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Productivity and the ('synthetic') euro-dollar exchange rate

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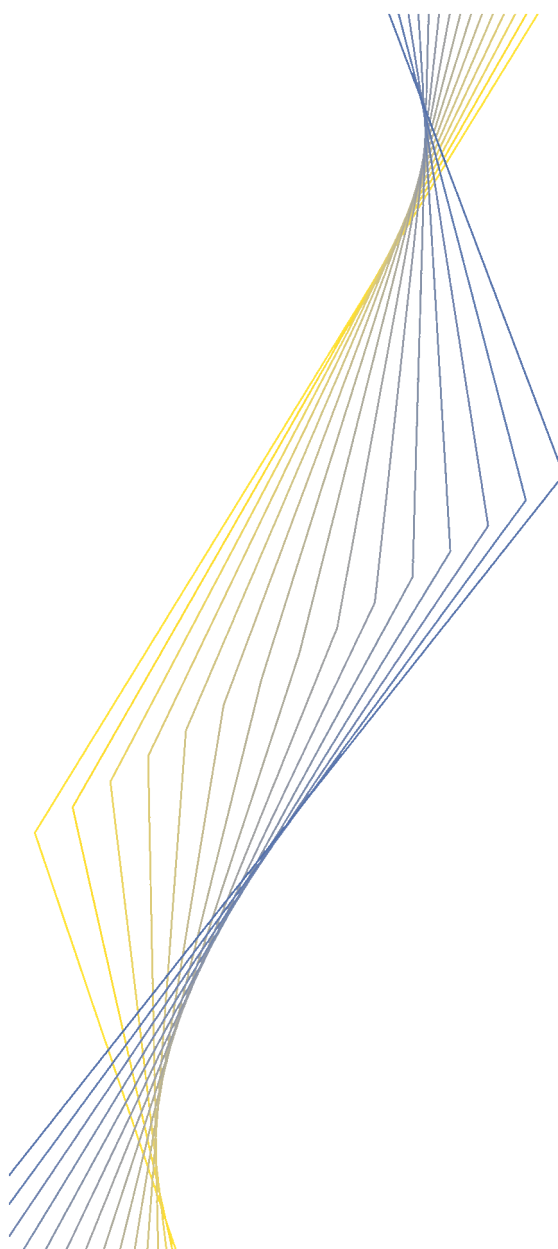
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**BY BERND SCHNATZ²,
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Abstract: This paper analyses the impact of productivity developments in the United States and the euro area on the euro-dollar exchange rate. The paper presents a new measure of relative average labour productivity (ALP), which does not suffer from the biases implicit in readily available relative ALP data. Importantly, the patterns of these series differ widely. Employing the Johansen cointegration framework, four Behavioural Equilibrium Exchange Rate models are estimated using four different productivity proxies. Our results indicate that the extent to which productivity can explain the euro depreciation varies with the productivity proxy used: readily available measures explain most, our new, preferred measure least. If foreign exchange traders used the former to assess productivity developments, this might thus have contributed to the weakness of the euro in 2000/2001. In all models, however, productivity can explain only a fraction of the actual euro depreciation experienced in 1999/2000.

JEL classification: F31, C32, O47.

Keywords: real exchange rate, euro, US dollar, average labour productivity, BEER, cointegration.

Non-technical summary

The real exchange rate of the (“synthetic”) euro vis-à-vis the dollar has declined markedly in the period from 1995 to 2002. This decline has often been associated with relative productivity developments of the United States and the euro area over this time span. In particular, average labour productivity (ALP) accelerated in the United States, while it decelerated in the euro area.

Economic theory suggests that the equilibrium real exchange rate will unambiguously appreciate following an actual or expected shock in ALP in the traded goods sector. Such an equilibrium appreciation may be intensified in the medium term by demand side effects. In particular, productivity increases raise expected (future) income, which leads to an increased demand for goods. The increase in demand for traded goods can be satisfied by running a trade balance deficit. The increased demand for non-traded goods, however, will lead to an increase in prices of non-traded goods instead. Thus, demand effects lead to a relative price shift and thereby to a real appreciation. A productivity shock also generates a rise in the real interest rate differential and capital inflows, which will also lead to a real appreciation. Overall, however, it is difficult to determine a priori the magnitude of the impact of a rise in productivity on the real exchange rate.

Some recent empirical studies suggested that the productivity increase in the United States would have indeed facilitated an appreciation of the dollar vis-à-vis the euro. However, this paper argues that the euro’s persistent weakness experienced in 2000/2001 cannot be explained on the basis of trends in productivity differentials. The paper analyses in detail the impact of relative productivity developments in the United States and the euro area on the euro-dollar exchange rate. It focuses thereby on relative ALP developments, a focus which is shown to be consistent with theory. It presents a new measure for ALP, which does not suffer from the biases inherent in readily available productivity proxies. In particular, two potential sources of bias in comparing direct ALP measures between the euro area and the United States can be identified, which both apply to relative labour productivity measures based on the most readily available data.

The labour productivity measure that is most widely used for the United States is based on non-farm business sector output per hour, while for the euro area GDP per person employed is generally used. Using non-farm business output for the United States and GDP for the euro area creates a bias in productivity developments for two reasons. First, the different treatment of the government sector in the two output series biases euro area ALP growth downwards vis-à-vis the United States. A second source of downward bias is introduced by the use of persons employed as a denominator for the euro area as opposed to hours worked in the United States. This practice fails to take into account the trend decline in the average annual hours worked in the euro area, which was not matched by a similar decline in the United States, implying another source of downward bias of euro area ALP growth vis-à-vis the United States. In order to avoid these biases, we use in our newly constructed measure of relative productivity internationally comparable data on real GDP per hour worked.

This paper then provides evidence on the long-run relationship between the real euro-dollar exchange rate and various productivity measures, controlling for the real interest rate differential, the real price of oil, and relative government spending in a Behavioural Equilibrium Exchange Rate framework (BEER). A BEER effectively involves reduced form modelling of the exchange rate based on standard cointegration techniques. As a first and striking result, it appears that the estimated elasticities of the direct productivity variables in particular, are virtually the same. This could suggest that it is unimportant which measure is used for calculating the impact of productivity on the real exchange rate. However, the developments of the different measures of direct ALP since 1995 differ widely. This implies that our new, and preferable measure of ALP can explain only a small fraction of the euro depreciation against the US dollar since the mid-1990s (about 18% of the actual depreciation). Accordingly, productivity cannot explain the weakness of the euro vis-à-vis the US dollar in 2000/2001. This outcome is confirmed by a specification based on an indirect productivity measure.

Importantly, however, the direct productivity variable commonly available for market analysts would suggest a much stronger depreciation (up to 41% of the actual depreciation). To the extent that traders in foreign exchange markets acted in response to the readily available productivity data, they would have assessed developments in the euro area relative to the United States on the basis of the “wrong” indicator. This may have contributed to the weakness of the euro vis-à-vis the US dollar in 2000/2001, as *perceived* euro area productivity growth may have been weaker than its *actual* development.

1. Introduction

From the first to the second half of the 1990s, average labour productivity accelerated in the United States, while it decelerated in the euro area. This asymmetry has stimulated a discussion on the relationship between productivity and the appreciation of the US dollar vis-à-vis the euro. Bailey et al. (2001), for instance, argue that a structural improvement in US productivity increased the rate of return on capital and triggered substantial capital flows to the United States which might explain at least part of the sizeable appreciation of the US dollar. Moreover, these capital inflows may also reflect consumption smoothing motives in periods characterised by a perception of higher future growth. Tille et al. (2001) confirm empirically that developments in relative labour productivity can account for part of the change in the external value of the US dollar over the past three decades. More strikingly, Alquist and Chinn (2002) argue in favour of a robust correlation between the euro area–United States labour productivity differential and the euro-dollar exchange rate, which would explain the largest part of the euro’s decline vis-à-vis the US dollar.

This paper argues that the euro’s persistent weakness in 2000/2001 cannot be explained by taking into consideration productivity differentials. In particular, the paper analyses in detail the impact of relative productivity developments in the United States and the euro area on the euro-dollar exchange rate. It discusses practical arguments for using labour productivity as a measure of productivity in the context of exchange rate models, and shows that this preference is consistent with theory. However, the use of different labour productivity proxies gives rise to potential incongruity among different approaches. This incongruity is directly related to the particular measure of labour productivity used in comparisons between the euro area and the United States. In particular, estimated elasticities appear to be quite similar among the different productivity measures applied in the paper. However, when these elasticities are applied to a newly constructed and more accurate measure of relative labour productivity developments (relative GDP per hour worked), it appears that relative productivity developments cannot account for the weakness of the euro vis-à-vis the US dollar in 2000/2001.

This study is organised as follows: the next section explains the relationship between productivity advances and the real exchange rate from a theoretical perspective. Subsequently, section 3 discusses different measures of productivity and motivates the choice of average labour productivity as our preferred direct measure of productivity. This section also describes the data used in the empirical analysis in detail. Section 4 analyses the relationship between euro area-US productivity differentials and the euro-dollar real exchange rate. Section 5 summarises the results and concludes.

2. The real exchange rate and productivity developments

The theoretical relationships that link fundamentals to the real exchange rate in the long-term centre around the Balassa-Samuelson model, portfolio balance considerations as well as the uncovered (real)

interest rate parity condition.¹ This paper will focus on the role of productivity differentials in the determination of the euro-dollar exchange rate. This is done in a Behavioural Equilibrium Exchange Rate (BEER) framework, as we need to control for the potential influence of other fundamental factors when conducting the empirical analysis. As a consequence, other fundamentals will be employed as control variables in the empirical part of the paper.

According to the Balassa-Samuelson framework, the distribution of productivity gains between countries and across tradable and non-tradable goods sectors in each country is important for assessing the impact of productivity advances on the real exchange rate. The intuition behind the so-called Balassa-Samuelson effect is rather straightforward: assuming, for the sake of simplicity, that productivity in the traded goods sector increases only in the home country, marginal costs will fall – *ceteris paribus* – for domestic firms in the traded-goods sector. This leads – under the perfect competition condition – to a rise in wages in the traded goods sector at given prices. If labour is mobile between sectors in the economy, workers shift from the non-traded sector to the traded sector in response to the higher wages, thus triggering a wage rise in the non-traded goods sector as well, until wages equalise again across sectors.² However, since the increase in wages in the non-traded goods sector is not accompanied by productivity gains, firms need to increase their prices. The increase in the relative price of non-traded to traded goods implies an appreciation of the real exchange rate (based on broad price indices), which however does not jeopardise the international price competitiveness of firms in the traded goods sector.

More formally, the Balassa-Samuelson model assumes a two-country, two-commodity world with perfect competition. Equation (1) is the standard Balassa-Samuelson representation in log differentiated form:³

$$(1) \quad \begin{aligned} \hat{q} &= \hat{q}_T + (1 - \alpha) \cdot \hat{q}_I - (1 - \alpha^*) \cdot \hat{q}_I^* \\ &= \hat{q}_T + (1 - \alpha) \left[\frac{\sigma_N}{\sigma_T} \hat{A}_T - \hat{A}_N \right] - (1 - \alpha^*) \left[\frac{\sigma_N^*}{\sigma_T^*} \hat{A}_T^* - \hat{A}_N^* \right] \end{aligned}$$

where $\hat{}$ represents a change over time, $*$ a foreign country variable, q is the real exchange rate, q_T the relative price of traded goods between the home and foreign country, q_I the price differential for traded to non-traded goods, α the share of traded goods in the goods basket, σ_i the labour income share in sector i , A_i technical progress in sector i , $i = \text{tradable, non-tradable}$.

Equation (1) can be divided in two components. According to the first component, traded goods prices are characterised by purchasing power parity. In the long run, therefore, \hat{q}_T equals zero. The second component establishes a link between the relative price of non-traded goods and the relative

¹ See Faruquee (1995) and Frenkel and Mussa (1985) for portfolio balance models of the real exchange rate, and MacDonald (1997) and Clostermann and Schnatz (2000) for empirical models including a broad set of fundamentals.

² This effect does not rely strictly on labour mobility, as a centralised wage determination mechanism will produce the same effects (assuming constant marginal costs). What matters, is that wages in the non-traded sector adjust in response to the wages in the traded sector.

³ See Asea and Corden (1994) as well as De Gregorio et al. (1994) for a detailed derivation.

productivity in the traded and non-traded goods sectors. However, the standard Balassa-Samuelson framework refers to TFP, which entails significant practical data problems that are addressed in some more detail in section 3.

As a consequence of these practical problems, Canzoneri et al. (1999), for instance, suggest using labour productivity for analysing the Balassa-Samuelson effect in empirical work. As perfect competition implies that labour is paid the value of its marginal product, and labour mobility implies that the nominal wage rate, W , is equal in the two sectors, the following relationship holds for each sector i :

$$(2) \quad \frac{\partial Y_i}{\partial L_i} = \frac{W}{P_i}$$

Exploiting the fact that the marginal product of labour is proportional to the average product of labour in Cobb-Douglas production functions, equation (2) can be transformed into:⁴

$$(3) \quad \sigma_i \frac{Y_i}{L_i} = \frac{W}{P_i}$$

Substituting (3) into (2) for the two sectors of the economy, it follows that the internal price ratio, q_I , is also proportional to the ratio of the average labour products. In logarithms, this yields:

$$(4) \quad q_I = p_N - p_T = \log \left[\frac{\sigma_T}{\sigma_N} \right] + l_T - l_N$$

where l_i stands for the log of labour productivity in sector i . Equation (4) can be differentiated and inserted into (1), assuming that the same relationships hold for the foreign country.

According to this set-up, there should be a proportional link between relative prices and relative productivity. Labour productivity, however, is also influenced by demand-side factors, though their effect should be of a transitory rather than of a permanent nature. Although the sample period considered in the empirical part of this paper (section 4) covers roughly 20 years of data, it cannot be ruled out that such effects on the exchange rate are persistent enough to justify an elasticity of the real exchange rate to changes in productivity larger than one. In particular, as the productivity increase raises future income, and if consumers value current consumption more than future consumption, they will try to smooth their consumption pattern (see Bailey et al., 2001). This leads to an immediate increased demand for both traded and non-traded goods. The increase in demand for traded goods can be satisfied by running a trade balance deficit. The increased demand for non-traded goods, however, cannot be satisfied and will lead to an increase in prices of non-traded goods instead. Thus, demand effects lead to a relative price shift and thereby to a real appreciation.

⁴ It is worth emphasizing that this equation will also hold under assumptions that are much less restrictive than those of Cobb Douglas technology. In this neo-classical framework, wages react instantaneously to changes in productivity. Following Ball and Moffitt (2001), it could be argued, however, that workers' aspirations for wage increases adjust only slowly to shifts in productivity growth. Since we focus on long-run exchange rate developments, to account for this possibility, a sufficient additional assumption would be that real wages are tied closely to labour productivity in the long run.

Moreover, some extensions of the Balassa-Samuelson framework reinforce the intuition that the magnitude of the relative productivity coefficient may be above unity. First, Bergstrand (1991) shows that if consumer preferences are not homothetic, rising productivity and domestic income may lead to a shift in the composition of domestic demand towards non-traded goods, increasing their relative price *ceteris paribus*. Second, Fischer (2002) extends the Balassa-Samuelson framework by accounting for skilled and unskilled labour and shows that, in such a model, demand factors, in addition to the supply-side effects, can influence the real exchange rate. As a result, the assumption of a unit elasticity of the real exchange rate with respect to productivity appears to hold only in the standard framework, while in more sophisticated models, the magnitude of the impact of a rise in productivity on the real exchange rate appears more difficult to determine *a priori*.

The demand effects associated with the rise in productivity may also generate a “transitory” increase in the real interest rate, triggering a real appreciation of the domestic currency. As consumers spread the increase in expected income to the current period by decreasing current savings, they will also drive up the real interest rate. Thus, consumption smoothing affects not only relative prices, but also the real interest rate. Therefore, an increase in ALP will affect the real exchange rate also via a real interest rate channel. Such a channel can be motivated formally through the real interest rate parity condition.

Note that an increase in TFP or capital productivity could also trigger a reinforcement of the real interest rate channel.⁵ In particular, an economy that experiences higher productivity growth will also experience a higher return on capital, at least initially. *Ex ante*, such a difference in expected rates of return encourages capital inflows also in form of equity portfolio and foreign direct investment. Such reallocations of international portfolios may have an effect on exchange rate developments. However, while such an effect could last for some time, it is not an equilibrium outcome, as eventually, at the margin, risk-adjusted rates of return will be equalised again. Thus any such effect would be only of a transitory nature.

To sum up, this discussion suggests that the equilibrium real exchange rate will unambiguously appreciate in this framework following an actual or expected shock in ALP in the traded goods sector. The real exchange rate declines in the long run if the productivity shock occurs in the non-traded goods sector, giving rise to an increase of production of non-traded goods in the home market, which requires a decline in their relative price. However, this decline may be mitigated or even reversed in the medium term by demand-side effects. A productivity shock – regardless of its origin – also generates a rise in the real interest rate differential and capital inflows, reinforcing the productivity effect of a shock in the traded goods sector and counterbalancing the productivity effect of a shock in the non-traded goods sector. Overall, this discussion suggests that it is difficult to determine *a priori* the magnitude of the impact of a rise in productivity on the real exchange rate. We will return to that issue in section 4.3 when we discuss the estimation results.

⁵ In addition, factors such as the US debt-buyback programme might have had a temporary impact on real interest rates.

3. Measuring productivity

One must also take into account practical (in addition to theoretical) considerations when defining useful measures of productivity in the context of empirical exchange rate models. Overall, the choice of the productivity variable for the empirical analysis needs to follow a two-step procedure: one must first make a decision upon the most appropriate productivity concept, and then choose a proper statistical definition of this concept.

Total factor productivity is the measure often favoured by economists on theoretical grounds. In the mainstream interpretation, TFP growth signals the improvement in the overall efficiency of the economic process. A famous other interpretation is that of Abramowitz (1956): “a measure of our ignorance”. Most importantly, TFP cannot be measured directly and is difficult to estimate, because its estimation hinges, *inter alia*, on the assumptions made in constructing capital stocks.⁶ Furthermore, international comparisons of TFP could be highly misleading, because they are subject to various arbitrary assumptions.

In contrast, average **labour productivity** provides a relatively straightforward measure of economic efficiency. It measures the output per unit of labour input, which is often defined in terms of the number of persons employed, but should preferably be based on the amount of hours worked. International comparisons are relatively straightforward as well – as long as the same concepts of output and labour input are used. Thus, given its relative straightforward computation and its international comparability, ALP is our preferred empirical measure of productivity.

ALP is relatively straightforward to calculate, but the following three considerations should be taken into account in the context of the current exercise:

First, preferably, a distinction should be made between developments in productivity in the traded and in the non-traded goods sector.⁷ Due to limited data availability, however, we concentrate on overall relative ALP between the US and the euro area. It could be argued that in practice this focus does not introduce a strong bias, because productivity growth in the traded goods sector is typically higher than in the non-traded sector (implying that the relative price of non-traded goods has to increase in both countries), and developments in the productivity differential for the total economy reflect, to a large extent, that in the traded goods sector. For the United States and the euro area, this is apparent from annual sectoral data for the 1990s (see, for example, McGuckin and Van Ark 2002). Nonetheless, in

⁶ Sakellaris and Wilson (2002), for example, argue that the technological change that is embodied in capital goods is not measured properly. This introduces a downward bias in measured growth of capital stock, and consequently biases measured TFP growth upwards. See Blaug (1997) for a discussion of the so-called Cambridge Controversy on the fundamental point whether it is possible at all to aggregate different kinds of capital in a meaningful way.

⁷ Using sectoral productivity measures also has some limitations. Most importantly, the borderline between traded and non-traded goods is far from straightforward, and it becomes the more disputable, the longer the time horizon. Moreover, in an era of increased globalisation, the frontiers between tradability and non-tradability may have become more fluid over time.

order to capture sectoral productivity developments indirectly, we will also use relative prices in the non-traded and traded goods sector (as is often done in the context of exchange rate models).⁸

Second, two potential sources of bias in comparing direct ALP measures between the euro area and the United States can be identified. Both apply to relative labour productivity measures based on the most readily available data. The labour productivity measure that is most widely used for the United States is based on non-farm business sector output per hour, while for the euro area GDP per person employed is used. Using non-farm business output for the United States and GDP for the euro area creates a bias in productivity developments for two reasons.⁹ First, the different treatment of the government sector in the two output series biases euro area ALP growth downwards vis-à-vis the United States. A second source of downward bias is introduced by the use of persons employed as a denominator for the euro area as opposed to hours worked in the US. This practice fails to take into account the trend decline in the average annual hours worked in the euro area, which was not matched by a similar decline in the United States, implying another source of downward bias of euro area ALP growth vis-à-vis the United States (see also Vijselaar and Albers 2002).

In order to avoid these sources of bias, we use internationally comparable data on real GDP per hour worked in our definition of relative productivity. We use GDP as the output measure for both the euro area and the US, for the practical reason that it is the only measure available for the euro area and one should use similar quantities when making cross-country comparisons. Our measure of GDP per hour worked is based on own calculations from national accounts and OECD data (see appendix 1). However, hours worked data are difficult to obtain, in particular for the euro area countries; they are available after a rather long lag, and in most cases they are available only on an annual basis. Although economists generally agree that GDP per hour worked is a better measure of labour productivity, the most readily available proxies remain predominant in the literature due to these practical constraints. However, as argued above, the picture of relative ALP developments depends crucially on the measure used. In particular, when looking at our preferred measure, it appears that the much-debated difference in productivity growth in the second half of the 1990s was much less pronounced than is generally assumed (Chart 1).

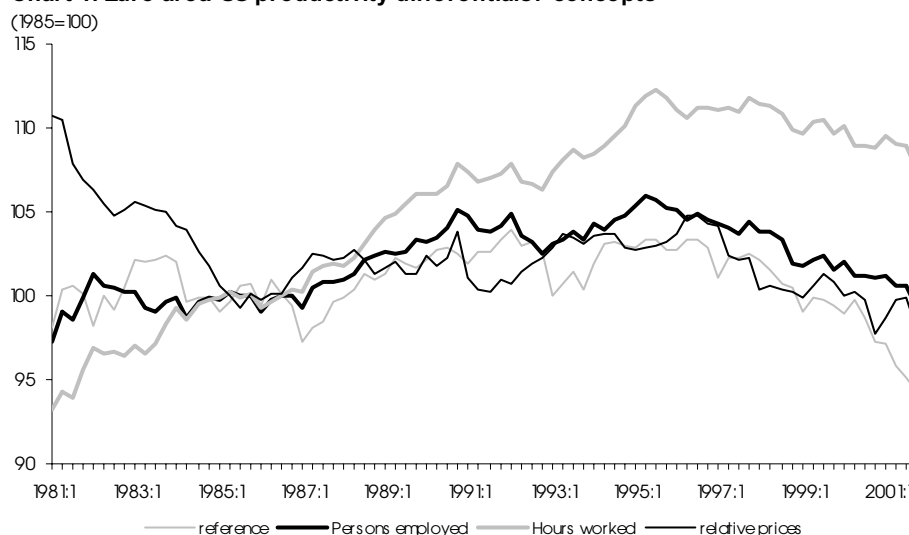
Third, as regards labour input, employment is not adjusted for quality in our analysis due to lack of data – thus implicitly assuming that labour is of uniform quality across the euro area and the United States, which is a common assumption in international comparisons. In this context, it could be argued that labour productivity data encompasses only the employed persons, while many relatively low-skilled and inexperienced workers are unemployed, in particular in the euro area. However, the

⁸ Obviously, there are other factors than productivity, which might affect relative price developments. For example, changes in value-added taxes that affect the proxy for non-traded goods (consumer prices) but not that for traded goods (producer prices). Furthermore, changes in the exchange rate itself may have different degrees of pass-through to import prices, which may explain the peculiar development of this proxy in the first half of the 1980s, when the US dollar appreciated strongly. Accordingly, it is difficult to determine *a priori* which proxy to prefer. In this paper, the focus lies mainly on direct productivity variables, but we ‘control’ whether the indirect proxy gives similar results.

⁹ Alquist and Chinn (2002) also use the readily available measures, but they explicitly acknowledge that this can induce a bias.

acceleration of employment between the first and the second half of the 1990s was stronger in the euro area than in the United States, and the euro area unemployment rate declined quite significantly between the mid-1990s and 2001, suggesting that many jobs have been created for the lower-paid, lower-skilled workers. As a consequence, labour productivity growth in the euro area could (if anything) be biased downward vis-à-vis the United States over this period.

Chart 1: Euro area-US productivity differentials: concepts



Source: Own calculations based on OECD, BLS and National Account statistics

In order to quantify the impact of labour productivity developments on the exchange rate, the empirical analysis in this paper considers four alternative measures, three direct and one indirect:

- Non-farm business sector output per hour worked for the United States and GDP per person employed for the euro area. This is the most readily available measure, and as such it is taken as a kind of “reference” measure throughout the paper.
- GDP per person employed, for both the euro area and the United States;
- GDP per hour worked, the most consistent and therefore our preferred measure, for both the euro area and the United States;
- finally, as an indirect measure, relative prices of traded and non-traded goods and services, which is commonly used as a proxy for relative sectoral productivity developments.

4. Empirical Analysis

4.1. Econometric methodology

Chart A2 in the appendix suggests that the data are nonstationary. The empirical analysis, therefore, employs cointegration tests as developed by Johansen (1995). Since it is well known that standard ADF tests have low power (see for instance Phillips and Xiao, 1999), the stochastic properties of the data are tested within the cointegrating system, hence taking into account information in all series. In the present setting, some variables (such as the real interest rate differential) would theoretically be

expected to be stationary, but appear to be near-integrated processes empirically. The presence of the so-called naïve cointegration relationships is tested in a multivariate setting, keeping in mind that the cointegration rank rises by one for each stationary variable included in the system.

The standard starting point for cointegration analysis is a linear dynamic system of variables with a maximum lag length of k periods over the sample $t = 1, \dots, T$, in the form of a vector autoregression model of order k , which can be reparameterised as the vector error-correction model (VECM):

$$(5) \quad \Delta y_t = \alpha \begin{pmatrix} \beta \\ \mu_1 \\ \delta_1 \end{pmatrix} \tilde{y}_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-i} + \gamma + \tau t + \varepsilon_t.$$

where y_t is a $n \times 1$ vector of the n variables of interest, here including the real exchange rate, productivity, the real price of oil, the real interest rate differential and relative government spending, Γ_i are matrices of short-run coefficients, ε_t denotes a $n \times 1$ vector of white noise errors.¹⁰ Moreover, $\tilde{y}_{t-1} = [y_{t-1}, 1, t]$, and $\mu_1, \delta_1, \gamma, \tau$ are the coefficients to the deterministic components of the model. Imposing the restriction $\tau = 0$ rules out quadratic trends in the data, which is a natural assumption. As regards the other deterministic components, Doornik et al. (1999) show that including an unrestricted constant and a restricted trend mitigates chances of a mis-specification bias. Erroneously omitting these variables leads to a substantial mis-specification bias, but erroneously including these variables imposes only a marginal bias to the results. Pesaran and Smith (1998) support these conclusions and find that the restricted trend model is preferable when one or more underlying variables exhibit linear trends. As noted in Nielsen and Rahbek (2000), this deterministic specification ensures asymptotic similarity of the trace test with respect to the parameters of the deterministic components, i.e. the choice of the cointegration rank based on the trace test is not contingent on the choice of the deterministic specification. This implies that it is possible to test for the rank without having to simultaneously determine the deterministic specification. All these considerations suggest that in the first step a trend should be included in the cointegrating space (restricted), and that the significance of the coefficients of the deterministic components should be tested explicitly (i.e. μ_1, δ_1 and γ are unrestricted in (5)).

Following Johansen (1995), the model is estimated by maximum likelihood. The rank of the $n \times n$ coefficient matrix Π is central to this methodology, as it determines the number of cointegrating vectors. If the matrix Π is found to have reduced rank ($0 < r < n$), there will be r linear combinations of y_t – the so-called cointegration relations – which are stationary. In this case, the matrix Π can be decomposed into a $n \times r$ matrix of loading coefficients α , and a $n \times r$ matrix of cointegrating vectors β . The estimate for β is given by the r eigenvectors of Π . One important condition, which needs to be met in this context, is that the real exchange rate itself should not be weakly exogenous (tested on the basis of a χ^2 test on the respective feedback coefficient α). The magnitude of the α coefficient also gives an indication of the speed of adjustment to disequilibrium.

¹⁰ The deterministic terms μ (constant) and δ (time trend) have been decomposed into $\mu = \alpha\mu_1 + \gamma$, $\delta = \alpha\delta_1 + \tau$

4.2. *Data for additional variables*

For the period prior to 1999, the real euro-dollar exchange rate (based on consumer prices) has been computed as a weighted geometric average of the bilateral exchange rates of the euro legacy currencies against the dollar. The weights were given by the share of external trade of each euro area member state in total euro area trade. It may appear more straightforward to use the ecu-US dollar exchange rate prior to 1999. However, the ecu basket included currencies such as the pound sterling and the Danish krone, which did not join the euro, while the currencies of countries which have adopted the euro (such as the Austrian shilling and the Finish markka) were not included in the ecu. This suggests that the euro and the ecu are distinct currencies, which cannot be easily chain-linked. Accordingly, using a “synthetic” euro-dollar exchange rate based on trade weights seems to be the most consistent procedure in the present context, since it facilitates a correspondence between the countries included in the computation of the euro area fundamentals, and the currencies included in the “synthetic” euro.¹¹

As regards the real interest rate differential, data on bond yields for the United States and a weighted average of long-term interest rates of the countries constituting the euro area have been employed. The expected rate of inflation is proxied by the annual rate of inflation in the previous year. In addition, the model was estimated controlling for several other variables, as usually done in the literature, but only the real price of oil and the relative ratio of government spending to GDP appeared significant. As regards the real price of oil, its usefulness for explaining trends in real exchange rates is documented, for example, by Amano and Van Norden (1998a and 1998b), who found strong evidence of a long-term relationship between the real effective exchange rate of the US dollar and the oil price.¹² As net oil imports relative to GDP are higher for the euro area than for the United States, the negative impact of a rise in oil prices should be stronger on the economy of the euro area, thus suggesting an inverse relationship with the exchange rate of the euro. As regards government spending, the fiscal balance constitutes one of the key components of national saving. In particular, Frenkel and Mussa (1985) argued that a fiscal tightening causes a permanent increase in the net foreign asset position of a country and, consequently, an appreciation of its equilibrium exchange rate in the long term, provided that the fiscal consolidation is considered to have a permanent character.

¹¹ Overall, the difference between different real euro-dollar exchange rates does not seem to be large, no matter whether the synthetic index is based on trade weights or ecu weights, or whether the D-mark is used as a proxy for the euro.

¹² Other studies have employed this variable on bilateral exchange rates. Rogoff (1991) presents a theoretical model and includes in its empirical application the real price of oil – defined as the oil price in US dollars relative to a US price index – in equations on the real yen-dollar exchange rate. Chen and Rogoff (2002) investigate the relationship between bilateral as well as effective exchange rates and real commodity prices in US dollars, deflated by US consumer prices. Clostermann and Schnatz (2000) find strong evidence for an impact of the real price of oil on the euro-dollar exchange rate, while Chinn and Alquist (2002) find such evidence in some of their specifications.

4.3. Productivity and the real euro-dollar exchange rate

This section presents evidence in favour of stable long-run relationships between the real euro-dollar exchange rate, the various alternative productivity measures and the other variables. One model specification was estimated for each of the four productivity measures outlined above. The sample covers the period from the first quarter of 1981 to the fourth quarter of 2001, since productivity data are unavailable before 1981 for some of the measures. Likelihood ratio tests in unrestricted VAR estimates suggest that the optimal lag length is five in the VAR in levels. In the first step, we estimated a model including all variables discussed above as well as deterministic components. Within this quite general model, we carried out trace tests to determine the cointegration rank along with the deterministic specification. In the second step, coefficients that turned out insignificant in the cointegration vector were restricted to zero. In the case of the real interest rate differential, the long-run coefficient was zero but the adjustment coefficient was significant, hence we left this variable in the model. In the third step, (weak) exogeneity properties of the variables were analysed by restricting the insignificant adjustment terms to zero.

Accordingly, in the most general specification (6), q_t indicates the real exchange rate, pd_t is the productivity differential, rid_t stands for the real interest rate differential, oil_t is the real price of oil, and gov_t is the difference of the logs of government spending in the euro area and the United States:

$$(6) \quad \begin{bmatrix} \Delta q_t \\ \Delta pd_t \\ \Delta rid_t \\ \Delta oil_t \\ \Delta gov_t \end{bmatrix} = \alpha \begin{bmatrix} \beta \\ \mu_1 \\ \delta_1 \end{bmatrix}' \begin{bmatrix} q_t \\ pd_t \\ rid_t \\ oil_t \\ gov_t \\ 1 \\ t \end{bmatrix} + \sum_{i=1}^4 \Gamma_i \begin{bmatrix} \Delta q_{t-i} \\ \Delta pd_{t-i} \\ \Delta rid_{t-i} \\ \Delta oil_{t-i} \\ \Delta gov_{t-i} \end{bmatrix} + \gamma + \psi d_{EMU,t} + \varepsilon_t$$

In (6), γ is a $n \times 1$ vector of constants, β is the $5 \times r$ matrix containing long-run coefficients, α is the $5 \times r$ matrix of adjustment coefficients, μ_1 and δ_1 indicate the coefficients to the constant and linear trend in the cointegrating vectors respectively. However, constant and trend were found insignificant in all specifications and were therefore dropped from the final model specifications. In addition, an exogenous step-dummy, d_{EMU} , has been included in the short-term dynamics of the equation for the period following the introduction of the euro. The cumulation of this dummy introduces a broken trend in the levels equations. Such a trend cannot persist indefinitely, hence it should be interpreted as a temporary device, able to capture the instability in the estimated parameters following the start of EMU. If the dummy currently captures the undervaluation of the currency itself, it should become insignificant in the future, as the exchange rate converges to more appropriate levels.¹³ By contrast, if this dummy reflects a sustained structural change in the relationships, it needs to be set to zero after

¹³ This dummy could, for example, capture the substantial capital flows from the euro area into the US following the “new economy” hype. As argued in section 2, however, this would not be an equilibrium phenomenon. Although it may perhaps be helpful in explaining why the euro-dollar exchange rate deviated from its equilibrium, modelling this phenomenon explicitly would thus be beyond the scope of this paper.

the exchange rate reached a new equilibrium plateau. For simplicity at this stage, the dummy was set to 1 for the entire period. It is highly significant in each specification, and restores a high degree of stability in the estimated coefficients in the long-run vector for the period before and after existence of EMU. This is confirmed by the results obtained by estimating the four models up to the last quarter of 1998, which are reported for comparison in the appendix (Table A2).

The test statistics and estimated parameters for the final models are summarised in Table 1. Panel (a) shows the results of the cointegration tests. None of the inverse roots of the companion matrix lie outside the unit circle, allowing interpretation of the results within a non-explosive framework. According to standard critical values for the trace test, evidence for one cointegration vector was found in each specification at the 5% level of significance.¹⁴ Using the more restrictive procedure suggested by Reimers (1992), which corrects the trace test for degrees of freedom, we still find evidence for cointegration in most specifications at the 5% level of significance. Doornik et al. (1999) claim, however, that a small-sample scaling of the trace test is not theoretically founded and may overcorrect the statistics in certain cases. This suggests a rather pragmatic interpretation of the Reimers test. It was also tested whether the long-run relationship(s) in specification IV is due to the stationarity of the real interest rate differential. This hypothesis, formulated as the restriction that in a cointegration vector normalised on the real interest differential, the coefficients of all other variables are zero, is strongly rejected on the basis of the LR test for exclusion in the cointegrating vector. Moreover, standard misspecification tests on the residuals indicate that the model is well specified. Overall, the results suggest that it is reasonable to assume a single cointegration relationship between the variables of interest.

Panel (b) of the table shows the long-run coefficients. As indicated above, the restricted constant was found to be insignificant in all model specifications. As a consequence, all models were re-estimated with the long-run constant restricted to zero.¹⁵ In each specification the variables have the expected signs and they are mostly statistically significant (one exception being the real interest rate differential in the specifications which include a direct productivity measure). The long-run coefficients on the real interest rate differential, as well as the adjustment coefficients of variables that were found to be weakly exogenous, have been restricted to zero in the final estimation. The table reports the corresponding LR tests, which are distributed as χ^2 . Overall, increases in the productivity differential in favour of the euro area are associated with a real appreciation of the euro. By contrast, increases in oil prices and in relative government spending generate a depreciation of the euro vis-à-vis the US currency (in real terms).

¹⁴ The reported tests exclude the dummy variable, on account of the effect of the inclusion of this dummy on the asymptotic distribution of the trace test.

¹⁵ This implies that the average disequilibrium is zero. This restriction does not affect the decision on the rank test.

Table 1: VECM results (t-statistics in parentheses)

		Model I <i>“reference” data</i>		Model II <i>persons employed data</i>		Model III <i>Hours worked data</i>		Model IV <i>Relative price ratio</i>	
(a) Cointegration test									
Trace ^{a)}	None	121.7	**	112.5	**	107.5	**	105.2	**
	1	60.4	**	51.7		52.6		54.8	*
	2	35.1	*	29.4		27.6		21.9	
	3	19.0		14.7		16.3		11.4	
Trace ^{b)}	None	83.2	*	76.9	*	80.3	*	71.9	
	1	41.3		35.3		36.0		37.5	
(b) Long-term coefficients β									
q		1.00		1.00		1.00		1.00	
pd		-1.87 (-7.7)		-1.93 (-7.8)		-1.91 (-7.0)		-1.46 (-6.9)	
rid		0		0		0		-2.96 (-6.0)	
oil		0.35 (9.7)		0.31 (9.9)		0.16 (5.6)		0.26 (6.1)	
gov		0.52 (2.4)		0.62 (2.8)		0.72 (2.7)		0.21 (1.2)	
(c) Adjustment terms α									
q		-0.31 (-4.3)		-0.35 (-4.7)		-0.36 (-4.9)		-0.55 (-6.1)	
pd		0		0		0		0	
rid		-0.05 (-7.6)		-0.05 (-7.1)		-0.05 (-6.8)		-0.06 (-5.7)	
oil		0		0		0		0	
gov		0		0		0.04 (1.8)		0.06 (2.1)	
LR test for restrictions (p-value)		7.1 [0.21]		6.0 [0.30]		3.1 [0.54]		2.6 [0.45]	
(d) Summary Statistics:									
Number of lags:		5		5		5		5	
LM(1) (p-value)		0.17		0.19		0.61		0.25	
LM(4) (p-value)		0.35		0.29		0.62		0.36	
White test		0.20		0.20		0.52		0.28	

^{a)} Significant at the 10%/5% level, ^{a)} Critical values for the trace test according to Osterwald-Lenum. ^{b)} trace statistics adjusted for small-sample bias according to Reimers (1992).

The magnitude of the elasticity of the real euro-dollar exchange rate with respect to the productivity differential ranges in a relatively narrow band between 1.5 and 2.0 in our estimates. Indeed, strikingly, the estimated elasticities for the direct productivity variable are quite similar independently of the measure that is chosen. *A priori*, however, as argued in section 2, it appears difficult to determine the expected magnitude of this elasticity based on economy-wide productivity data. Using productivity in the traded goods sectors, the Balassa-Samuelson framework would suggest a coefficient close to one. This result has been broadly confirmed based on a sectoral productivity measure by Canzoneri et al.

(1999) in a panel context as well as Faruquee (1995) for the effective exchange rate of the US dollar and the Japanese yen, and Feyzioglu (1997) for the real effective exchange rate of the Finnish markka. Owing to data limitations, however, the productivity measures employed in this paper, as well as the one used by Alquist and Chinn (2002), refer to economy-wide productivity, which complicates the derivation of a “theoretical” level of the coefficient, which encompasses supply and demand factors. It could be argued that the use of cointegration methods, which are standard in the literature on the long-term relationships between fundamentals and the real exchange rate, reduces the impact of transitory demand effects. However, even in a sample spanning over 20 years, it appears unlikely that the relationship is fully purged of demand factors. Economy-wide average labour productivity is actually used in only a few studies: Clostermann and Friedmann (1998) – studying the real effective D-mark exchange rate – on the basis of such a definition of productivity in a dynamic error correction model, find an elasticity between 1.1 and 1.5, while Stein (2001) estimates an elasticity of 1.7 for the euro-dollar exchange rate. The magnitudes of the coefficients presented in this paper are broadly in line with these studies. In contrast, however, Maeso-Fenandez et al. (2002), who also employ an economy-wide measure for the euro area relative to its main trading partners in a study on the effective (“synthetic”) exchange rate of the euro, report elasticities in the range of 4.2 and 5.1. This is closer to the results of Chinn and Alquist (2002), who report coefficients in the range of 2.3 to 5.1 for the “synthetic” euro-dollar exchange rate.

To focus more on the elasticities as estimated in the present paper and in Chinn and Alquist (2002), the other study on the euro-dollar exchange rate, the differences may be related to a combination of three main factors. First, in our specification we control for various other variables, which should have an impact on the magnitude of the coefficient. The estimated coefficient on productivity may partly capture the effects of potentially omitted variables in Chinn and Alquist (2002), as also suggested by the fact that their estimated elasticity drops from 5.1 to 2.3 once the real oil price and relative government spending are included in the specification.¹⁶ Second, the sample period underlying our estimates exploits the information incorporated over the longest sample for which the data are available, i.e. not excluding *a priori* the first half of the 1980s, when larger fluctuations in oil prices and exchange rates were observed. However, the estimated coefficients in our models appeared to be stable also over shorter sample periods. Appendix 2 elaborates further on this issue and replicates the results of Chinn and Alquist (2002) over this shorter sample period. Third, the restriction of the insignificant constants to zero results in a lower elasticity for some productivity variables.¹⁷

The adjustment terms α are reported in panel (c) of Table 1. In each specification based on the direct productivity data, the adjustment term for the real exchange rate is highly significant and negative, signifying that the real exchange rate is indeed one of the variables responding to the other variables in the system and reverting to some long-run equilibrium. The adjustment coefficients for the productivity differential, the real price of oil and – in some specifications – government spending are

¹⁶ See their specification (7) in Table 2, for instance, op. cit.

¹⁷ In model I and II, the coefficient rises to 2.7 and 3.0 respectively, but in model III and IV, it declines to 1.4 and 1.6, respectively.

insignificant, indicating that these variables are weakly exogenous for the long-run parameters in this model, while the adjustment term for the real interest rate differential is always significant. The results reported in the table were estimated on the basis of the restricted models where the weak-exogeneity restrictions were imposed.

4.4. Explaining the euro decline by productivity developments

How much of the decline of the euro vis-à-vis the US dollar can be attributed to relative changes in productivity in the United States and the euro area? While the estimation covers the period 1981 – 2001, the following analysis concentrates on two particular episodes:

- **Period I:** 1995Q4 to 2001Q4, as it covers the entire episode of US dollar appreciation against the euro (Chart 2). Moreover, it encompasses the period during which the productivity revival in the United States has arguably taken place. Over this period, the dollar appreciated by almost 45% vis-à-vis the (“synthetic”) euro.
- **Period II:** 1998Q4 and 2001Q4, i.e. the first three years of euro existence, when the euro depreciated by almost 30% vis-à-vis the US dollar.

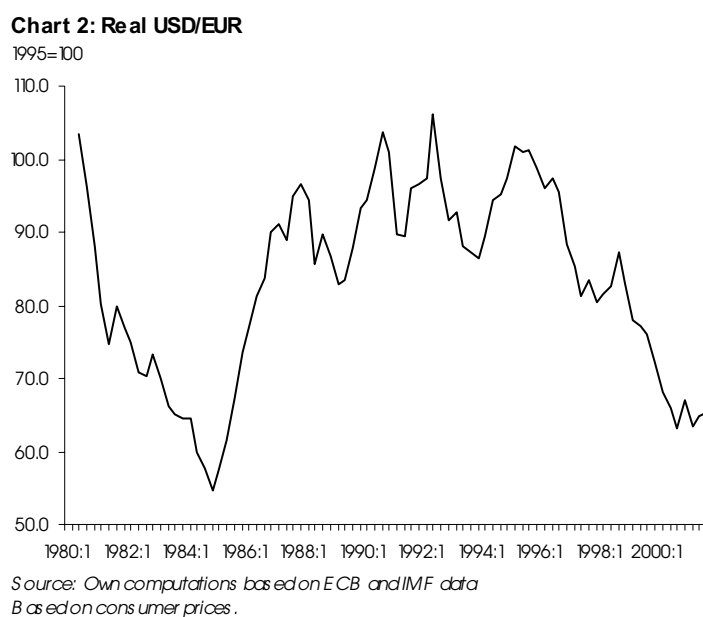
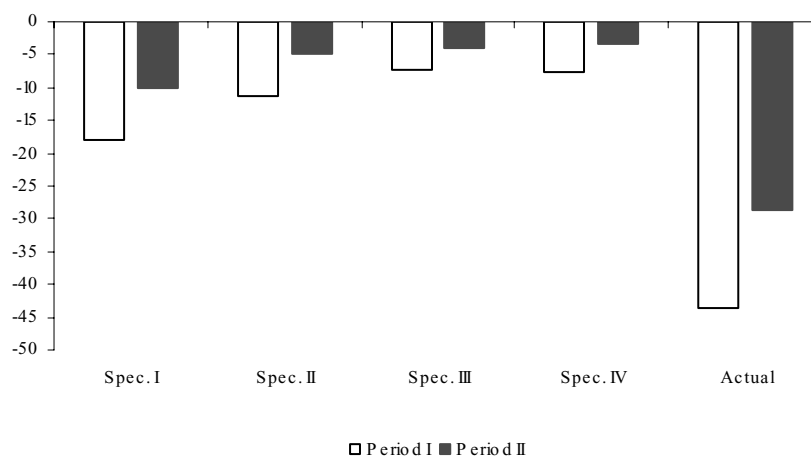


Chart 3 shows the impact of a change in relative productivity developments over these periods on the equilibrium real exchange rate. The contribution of relative developments in productivity to the explanation of the depreciation of the euro against the US dollar since 1995 depends on the productivity proxy used. Even though the estimated elasticities are very close, as shown above, the actual development of the proxies differed substantially after 1995. In any case, these developments are far from explaining the entire euro decline.

Chart 3: Euro depreciation due to changes in productivity and actual



- If the “reference” data are used (specification I), the productivity differential suggests a depreciation of the euro of almost 18% due to productivity developments since 1995 and more than 10% since the euro’s launch.¹⁸ As outlined above, however, these data are biased, due to the different treatment of the government sector and the use of persons employed rather than hours-worked.
- By using better comparable output data, but still persons employed as the relevant input factor, the productivity differential could account for a depreciation of the euro by more than 11% since 1995 and by roughly 5% since 1998 (see specification II).
- Employing our preferred measure of productivity, which in addition accounts for the decline in the average hours worked per person, leads to a further and substantial drop in the explanatory content of the relative productivity variable for the depreciation of the euro (specification III). The trends in this relative productivity variable would suggest a depreciation of the euro by slightly less than 8% since 1995, while it actually declined by 44%. This measure accounts for a depreciation of the euro of about 4% since the fourth quarter of 1998.
- The results based on the indirect productivity variable suggest a euro depreciation of roughly 7½% since 1995 (period I) and 3½% over the shorter reference period since 1998.

4.5. Discussion of the results

Evidently, productivity is not the only variable affecting the real exchange rate in the models specified. The other fundamentals identified also affected the euro-dollar exchange rate. In particular, the surge

¹⁸ Applying an elasticity of close to 5 as in Alquist and Chinn (2002) to the “reference” productivity data, the productivity differential explains even slightly more than the actual depreciation of the euro-dollar exchange rate in period I and almost all of it in period II.

in oil prices since early 1999 seems to have contributed to the weakening of the euro, while the real interest rate differential and relative government spending have had only marginal effects on the euro-dollar exchange rate.

The magnitude of the long-run impact of changes in the real price of oil on the euro-dollar exchange rate is non-negligible. Applying the estimated elasticities strictly to the rise in (real) oil prices between 1998Q4 and 2001Q4, the models indicate on average that the “equilibrium” euro depreciation related to oil price developments could have been around 10%, which would “explain” almost 40% of the actual euro depreciation. However, a caveat regarding the potential impact of oil seems in order. The concept of the equilibrium exchange rate and the empirical analysis presented here are based on long-term relationships. Accordingly, sudden shocks to an exchange rate fundamental should lead to a lasting revision of the equilibrium exchange rate only if they are sustained. Oil prices, however, were unusually low by historical standards in 1998, but in 2000 they rose to their highest level since the Gulf War and were still relatively high in 2001. In an equilibrium exchange rate based on a medium-term framework, such volatility in fundamentals should not be interpreted as a persistent change. That said, a further assessment of the effect of oil prices on the behaviour of the euro-dollar exchange rate is beyond the scope of this paper.

Overall, the models are surrounded by significant uncertainty, reflecting the inherent difficulty of modelling exchange rate behaviour. While we find that in 2000/2001 the euro has traded well below the central estimates derived from these specifications – reinforcing the results summarised in ECB (2001) – this uncertainty precludes any quantification of the precise amount of “over-/undervaluation” at any particular point in time. This point is also made clear in Detken et al. (2002), who employ a wide range of modelling strategies and show that the deviation from the estimated equilibrium differs widely across models and is surrounded by some non-negligible uncertainty. Moreover, it broadly reinforces the results provided by Maeso-Fernandez et al. (2001) who concentrate on only one modelling approach equivalent to the one used in this paper. They also find various reasonable but non-encompassing specifications leading to different exchange rate equilibria, again suggesting a very cautious interpretation of the magnitude of over-/undervaluation.

This point is also underscored by the finding that developments in the implied equilibrium euro-dollar exchange rate appear to depend crucially on the productivity measure used in the estimation. The change in the most consistent direct measure of labour productivity – output per hour worked – accounts only for about 18% of the actual depreciation of the euro vis-à-vis the US dollar, both since the mid-1990s and since the launch of the euro (up to 2001Q4). In this context, it is important to note that this variable is usually unavailable for market analysts. Accordingly, if traders acted in response to the productivity data which are readily available (in particular, what we have called our “reference” data), part of the observed depreciation of the euro-dollar exchange rate may be simply explained by the fact that they assessed developments in the euro area relative to the United States on the basis of the “wrong” indicator.

5. Conclusion

This paper provides evidence on the long-run relationship between the real euro-dollar exchange rate and various productivity measures, controlling for the real interest rate differential, the real price of oil, and relative government spending. It argues that given its relatively straightforward computation and international comparability, ALP is the best direct productivity measure to use in the context of exchange rate models.

In this paper, we examined four different measures of ALP. As a first and striking result, it appears that the estimated elasticities of the direct productivity variables in particular, are virtually the same. This could suggest that it is unimportant which measure is used for calculating the impact of productivity on the real exchange rate. However, the developments of the different measures of direct ALP since 1995 differ widely. In particular, the differential in terms of GDP per hour worked did not decrease further, but contrary to the other direct measures of ALP used, it did not go substantially into reverse either. This implies that this generally preferable measure of ALP can explain only about 18% of the actual amount of depreciation of the euro against the US dollar since the mid-1990s. Accordingly, productivity cannot explain the weakness of the euro vis-à-vis the US dollar in 2000/2001. This outcome is confirmed by a specification based on an indirect productivity measure.

Importantly, however, the direct productivity variable commonly available for market analysts would suggest a much stronger depreciation (up to 41% of the actual depreciation). To the extent that traders in foreign exchange markets acted in response to the readily available productivity data, they would have assessed developments in the euro area relative to the United States on the basis of the “wrong” indicator. This may have contributed to the weakness of the euro vis-à-vis the US dollar, as *perceived* euro area productivity growth may have been weaker than its *actual* development.

As regards other exchange rate fundamentals, the surge in oil prices in 1999/2000 might have weighed on the euro-dollar exchange rate. From an equilibrium perspective, however, the fact that oil prices peaked in 2000 suggests that a cautious interpretation of the implied equilibrium exchange rates is warranted. Overall, two main results can be reconciled: firstly, the euro has traded well below the central estimates derived from these specifications in 2000/2001, and, secondly, relative productivity developments appear to account for only a small fraction of the euro depreciation.

Appendix 1: Data

- Nominal exchange rate: IFS (line rf). The exchange rates of the euro legacy currencies are geometrically weighted together using trade weights (weights: Austria: 2.89; Belgium: 7.98; Finland: 3.27; France: 17.75; Germany: 34.49; Greece: 0.74; Ireland: 3.76; Italy: 13.99; Netherlands: 9.16; Portugal: 1.07; Spain: 4.90).
- Real exchange rate: Inverse of the nominal exchange rate, multiplied by the ratio of euro area to US consumer prices. Sources for consumer price indices are outlined below.

Data for the euro area:

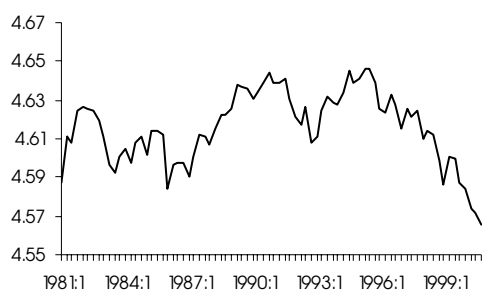
- For all series: All German levels are backcast by using West-German growth rates.
- GDP: Eurostat for euro area, backcast with national accounts of individual euro area countries.
- Total employment: Individual euro area national accounts data, for some countries backcast with BIS data at the annual frequency. Data at the quarterly frequency from the national accounts cover 83%-97% of the euro area (varying over time). The series covering 97% were for- and backcast using the growth rates of the series with less coverage. The resulting series subsequently served as an instrumental variable to interpolate the annual euro area series using the Chow-Lin method (Chow and Lin 1971).
- Hours worked: Average annual hours worked from OECD Employment Outlook (2002). The annual average hours worked series was interpolated by using the Chow-Lin method taking a deterministic trend and a proxy for cyclical tension on the labour market as instrumental variables, including an AR(1) term. The deterministic trend captures the secular decline in the annual hours worked series over the sample period.
- Relative price ratio: Consumer prices divided by wholesale or producer prices (geometrically weighted using average overall trade weights). For consumer prices, IFS (line 64 up to 1998 and line 64h thereafter). For wholesale/producer prices, IFS (line 63) for all countries except Portugal, where OECD data is used.
- Real interest rate: The nominal long-term interest rate for the euro area are geometrically weighted national interest rates using average overall trade weights. IFS (line 61) was used. For Finland, OECD data from 1993:1 onwards, from 1991:4 to 1992:4, secondary market for 10 year government bonds (BIS data), from 1982:2 to 1991:3, secondary market for three to seven year government bonds (BIS data), from 1980:4 to 1982:1 secondary market public issues (four to five years). The real interest rate is computed as nominal interest rate minus the annual rate of consumer price inflation of the previous year. Consumer price data from IFS (line 64) up to 1999:4, and harmonised consumer price data (line 64h) thereafter.
- Government spending: AMECO (code 1.0.0.0.UCTG), except Germany (data from IFS). For partners countries, data from IFS. GDP at current prices from the same source as government consumption.

Data for the United States:

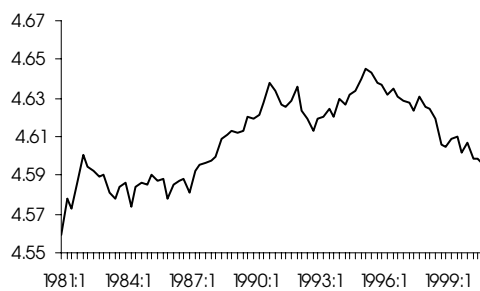
- GDP: Bureau of Economic Analysis (BEA).
- Total employment: Bureau of Economic Analysis (BEA).
- Hours worked: Average annual hours worked from OECD Employment Outlook (2002). The annual total hours worked series was interpolated by using the Chow-Lin method taking the Bureau of Labour Statistics (BLS) series for total hours worked in the non-farm private business sector as an instrumental variable.
- Relative price ratio: Consumer prices divided by wholesale or producer prices. For consumer prices, IFS (line 64). For producer prices, IFS (line 63).
- Real interest rate: The nominal long-term interest rate, IFS (line 61). The real interest rate is computed as nominal interest rate minus the annual rate of consumer price inflation of the previous year.
- Real price of oil: IFS spot price index (line 00176AADZF) divided by the US wholesale price index (IFS line 63).
- Government spending: IFS. GDP at current prices from the same source as government consumption.

Chart A1: Data (Differentials: euro area – USA, except for oil price)

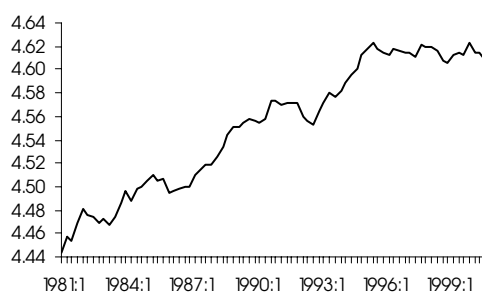
Productivity I (Alquist-Chinn definition), in logs



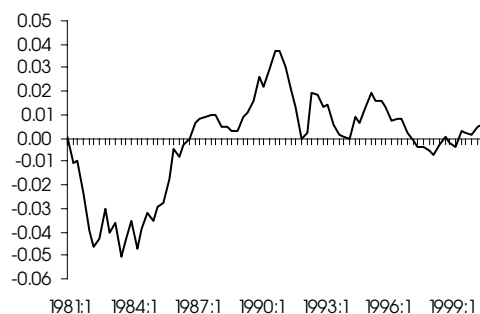
Productivity II (GDP/persons employed), in logs



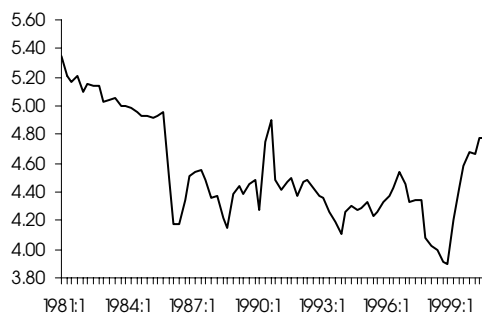
Productivity III (GDP/hours worked), in logs



Real interest rate differential



Real price of oil



Appendix 2: Analysis of shorter sample span

Table A1 uses the shorter sample period and excludes the real interest rate differential and relative government spending, as in the central equation used by Chinn and Alquist (2002). The first two columns broadly replicate the results of their specifications (3) in Table 2 and (3) in Table 3. There are only very small differences in the results, which may be due, for instance, to different updating of the data or weighting of the euro area aggregates. Overall, the results provide evidence for cointegration and suggest a significant elasticity of exchange rates with respect to productivity of 4.76 using DOLS and 4.60 using the VEC model, while the corresponding elasticities in their original work were 4.85 and 4.67, respectively. Moreover, the real price of oil is insignificant in both specifications.

Using the same specification framework – a shorter sample period and only productivity and oil as fundamentals – the elasticity of the productivity differential based on more comparable output data and persons employed as input factor, rises drastically, even above those of the reference data, and remains significant.¹⁹ Using hours worked as the relevant input factor in the productivity variable results in an elasticity whose magnitude is close to the one reported in the first two columns, which is, however, significant only at the borderline. Moreover, in this specification, oil prices become significant again, but the size of the coefficient is very large. Accordingly, the specifications in Table 1 are chosen in the subsequent discussion.

Table A1: VECM results (t-statistics in parentheses), 1985Q3 – 2001Q4

	DOLS <i>“Reference” data</i>		VEC model <i>“Reference” data</i>		VEC model <i>Persons employed data</i>		VEC model <i>Hours worked data</i>	
(a) Cointegration test	1 lag		1 lag		5 lags		5 lags	
Trace ^{a)} None			38.97	**	37.00	**	36.14	**
1			15.76		14.87		17.85	
2			1.04		2.49		7.01	
(b) Long-term coefficients β								
q	1.00		1.00		1.00		1.00	
pd	-4.76 (-4.92)		-4.60 (-4.86)		-6.08 (-4.40)		-4.28 (-1.82)	
oil	-0.04 (-0.37)		0.02 (0.22)		-0.19 (-1.50)		-1.21 (-2.96)	

** Significant at the 10%/5% level, ^{a)} Critical values for the trace test according to Osterwald-Lenum.

¹⁹ The same lag length as in the original specifications has been chosen. Using only one lag in columns (3) and (4) instead of five increases the elasticity of the coefficient on the productivity differential even further but there also appear instabilities in the specification.

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