as in the benchmark case, but we use a different measure of the real exchange rate. Using different price indicators to construct the exchange rate can be important especially if there are significant differences in their composition of traded and non-traded goods. Betts and Kehoe (2006) document that the choice of price series matters and that "if the goal is to capture prices of traded-goods[] then production based measures are preferable to consumption based price". With that in mind, we use the "Price of GDP" available from the Upenn World Tables (code: P). More details on the construction of this measure of relative prices are provided in the appendix. Figure 6 which plots both exchange rate series depicts a major discrepancy at the beginning of the sample and up to 1980. Stationarity results are still doubtful as in the benchmark case with p-values for the ADF and PP test being 0.0454 and 0.1325 respectively [25]. DF-GLS rejects the null of a unit root at ten but not at five percent level and KPSS rejects the null of stationarity only at 10%.

IRFs are very similar so they are not analysed in detail for the sake of brevity. On variance decompositions, we observe that the contributions of the permanent technology shock to US-productivity growth is significantly decreased to 53.2% in the long-run whereas the effect on productivity differentials is largely unchanged. The most interesting results come, however, on the effect of the shock to real exchange rate variations where, as in the 4-variables SVAR system estimated above, the significance of permanent technology innovations is greatly magnified at all horizons. The contribution starts at 33.0% on impact - tripling the corresponding effect in the benchmark case - an at 12-years horizon this is

[25] One lag in first differences used for the ADF and two for the PP bandwidth

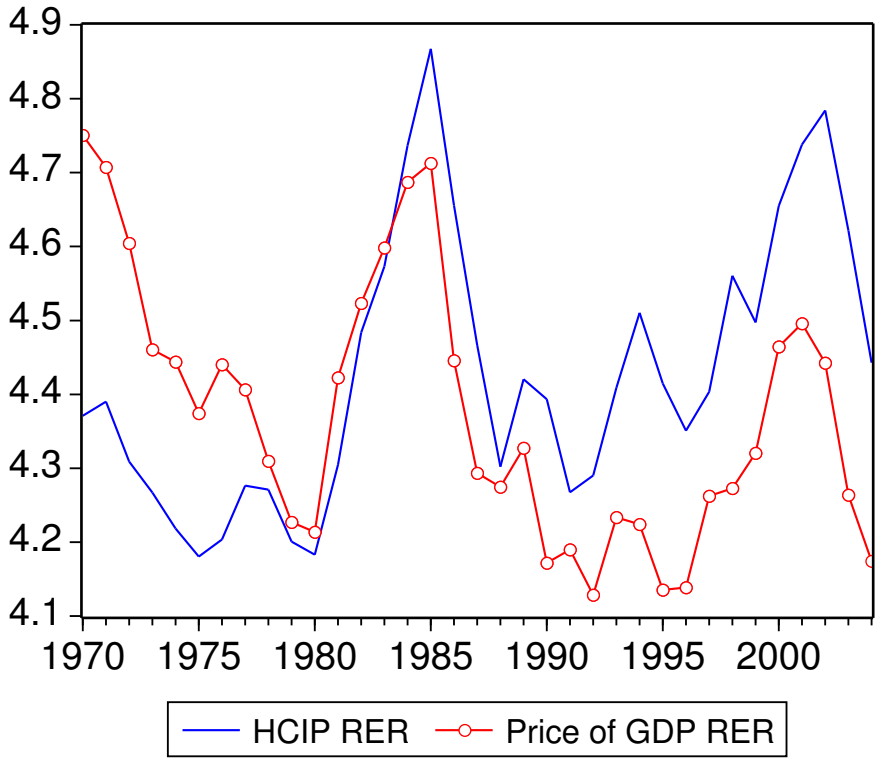

Figure 6: IRFs of to Structural One Standard Deviation World Productivity Innovations

even higher at 36.1% (see Table 2, Panel A nder specification 5). So, if using GDP instead of consumption deflators constitutes a more proper measure of relative prices across the two regions, our results suggest that permanent technology improvements coming from a common trend in the underlying country-productivity series account for more than one-third of the observed discrepancy in these relative prices. This provides even more support to macroeconomic models that emphasise the role of real variables on real-exchange rates and has even policy dimensions; in a sense that technology improvements can (or should) be taken seriously into account in monetary and exchange-rate policies.

Finally, we note that the results in this section are consistent with Bets and Kehoe (2006) who test the traditional theory that real exchange rate movements depend solely on variations in non-traded goods prices. They find that their preferred measure of traded goods prices - which is very similar to a GDP deflator - provides the most solid evidence for that theory whereas the results coming from the use of consumer price indices are less clear cut. Similarly here, the Balassa-Samuelson effect that higher (tradeble goods) productivity

dominates real exchange rate movements is more pronounced in variance decompositions of the GDP deflated real exchange rate than in the benchmark case.

6 Conclusions

This paper has used a structural macroeconometric model to study the influence of a common, worldwide, permanent shock to productivity on own-country productivities and most importantly on the euro-dollar real exchange rate over the period 1970-2004. We derive a model with long-run restrictions and we assume cointegrated productivities across EA and the US, with $(1-1)$ cointegrating vector; a sufficient condition for a balanced growth path in a two-country world. Also, we assume that the log level of the real exchange rate is stationary by virtue of the PPP. Both assumptions are tested with statistical methods.

Our results suggest that the world technology shock is extremely important in explaining US productivity growth over the sampling period - more than 84% at all horizons - and the EA-US productivity differentials (53%-57%). Moreover, world technology disturbances are very influential, albeit not dominant, in explaining movements in relative prices across the two regions. In particular, 10.2% of the one-year forecast variance of the euro-dollar exchange rate and 21.8% of its long-run variability are explained by the world productivity shock. Robustness checks lead us to the conclusions that the contribution of permanent world technology shocks on real exchange rate movements can go as high as 40% in the long-run and 30% in the short run. This finding stands in contrast with other studies that follow - and confirm - the Clarida and Gali (1994) paradigm that real factors fail to be an important source of variations in real exchange rates and consequently casts doubts on theoretical models that assign an important role to frictions. Further, our results are suggestive that our method of identifying permanent technology disturbances - using cointegrated productivities - uncovers sources of real exchange rate movements that were possibly not well identified in previous studies. Equivalently, it suggests that supply shocks do not capture very well technological innovations, as they might be significantly "contaminated" by other type of disturbances that constitute, in the words of Chari et al. (2009), a "labour wedge".

Hence, this work can suggest two lines of further research that could move in parallel. First, the debate whether real or nominal factors are the prime source of real exchange rate movements goes on and one cannot confidently exclude any of the two. Second, more

research is needed into properly identifying and decomposing technology shocks from structural VARs. Obviously, clearer evidence on the latter will help in answering the former.

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7 Appendix I

Real Exchange Rate: The series of the euro-dollar real exchange rate was constructed using values of the nominal "synthetic" euro, provided by Datastream and consumer prices indices from the AWM for the Euro Area and the Bureu of Labour statistics or the US. The AWM Harmonised Consumer Price Index (HCIP) provides aggregate price data for eleven European countries at quarterly frequency, seasonally adjusted. The series was converted to annual frequency by simple averaging of the quarterly data. The US price series used concerns US-city average HCIP data, non-seasonally adjusted. The base of the real exchange rate index are the years 1982-84.

When "Price of GDP" was used as the relevant price index, price data were taken from Upenn World Tables (series P). Series P itself was taken to be the euro-dollar real exchange rate. According to the appendix for Upenn data: "Price Level of GDP (P) is the PPP over GDP divided by the exchange rate times 100. The PPP of GDP or any component is the national currency value divided by the real value in international dollars. The PPP and the exchange rate are both expressed as national currency units per US dollar. The value of P for the United States is made equal to 100."[26] According to the same source, the nominal

[26] http://pwt.econ.upenn.edu/Documentation/append61.pdf

exchange rate is derived from "UN and World Bank sources, [and is] usually the same as the IMF annual rate". Then I constructed an index where the average value between 1982-84 is equal to 100.

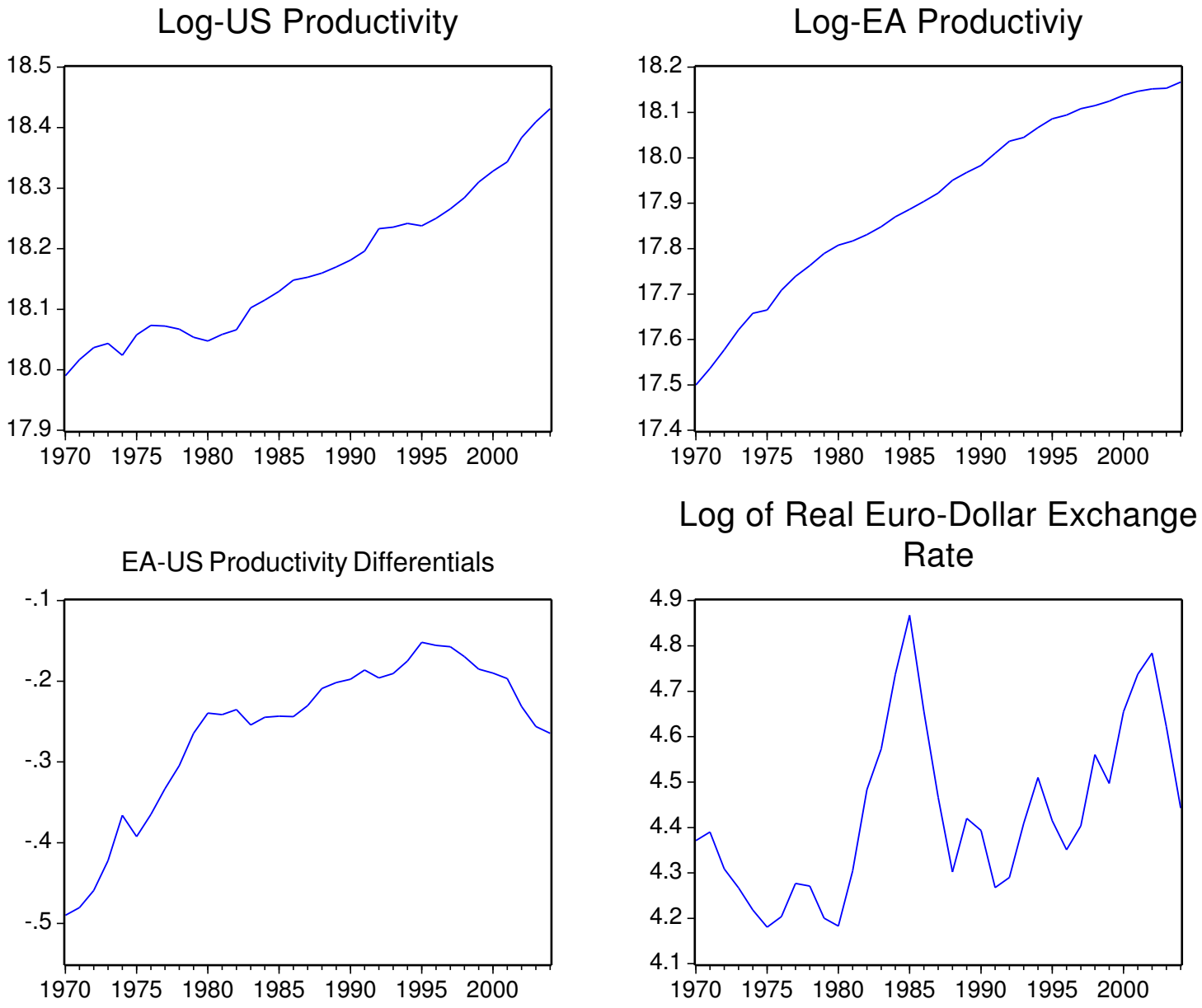

Figure 7: Data Series

8 Appendix II

Table 3: Stationarity Tests for the log EA Productivity

	Test			
	ADF	Philips Perron	DF-GLS	KPSS
Null Hypothesis:	Series has a unit root	Series has a unit root	Series has a unit root	Series is Stationary
t-Statistic	-1.9888	-2.024042	-1.010398	0.193466
Test Critical value				
1%	-4.262735	-4.252879	-3.770000	0.216000
5%	-3.552973	-3.548490	-3.190000	0.146000
10%	-3.209642	-3.207094	-2.890000	0.119000
p-value	0.5857	0.5678	-	-

Tests include trend and an intercept. We used one lag in first-differences for the ADF DF-GLS.PP and KPSS bandwidth were set to 3 and 4 respectively, as per the Newey-West Bandwidth.

Table 4: Stationarity Tests for the log US Productivity

	Test			
	ADF	Philips Perron	DF-GLS	KPSS
Null Hypothesis:	Series has a unit root	Series has a unit root	Series has a unit root	Series is Stationary
t-Statistic	1.751487	1.905274	1.560532	0.692353
Test Critical value				
1%	-3.646342	-3.639407	-2.636901	0.739000
5%	-2.954021	-2.951125	-1.951332	0.463000
10%	-2.615817	-2.614300	-1.610747	0.347000
p-value	0.9995	0.9997	-	-

Tests include an intercept. We used one lag in first-differences for the ADF and DF-GLS.

PP and KPSS bandwidth were set to 4 and 5 respectively, as per the Newey-West Bandwidth.

Table 5: Stationarity Tests for the EA-US log Productivity Differentials

	Test			
	ADF	Philips Perron	DF-GLS	KPSS
Null Hypothesis:	Series has a unit root	Series has a unit root	Series has a unit root	Series is Stationary
t-Statistic	-3.147770	-3.180216	-1.076427	0.537573
Test Critical value				
1%	-3.646342	-3.639407	-2.636901	0.739000
5%	-2.954021	-2.951125	-1.951332	0.463000
10%	-2.615817	-2.614300	-1.610747	0.347000
p-value	0.00326	0.0300	-	-

Tests include an intercept. We used one lag in first-differences for the ADF and DF-GLS.

PP and KPSS bandwidth were set to 2 and 5 respectively, as per the Newey-West Bandwidth.

Table 6: Stationarity Tests for the log Euro-Dollar Real Exchange Rate

	Test			
	ADF	Philips Perron	DF-GLS	KPSS
Null Hypothesis:	Series has a unit root	Series has a unit root	Series has a unit root	Series is Stationary
t-Statistic	-2.828014	-2.123345	-2.866862	0.341840
Test Critical value				
1%	-3.646342	-3.639407	-2.636901	0.739000
5%	-2.954021	-2.951125	-1.951332	0.463000
10%	-2.615817	-2.614300	-1.610747	0.347000
p-value	0.0653	0.2372	-	-

Tests include an intercept. We used one lag in first-differences for the ADF and DF-GLS.

PP and KPSS bandwidth were set to 2 and 4 respectively, as per the Newey-West Bandwidth.

9 Appendix III

Table 7: Cointegration Tests for EA-US Productivities

Tests' P-Values		
Number of cointegrating vectors	Trace	Max Eigenvalue
0	0.0005	0.0022
1	0.0516	0.0516
Restriction: $\beta = (1 - 1)$		
Number of cointegrating vectors		P- Value
1		0.217450

Tests were conducted by assuming that the data series exhibit no deterministic trend and by including a constant in the cointegrating vector We used one lag in first differences.