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WAGE DYNAMICS
NETWORK

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EFFECTS OF
SHOCKS TO WAGES
AND PRICES IN THE
UNITED STATES AND
THE EURO AREA

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**WAGE DYNAMICS
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Wage Dynamics Network

This paper contains research conducted within the Wage Dynamics Network (WDN). The WDN is a research network consisting of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the EU countries. The WDN aims at studying in depth the features and sources of wage and labour cost dynamics and their implications for monetary policy. The specific objectives of the network are: i) identifying the sources and features of wage and labour cost dynamics that are most relevant for monetary policy and ii) clarifying the relationship between wages, labour costs and prices both at the firm and macro-economic level.

The WDN is chaired by Frank Smets (ECB), Giuseppe Bertola (Università di Torino) and Julian Messina (Universitat de Girona) act as external consultants and Ana Lamo (ECB) as Secretary.

The refereeing process of this paper has been co-ordinated by a team composed of Gabriel Fagan (ECB, chairperson), Philip Vermeulen (ECB), Giuseppe Bertola, Julian Messina, Jan Babecký (CNB), Hervé Le Bihan (Banque de France) and Thomas Mathä (Banque centrale du Luxembourg).

The paper is released in order to make the results of WDN research generally available, in preliminary form, to encourage comments and suggestions prior to final publication. The views expressed in the paper are the author's own and do not necessarily reflect those of the ESCB.

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Abstract

This paper investigates the dynamics of aggregate wages and prices in the United States (US) and the Euro Area (EA) with a special focus on persistence of real wages, wage and price inflation. The analysis is conducted within a structural vector error-correction model, where the structural shocks are identified using the long-run properties of the theoretical model, as well as the cointegrating properties of the estimated system. Overall, in the long run, wage and price inflation emerge as more persistent in the EA than in the US in the face of import price, unemployment, or permanent productivity shocks. This finding is robust to the changes in the sample period and in the models' specifications entertained in the paper.

Keywords: structural error-correction model, impulse response function, persistence.

JEL Classification: C32, C51, E31, J30.

NON-TECHNICAL SUMMARY

The existence of wage and price rigidities is widely recognised as a crucial issue for macroeconomics and notably for monetary policy. On the theoretical front, recent literature has re-affirmed the importance of price and wage rigidities for the evolution of the macro economy in response to shocks and, on the empirical front, there is now a large bulk of evidence on the existence of price and wage rigidities at the firm level.

In the real world, the existence of price and nominal wage rigidities is expected to translate into persistent responses of wages and prices to shocks hitting the economy. This paper investigates wage and price dynamics in the United States (US) and the euro area (EA) with a special focus on persistence of real wages, wage and price inflation. The analysis is conducted within a structural vector error-correction model (SVECM), where the structural shocks are identified using the long-run properties of the underlying theoretical model, as well as the cointegrating properties of the estimated system.

Following the theoretical model, which assumes an economy where wages are determined through collective bargaining and prices are set by imperfectly competitive firms, an empirical SVECM involving nominal wages, prices, the unemployment rate, productivity and import prices is estimated and three permanent and two transitory structural shocks are identified. By definition, the three permanent shocks, labelled as import price, unemployment and productivity/technology shocks, are allowed to have significant long-run impacts on some or all the variables of the system, while the two transitory shocks, labelled as wage and price shocks are not allowed to have any long-run impact on the variables of the system.

Our main findings can be summarized as follows. Following an import price shock, wages and prices rise more significantly in the long run in the EA than in the US, in line with the relative degree of international openness of the two economies. However, given the homogeneity property of the model, real wages and the labour share remain unchanged in the long run. This is not the case after an unemployment or a productivity/technology shock. The unemployment shock implies a permanent decrease of real wages and of the labour share in both economies, but the productivity shock has different implications for the labour share in the long run as it decreases in the EA and

slightly increases in the US. This stems mainly from the fact that in the EA wages only absorb a small proportion of productivity gains whereas in the US they are completely absorbed.

Overall, in terms of long-run persistence, wage and price inflation emerge as more persistent in the EA than in the US in the face of the three permanent shocks, especially so for the unemployment and productivity shocks. This finding is robust to the changes in the sample period and in the models' specifications entertained in the paper. The evidence for real wages is not so clear-cut as their relative persistence depends on the type of shock hitting the economy. EA real wages emerge as more persistent following permanent unemployment and productivity shocks, but somewhat less persistent in the face of an import price shock.

The larger persistence of wage and price inflation in the EA compared to the US, as documented in this paper, appears consistent with the evidence for both economies on wage and price setting practices, as well as on the institutional rigidity of the labour market, which would suggest greater wage and price stickiness in the former. In turn, the relative inflation persistence is also consistent with the evidence found in the literature based on time series models with aggregate price data, which suggests that persistence of price inflation in the EA might be larger than in the US.

1 Introduction

The existence of wage and price rigidities is widely recognised as a crucial issue for macroeconomics and notably for monetary policy. On the theoretical front, recent literature - of which Erceg *et al.* (2000), Christiano *et al.* (2005), Levin *et al.* (2005) and Blanchard and Galí (2007) are some notable examples - has re-affirmed the importance of price and wage rigidities for the evolution of the macro economy in response to shocks. Erceg *et al.* (2000) show that introducing staggered nominal wage setting in addition to staggered price setting in their optimising-agent model changes the conclusions about the optimal monetary policy rules, as opposed to the case when staggered price setting is the sole form of nominal rigidity. Christiano *et al.* (2005) conclude that stickiness in nominal wages is crucial for the performance of their model, while price stickiness plays a relatively small role. Levin *et al.* (2005) show that the shape of the distribution of wage contracts in staggered wage-setting models matters significantly for monetary policy. In turn, Blanchard and Galí (2007) demonstrate that allowing for real wage rigidities in the standard new Keynesian model the so-called "divine coincidence" disappears and central banks face a trade-off between stabilising inflation and stabilising the welfare relevant output-gap.

On the empirical front, there is now a large bulk of evidence on the existence of price and wage rigidities at the firm level. For instance, using micro data on consumer prices Dhyne *et al.* (2006) document that the average duration of a price spell ranges from 4 to 5 quarters in the EA and from 2 to 3 quarters in the US; for the EA, Druant *et al.* (2009) find that around 60 percent of the firms change base wages once a year and 26 percent less frequently. In the real world, the existence of price and nominal wage rigidities is expected to translate into persistent responses of wages and prices to shocks hitting the economy.

This paper investigates wage and price dynamics in the United States (US) and the euro area (EA) with a special focus on persistence of real wages, wage and price inflation. The analysis is conducted within a structural vector error-correction model (SVECM), which allows for a distinction between permanent and transitory shocks (see, King *et*

al., 1991, and Jacobson *et al.*,1997). The economic approach draws on previous work by Marques (2008), but is extended in an important way by explicitly allowing for the potential endogeneity of unemployment and import prices.

Following the theoretical model, which assumes an economy where wages are determined through collective bargaining and prices are set by imperfectly competitive firms, an empirical SVECM involving nominal wages, prices, the unemployment rate, productivity and import prices is estimated and three permanent and two transitory structural shocks are defined. The three permanent shocks, labelled as import price, unemployment and productivity/technology shocks are identified using the properties of the theoretical model, as well as the cointegrating properties of the system. By definition, these shocks are allowed to have significant long-run impacts on some or all the variables of the system. The two transitory shocks, which we label as wage and price shocks, are identified by imposing restrictions on the matrix of the contemporaneous effects and, by definition, are not allowed to have any long-run impact on the variables of the system.

Our main findings can be summarized as follows. Following an import price shock, wages and prices rise more significantly in the long run in the EA than in the US, in line with the relative degree of international openness of the two economies. However, given the homogeneity property of the model, real wages and the labour share remain unchanged in the long run. This is not the case after an unemployment or a productivity/technology shock. The unemployment shock implies a permanent decrease of real wages and of the labour share in both economies, but the productivity shock has different implications for the labour share in the long run. In fact, the labour share decreases in the EA and slightly increases in the US. This stems mainly from the fact that in the EA wages only absorb a small proportion of productivity gains whereas in the US they are completely absorbed.

Overall, in terms of long-run persistence, wage and price inflation emerge as more persistent in the EA than in the US in the face of the three permanent shocks, especially so for the unemployment and productivity shocks. This finding on the relative persistence is robust to the changes in the estimation period and in the models' speci-

cations entertained in the paper. The evidence for real wages is not so clear-cut as their relative persistence depends on the type of shock hitting the economy. EA real wages emerge as more persistent following permanent unemployment and productivity shocks, but somewhat less persistent in the face of an import price shock.

Following a permanent unemployment shock it takes around 10 years for real wages and 12 years for wage and price inflation for 99 percent of the disequilibrium to dissipate in the EA. For the US, the corresponding figures are 8 to 9 years for real wages and 9 and 10 years for wage and price inflation, respectively. After an unexpected permanent productivity/technology shock, it takes about 12 years for the full adjustment to take place in real wages and between 10 and 11 years in wage and price inflation in the EA, compared to around 10 years and between 8 and 10 years in the US, respectively. Following a permanent import price shock, it takes about 11 years for the full adjustment in wage and price inflation to take place in the EA, slightly more than in the US.

The larger persistence of wage and price inflation in the EA compared to the US, as documented in this paper, appears consistent with the micro evidence for both economies on wage and price setting practices and on the institutional rigidity of the labour market, which would suggest greater wage and price stickiness in the former. In turn, the relative inflation persistence is also consistent with the evidence found in the literature based on time series models with aggregate price data, which suggests that persistence of price inflation in the EA might be larger than in the US.

In this paper the analysis is conducted using separate VAR models without taking into account the interlinkages between the US and the EA. Even though such an approach is very common in the literature where structural VAR models are used to compare impulse response functions of small or large economies (see, for instance, Peersman, 2005, Canova *et al.*, 2007, or Peersman and Robays, 2009, for the EA and the US, Balsameda *et al.*, 2000, for the OECD countries, and Jacobson *et al.*, 1997, for the Scandinavian countries) one should not overlook the fact that the *ceteris paribus* assumption may have implications for the impulse response functions of the shocks and thus, for the conclusions

drawn here on the relative persistence of real wages, wage and price inflation in the US and the EA¹.

The rest of the paper is organized as follows. Section 2 presents a simple theoretical model of wages and prices, which will be used to identify the long-run wage and price equations, as well as the permanent structural shocks. Section 3 describes the data used for the estimation of the model. Section 4 presents the econometric analysis with a special emphasis on the estimation and identification of the long-run wage and price equations. Section 5 focus on the identification of the structural shocks and on the dynamic response of wages and prices to these shocks, including some measures of short and long-run persistence. Section 6 carries out some robustness checks and tries to account for the main differences in the impulse responses of the shocks in the US and the EA. Section 7 concludes.

2 A macroeconomic model for wages and prices in an open economy

This section presents and discusses a simple model for the determination of wages and prices. The model consists of a production function, a wage setting equation, an equation describing price formation, an equation for the unemployment rate and an equation for the import prices in domestic currency. The equations contain a minimum of dynamics in order to simplify the discussion about the long-run properties of the model.

We assume that production in the economy may be described by a constant returns to scale Cobb-Douglas function (with lower case letters denoting logs):

$$y - e = \eta + (1 - \gamma)(k - e) \quad (1)$$

¹The use of a Global VAR (GVAR) as suggested in Pesaran *et al.* (2004), and Dees *et al.* (2007) would allow us to account for the interdependencies that exist across the two economies and thus could be seen as an alternative approach to the one followed in this paper. However, in our case the advantages of this approach would have to be weighted against its potential limitations, as the identification of the structural shocks based on the properties of an underlying theoretical model and on the cointegrating properties of the system, as done in this paper, would probably not be feasible.

where y is output, e is employment, k is the stock of capital and η a stochastic technology variable. We may further simplify the production function and simply write:

$$h = y - e = \xi_h \quad (2)$$

where h stands for labour productivity and ξ_h for a stochastic technology trend (technical progress and capital accumulation) that shifts labour productivity in the long run. It is assumed that technology is exogenous and follows a stochastic random-walk process, i.e., $\xi_h = \xi_{h-1} + \phi_h$ where ϕ_h is a pure technology innovation².

As regards the wage formation, we assume that wages are determined through a bargaining process between firms and employees (or labour unions). This type of models predicts that the bargaining solution will depend on the real producer wage and productivity on the firm side, and on the real consumer wage on the workers side³. A simple log-linear form of the wage equation corresponding to the bargaining solution can be written as:

$$w - q = k_1 + \mu(p - q) + \delta h - \theta u, \quad 0 \leq \mu, \delta \leq 1, \theta \geq 0, \quad (3)$$

where w is the nominal wage rate, q is the producer price level, p is the consumer price level and u is the unemployment rate.

According to (3), the real wage faced by firms (real producer wage) is affected by $(p - q)$, h and u . The relative price $(p - q)$, which measures the difference between the producer real wage and the consumer real wage, is usually referred to as the *price wedge*, and plays an important role in theoretical wage bargaining models. Its coefficient, μ , can be interpreted as a measure of "real wage resistance" (see Layard *et al.*, 1991), which measures the unions ability to obtain higher wages to compensate for exogenous changes in workers' living standards (increases in p brought about, for example, by changes in

²The assumption that ξ_h follows a random-walk process, rather than a more general I(1) process, is a simplification with no loss of generality, as in the empirical section we will study a VAR which allows for more complex dynamics. A similar remark applies to the other shocks that will be discussed below.

³For text book expositions of the model for wages and prices see, for instance, Layard *et al.* (1991), Lindbeck (1993) or Bardsen *et al.* (2005). The presentation here follows closely the discussion in Bardsen and Fisher (1999), Pétursson (2002), Bardsen *et al.* (2005) and Bardsen *et al.* (2006).



indirect taxes). The bargaining solution (3) also implies that an increase in labour productivity, h , will increase wages, since higher productivity increases the profitability of firms, making them more likely to accept higher wage claims from the unions. The unemployment rate, u , represents the degree of tightness in the labour market, which influences the outcome of the bargaining process through the relative bargaining power of the labour unions and employers organizations.

The wage equation sometimes includes additional terms not explicitly considered in equation (3) that may affect the bargaining outcome, namely some institutional features of the labour market⁴. However, these aspects will not be explicitly modelled or taken into account in the present study. Here we focus on the responses of wages and prices to different types of shocks, assuming that the institutional features of the labour market are given⁵.

For the process of price formation we assume an economy with imperfect competition where producers target their prices, q , as a mark up, ω , over marginal costs. If there are constant returns to scale, marginal costs are constant and therefore prices are set as a mark-up over unit labour costs:

$$q = \omega + (w - h). \quad (4)$$

The mark-up is not necessarily constant and, in an open-economy, it may be a function of the level of international competitiveness (see Layard *et al.*, 1991). Here, we assume that the mark-up may be written as:

$$\omega = k_2 + \lambda(z - q), \quad k_2, \lambda \geq 0, \quad (5)$$

⁴Examples of such terms are changes in the employers and employees tax rates, in the replacement ratio, in the reservation wage or in the union power. See, among others, Nickell and Andrews (1983), Layard *et al.* (1991), Blanchard and Katz (1999).

⁵Nevertheless, as for the effects of this omission on the empirical results reported below, note that the finding of cointegrating relations within our information set implies that the omitted factors are not important in the long run, so that their effects may be seen as subsumed in the stationary part of the model.

where z is the domestic currency price of imports and λ reflects the exposure of domestic firms to international competition. Thus, the smaller is λ the smaller is the pass-through from foreign price or exchange rate shocks to domestic producer prices.

Substituting (5) into (4) gives the producer price level as a mark-up over unit labour costs and import prices:

$$q = \frac{k_2}{1 + \lambda} + \frac{1}{1 + \lambda}(w - h) + \frac{\lambda}{1 + \lambda}z. \quad (6)$$

If we further assume that consumer prices are a weighted average of producer and import prices:

$$p = (1 - \rho)q + \rho z, \quad 0 < \rho < 1, \quad (7)$$

the long-run solution for consumer prices may be written as:

$$p = \frac{(1 - \rho)k_2}{1 + \lambda} + \frac{1 - \rho}{1 + \lambda}(w - h) + \frac{\rho + \lambda}{1 + \lambda}z, \quad (8)$$

where consumer prices appear as a weighted average of unit labour costs and import prices.

From this equation we see that there are two channels through which foreign price and exchange rate shocks impact on domestic consumer prices. First, there is a direct channel through imported goods prices given by ρ . Second, a rise in import prices reduces competitiveness of foreign firms, allowing domestic producers to increase their mark-up and thus the price of their products.

Substituting (7) into (3) and using the price equation in (8) we obtain the long-run wage and price equations used in this paper (ignoring the constants for simplicity):

$$w = (1 + \alpha)p - \alpha z + \delta h - \theta u + \tau_w, \quad (9)$$

$$p = \beta(w - h) + (1 - \beta)z + \tau_p, \quad (10)$$

where $\alpha = \rho(1 - \mu)/(1 - \rho)$ and $\beta = (1 - \rho)/(1 + \lambda)$.

We see the wage and price equations (9) and (10) as long-run or equilibrium targets that are not necessarily achieved by workers and firms in a specific time period. Thus, under the assumption that the two relations are stationary, the stochastic variables τ_w and τ_p can be interpreted as exogenous wage and price shocks that follow stationary stochastic processes, i.e., $\tau_i = \sigma_i \tau_{i-1} + \epsilon_i$, $0 \leq \sigma_i < 1$, ($i = w, p$).

For the unemployment rate, we assume that it is the result of the difference between the labour supply and labour demand, so that in the long run unemployment may be affected both by real wages, $(w - p)$, and productivity, h :

$$u = \pi_1(w - p) + \pi_2 h + \xi_u, \quad (11)$$

where ξ_u is an exogenous stochastic variable. Equation (11), being a reduced form equation, has the implication that ξ_u is a combination of labour supply and demand shocks. If equation (11) turns out to be a cointegrating relation, ξ_u would be interpreted as a stationary shock, while in the absence of cointegration, ξ_u would be seen as stochastic random-walk process, i.e., $\xi_u = \xi_{u-1} + \phi_u$ where ϕ_u is a pure unemployment shock.

Finally, we assume that import prices in domestic currency may depend on unemployment, as well as on productivity:

$$z = \gamma_1 u + \gamma_2 h + \xi_z \quad (12)$$

This way we allow for the possibility of unemployment and productivity/technology shocks to have long-run impacts on import prices through changes in the prices of imported goods in foreign currency, as well as through changes in the exchange rate of the domestic currency. The stochastic variable ξ_z would be a stationary process if equation (12) is a cointegrating relationship. In the absence of cointegration, it will be assumed to follow a random-walk process, i.e., $\xi_z = \xi_{z-1} + \phi_z$ where ϕ_z is a pure exogenous import price shock.

Thus, our theoretical model expressed in terms of the variables we consider in the empirical analysis (w, p, u, h, z) is composed of equations (2),(9),(10),(11) and (12), which can be written compactly as:

$$\begin{bmatrix} 1 & -(1 + \alpha) & \theta & -\delta & \alpha \\ -\beta & 1 & 0 & \beta & -(1 - \beta) \\ -\pi_1 & \pi_1 & 1 & -\pi_2 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -\gamma_1 & -\gamma_2 & 1 \end{bmatrix} \begin{bmatrix} w \\ p \\ u \\ h \\ z \end{bmatrix} = \begin{bmatrix} \tau_w \\ \tau_p \\ \xi_u \\ \xi_h \\ \xi_z \end{bmatrix}. \quad (13)$$

3 The data

To estimate the model above for the US and the EA, we use quarterly seasonally adjusted data for wages (w), labour productivity (h), the unemployment rate (u) and consumer prices (p) and import prices (z). Wages refer to nominal compensation per employee for the whole economy, whereas labour productivity is measured as real GDP per employed person. Consumer prices are measured by the consumer price index (CPI) for the US and the Harmonized Consumer Price Index (HICP) for the EA. Our measure of import prices consists of price indexes for imports of goods in the case of the US and prices of extra-euro area imports of goods in the case of the EA⁶.

The samples comprise quarterly data for the period 1993q1-2007q4 in the case of the US and for the period 1989q1-2007q4 in the case of the EA. The decision not to use a larger sample aims at reducing the probability of significant structural breaks occurring in the sample period, and at the same time allowing us to focus on the most recent period for the two economies⁷.

Figure 1 plots the levels of the logs of all five variables, as well as the real wage, the labour share and the unit labour costs for the US and the EA in the common period

⁶Data for the US are from the Department of Labour (series on unemployment and prices) and the Department of Commerce (national accounts data). Data for the EA aggregate (with 13 countries) was collected from the Eurostat database, except for compensation per employee which is from the ECB database. In the case of the EA, the data had to be backdated, since the series are only available from mid-90s onwards. For this purpose we used the Area Wide Model database (see Fagan *et al.*, 2001) for data prior to 1995/1996 for compensation per employee, labour productivity, unemployment and consumer prices. The series of prices of extra-euro area imports of goods was growth chained linked backwards with Eurostat data for the EA with 12 countries up to the beginning of 1989.

⁷In the case of the EA the sample period was also determined by data availability as the series for the prices of extra-euro area imports of goods starts only in 1989q1.

1993q1-2007q4⁸. From this Figure we can see that real wages in the US decreased until 1997, but soared afterwards with a significantly larger growth rate than in the EA, where they seem to have levelled out after 2003. The labour share, $w - p - h$, also exhibits a different pattern in the two economies with a very pronounced downward trend in the EA and some levelling off from 1997 onwards in the US. An important point to keep in mind is that the labour share does not seem to behave as a stationary variable neither in the EA nor in the US.

For the analysis that follows we assume that w , p , h , z and u are all $I(1)$ variables for both economies. This assumption seems to be broadly supported by the Augmented Dickey-Fuller (ADF) unit-root tests reported in Table 1. In fact, from this Table we conclude that the null of a unit root is not rejected for w , p , h , z and u at a 5% test, while the null of a unit root is rejected for Δw , Δp , Δu , Δh , and Δz at a 5% test or at (around) a 10% test⁹. In addition to the results of the unit roots tests, it is important to notice that treating all the variables as $I(1)$ is also the most sensible choice for the properties of the data, given the theoretical features of our model. Productivity, import prices and unemployment are used to define the common trends of the model and thus, may be seen as the source of the nonstationarity of the system. Therefore, if they are assumed $I(1)$ (the most plausible choice), we cannot treat w , and p as $I(2)$ variables, although Δw and Δp seem to display some nonstationarity according to the unit root tests.

As regards unemployment, it should be mentioned that there are theoretical grounds for claiming that the population unemployment rate should be seen as $I(0)$. However, virtually all the papers in the empirical literature dealing with wage-price models treat the unemployment rate as $I(1)$ ¹⁰. In doing so, it is sometimes argued that it does not matter whether we regard unemployment as $I(1)$ or $I(0)$, as both can be handled in a

⁸In Figure 1, with the exception of the unemployment rate and import prices, the original series were adjusted so that they are equal to 100 in 1993q1 in both economies.

⁹The exceptions are w , Δw and Δp for the EA. Note, however, that the tests results might be reflecting what seems to be a break in the trend of w or in the mean of the Δw and Δp , occurred in early nineties. In fact, if we drop the two first years of the sample we will get $ADF(2)=-3.86$ for Δw and $ADF(2)=-2.96$ for Δp allowing us to reject the null of a unit root at a 5 % significance level.

¹⁰See, for instance, Bardsen *et al.* (2006), Pétursson and Slok (2001), Pétursson (2002), Bardsen and Fisher (1999), Greenslade *et al.* (2002) and Marcellino and Mizon (2000, 2001).

cointegrating VAR and thus, the crucial issue is rather whether or not the resultant long-run wage equation is a valid cointegration equation (see, for instance, Pétursson, 2002 and Bardsen *et al.*, 2006). This claim, however, does not go without problems because assuming that unemployment is $I(0)$ has strong implications for the identification of the long-run wage equation¹¹. In this paper, we treat unemployment as $I(1)$ not only because such an assumption is not inconsistent with the data, but also because, as we shall see below, it is required for cointegration and the identification of the wage equation.

4 Econometric Analysis

According to the model outlined in section 2, we expect two stationary relationships or, in other words, two cointegration vectors, one corresponding to the wage equation and the other to the price equation. Even though the model also allows for some endogeneity of unemployment and import prices, we do not expect these two equations to give rise to additional cointegration relations because the model does not include all the variables we believe might help explain long-run unemployment or import prices behaviour. In order to investigate whether this assumption is consistent with the data, we start by estimating a full-system unrestricted VAR model in the five variables w , p , u , h , and z and test for the existence of cointegration¹². Given that unrestricted cointegration vectors have generally no economic interpretation, the next step is to use structural information derived from the underlying theoretical model to identify its long-run relationships. Finally, it is also possible to test whether some of the variables of the system can be treated as weakly-exogenous for the parameters of the long-run equations.

4.1 Full-system cointegration analysis

We set up a VAR model with three lags and an unrestricted constant. The lag length of the VAR was chosen as the smallest number that ensures that the residuals of the model are normally distributed and do not exhibit significant serial correlation. In addition, we

¹¹For a discussion see Marques (2008).

¹²The model was estimated using Structural VAR 0.40, developed by Anders Warne.

include some impulse dummy variables to account for outliers in the residuals of some equations and, in the case of the US, the quarterly change in the price of oil, lagged one period, as an exogenous stationary variable. Thus, our reduced form VAR model reads as:

$$\Delta x_t = \mu_0 + \varphi \psi' x_{t-1} + \sum_{i=1}^{s-1} \Gamma_i \Delta x_{t-i} + \pi D_t + \eta E_t + \varepsilon_t, \quad t = 1, 2, \dots, T, \quad (14)$$

where $x_t = (w, p, u, h, z)$, D_t is the vector of the dummy variables¹³, E_t is a vector of exogenous difference stationary variables, φ and ψ are the $(5 \times r)$ matrices of the loading coefficients and cointegrating vectors, respectively, under the assumption of r cointegrating vectors (with $r \leq 5$).

It is well-known that the conventional critical values of the Johansen cointegration tests are not appropriate when the model includes intervention dummies¹⁴. One way of overcoming this is to look at the model without the intervention dummies, as in such a case the critical values available in the literature are directly applicable. Table 2 reports the Johansen cointegration trace tests for the unrestricted full systems, estimated without the dummy variables for the US and the EA. For the US, we use a trace test adjusted for the presence of a stationary exogenous variable. For the EA, we look to the small sample corrected tests obtained by using the so-called Reinsel-Ahn correction factor (Cheung and Lai, 1993) and the Bartlett correction factors (Johansen, 2002).

For the US, the trace test unambiguously suggests the existence of two cointegrating vectors. For the EA, the Reinsel-Ahn corrected trace test suggests the existence of two cointegrating vectors at a 5% significance level and of three vectors at a 10% significance level. In turn, the Bartlett corrected trace test suggests the existence of a single cointegrating vector at a 5% significance level, but the value of trace test for the null of at least two cointegrating vectors is not far from the 10% critical level. Thus, the hypothesis of two cointegrating vectors both for the US and the EA emerges as the natural choice that reconciles the empirical evidence in Table 2 with the theoretical features of the model.

¹³The model for the US includes two impulse dummies in the first and fourth quarter of 2006. The model for the EA includes three impulse dummies in the first quarter of 1992, 1994 and 2000, respectively.

¹⁴See, for instance, Johansen and Nielson (1993) or Johansen et al. (2000).

Therefore, we proceed by discussing the identification of the long-run wage and price equations under the assumption of two cointegrating vectors.

4.2 Identification of the wage and price equations

As the unrestricted cointegrating vectors are hardly given any economically meaningful interpretation, we use information derived from the underlying theoretical model developed in section 2 and the VECM model defined above.

In our framework, the identification of the long-run wage and price equations depends on the number of cointegrating vectors of the system. Under the assumption of two cointegrating vectors, the order condition for identification of the wage and price equations (9) and (10) requires one restriction in each equation (besides normalization). Given the restrictions on the parameters of the theoretical model, we see that equations (9) and (10) do meet the order condition for identification, as there is one restriction on the parameters of equation (9) (which involves the coefficients of p and z) and three restrictions on parameters of equation (10) (a zero restriction on the coefficient of the unemployment rate and two restrictions on the coefficients of w , h and z). However, the wage equation is not in fact identified because it does not meet the rank condition for identification. In particular, it can be shown that the restriction in the wage equation does not meet the necessary and sufficient condition stated in Theorem 3 of Johansen (1995).

In order to overcome this problem, we impose $\alpha = 0$ in equation (9) such that z drops from the wage equation¹⁵. In this case it is possible to show that the two equations do meet the necessary and sufficient condition for identification as postulated in Johansen (1995), so that both the wage and price equations become identified. This identifying restriction amounts at imposing $\mu = 1$ at the outset, which means that we are not able to estimate the degree of real wage resistance. Imposing $\alpha = 0$ in equation (9), the system becomes over-identified with three over-identifying testable restrictions.

¹⁵Imposing the restriction of $\delta = 1$ in equation (9) does not allow to overcome the identification problem. In fact, in such a case the restrictions of equation (9) are also met by equation (10), making the rank condition to fail.

For the EA, once we estimate the model imposing these three over-identifying restrictions we find that the coefficient of productivity, δ , becomes close to zero. If we impose this additional restriction, the null of the four over-identifying restrictions is not rejected by the data (the bootstrapped p-value is 0.10). Furthermore, the weak-exogeneity property of the unemployment, productivity and import prices for the parameters of the wage and price equation is also not rejected (the p-value of the test of the six zero restrictions in the φ matrix is 0.26).

For the US, the three over-identifying restrictions on the two cointegrating vectors are not accepted as a whole. This stems from the fact that the restriction of a symmetric coefficient of wages and productivity in the price equation is strongly rejected by the data. When we estimate the model by imposing the two remaining over-identifying restrictions it turns out that δ is not significantly different from one and the null of three over-identifying restrictions is not rejected (the bootstrapped p-value is equal to 0.62). Next, we investigate the weak-exogeneity property of unemployment, productivity and import prices for the parameters of the cointegrating vectors, which is also rejected by the data. This result has the implication that the long-run disequilibria in both wages and prices may have a direct effect on unemployment, productivity and import prices in the US, which is not the case of the EA.

After imposing the 4 over-identifying restrictions together with the weak-exogeneity restrictions, the two long-run estimated wage and price equations for the EA read as follows (with asymptotic standard errors in parenthesis):

$$w = p - \frac{0.157u}{(0.023)} \quad (15)$$

$$p = \frac{0.626(w - h)}{(0.045)} + \frac{0.374z}{(0.045)} \quad (16)$$

For the US, we get the following two long-run estimated wage and price equations (after imposing the three over-identifying restrictions):

$$w = p + h - \frac{0.327u}{(0.065)} \quad (17)$$

$$p = \underset{(0.042)}{0.872}w - \underset{(0.073)}{0.480}h + \underset{(0.042)}{0.128}z \quad (18)$$

Some comments on the long-run wage and price equations are in order. The fact that $\delta = 0$ in the wage equation for the EA probably reflects the fact that the labour share is decreasing during the sample period, which means that wages have not been able to capture a significant fraction of productivity gains. This phenomenon, however, seems not to be present in the wage equation for the US, where the coefficient on productivity turns out to be not statistically different from one, which means that in the long run wages will completely absorb productivity gains. This, as we shall see below, explains why productivity shocks have quite different consequences for the labour share in the two economies.

The coefficient of unemployment in the wage equation is significantly larger in the US, suggesting higher flexibility of wages to unemployment shocks, probably in line with the idea of a smaller degree of employment protection in the US vis-à-vis the EA.

As regards the price equations, we note that both include the restriction of nominal homogeneity, but, in contrast to the EA, the price equation for the US does not involve the unit labour costs as a relevant variable, as productivity enters in the equation with a lower (in absolute terms) coefficient than wages. This implies that not all the productivity gains are reflected in lower prices in the long run, which may suggest that the hypothesis of constant returns to scale is not fully consistent with US data. Another distinguishing feature between the two economies is the estimated parameter of import prices, which is significantly higher in the EA, in line with the relative degree of openness of the two economies.

5 Structural analysis

Having identified the two cointegrating vectors in the VECM we can now proceed to analyse the reaction to specific shocks that hit the economy. We start by discussing the identification of the structural shocks based on the theoretical model and the empirical cointegration results from the previous section. Next, we have a look at the impulse response functions of the structural shocks, with a special focus on their persistence,

and discuss the relative importance of each shock using forecast error variance decompositions.

5.1 Identification of the structural shocks

At this stage, we start by noticing that the VECM (14) is written in reduced form so that the innovations ε_t cannot be given an economic interpretation. In order to identify the structural model, let us assume that the relation between the reduced-form model errors, ε_t , and the structural innovations, v_t , is given by $\varepsilon_t = Bv_t$, where v_t has zero mean and identity covariance matrix. It may be shown that the VECM (14) can be inverted to obtain the so-called *common trends* representation (see Johansen, 1995), which, in the present setting, with 5 endogenous variables and 2 cointegrating vectors is given by (omitting the part concerning the exogenous stationary regressors and the dummy variables, for ease of presentation):

$$x_t = x_0 + A\xi_t + C^*(L)v_t \quad (19)$$

where the $A(5 \times 3)$ matrix has rank 3, and the 3-dimensional vector ξ_t is a *structural random walk*, or *common trend* i.e.,

$$\xi_t = \xi_{t-1} + \phi_t \quad (20)$$

such that

$$\varepsilon_t = Bv_t = B \begin{bmatrix} \phi_t \\ \epsilon_t \end{bmatrix} \quad (21)$$

where ϕ_t are the three trend (permanent) innovations and ϵ_t are the two transitory innovations. By transitory we mean that the innovations do not affect the permanent component of x_t in (19).

From (19), we find that the variables in x_t have an $I(1)$ (permanent) component ($A\xi_t$) and an $I(0)$ (transitory) component ($C^*(L)v_t$). The long-run properties of x_t (conditional on the exogenous stationary regressors, if any) are determined by the three independent stochastic trends ξ_t and the long-run impact matrix A .

In order to identify the structural model (19) from the reduced-form model (14) we need to obtain the (5×5) matrix B . It can be shown that, under the assumption of two cointegrating vectors, this can be achieved by imposing three restrictions on the long-run impact matrix A , which allows identifying the three permanent shocks (trend innovations, ϕ_t) and one restriction on B , the matrix of the contemporaneous impacts, which allows identifying the two transitory shocks ϵ_t ¹⁶.

To discuss further the identification of the permanent shocks in the context of our theoretical model, it is convenient to express the endogenous variables as a function of the exogenous shocks. Ignoring the two transitory shocks, the general solution of the economic model (13), under the assumption of $\alpha = 0$, is given by

$$\begin{bmatrix} w \\ p \\ u \\ h \\ z \end{bmatrix} = \begin{bmatrix} \frac{(1-\beta)\gamma_1-\theta}{(1-\beta)(1+\theta\pi_1)} & \frac{[(1-\beta)\gamma_1-\theta](\delta\pi_1+\pi_2)+[(1-\beta)\gamma_2+\delta-\beta](1+\theta\pi_1)}{(1-\beta)(1+\theta\pi_1)} & 1 \\ \frac{(1-\beta)\gamma_1-\beta\theta}{(1-\beta)(1+\theta\pi_1)} & \frac{[(1-\beta)\gamma_1-\beta\theta](\delta\pi_1+\pi_2)+[(1-\beta)\gamma_2+(\delta-1)\beta](1+\theta\pi_1)}{(1-\beta)(1+\theta\pi_1)} & 1 \\ \frac{1}{1+\theta\pi_1} & \frac{\delta\pi_1+\pi_2}{1+\theta\pi_1} & 0 \\ 0 & 1 & 0 \\ \frac{\gamma_1}{1+\theta\pi_1} & \frac{\gamma_1(\delta\pi_1+\pi_2)+\gamma_2(1+\theta\pi_1)}{1+\theta\pi_1} & 1 \end{bmatrix} \begin{bmatrix} \xi_u \\ \xi_h \\ \xi_z \end{bmatrix} \quad (22)$$

From equation (22) we see that an import price shock, ξ_z , has a zero long-run impact on unemployment and productivity and that an unemployment shock, ξ_u , has a zero long-run impact on productivity. On the other hand, productivity or technology shocks, ξ_h , may have a non-zero long-run impact on all the variables of the model. According to the discussion above, these three zero restrictions allow the exact identification of the three permanent shocks.

In terms of our theoretical model, the permanent import price shock is expected to have an equal long-run impact on nominal wages and prices, thus leaving the real wage unchanged in the long run and having no long-run impact on unemployment or produc-

¹⁶See, among others, King *et al.* (1991), Crowder *et al.* (1999), Gonzalo and Ng (2001) and Lütkephol (2006). For a critical assessment concerning the interpretation of the shocks, see Juselius (2006) and Giannone *et al.* (2008). In particular, Juselius (2006) argues that structural restrictions on the residuals derived from a theoretical model can only be interpretable and meaningful to the extent that the basic hypotheses derived from the theoretical model are in line with the information in the data. Similarly, Giannone *et al.* (2008) show that the estimation of the shocks is not consistent in models contaminated by omitted variables problems.

tivity. Such a shock may stem from an unexpected change in the prices of imported goods or from an unexpected change in the nominal exchange rate. The permanent unemployment shock is identified by the condition that it has a zero long-run effect on productivity and is interpreted as a shock that may stem from an unexpected increase in labour supply (or labour demand)¹⁷. The permanent productivity shock is interpreted as a technology shock (technical progress and capital accumulation) and is allowed to have permanent effects on all the variables of the system. Notice that this identification conforms to the restriction satisfied by a broad range of models, where only technology shocks have a permanent effect on labour productivity (see, for instance, Galí, 1999)¹⁸.

Finally, to identify the two transitory shocks we impose the restriction on the matrix of the contemporaneous impacts that the transitory price shock is not allowed to have a contemporaneous effect on wages. Thus, the transitory wage shock is the shock that may have contemporaneous effects on both wages and prices. As we shall discuss below, the interpretation of these two transitory shocks is not as intuitive as that of the permanent shocks, as in the context of our model they may stem from a variety of alternative sources with different implications for the dynamics of the model.

The matrices of the long-run and contemporaneous effects estimated according to the above identification restrictions are reported in Tables 3 and 4¹⁹. Note that in the case of

¹⁷In our model, it is not possible to distinguish between permanent labour supply and permanent labour demand shocks because none of these variables is explicitly modelled. Usually, it is assumed that labour demand shocks have only transitory effects in this type of models (see, for instance, Jacobson *et al.* 1997, Carstensen and Hansen, 2000, and Hansen and Warne, 2001). However, in Brüggemann (2006), both permanent supply and labour demand shocks are considered.

The important point to notice is that in our model a unit root in unemployment means that there must be some shocks which have permanent effects on unemployment. However, we do not take a stand on whether such permanent changes in unemployment are solely the result of supply shocks or may also result from permanent labour demand shocks.

¹⁸However, some recent papers question the idea that only technology shocks have permanent effects on labour productivity. A unit root in labour productivity may also stem from permanent shocks to the efficiency of investment (investment-specific technical change) according to Fisher (2006), or from shocks to the capital income tax (dividend taxation), according to Uhlig (2004). For a discussion on the interpretation and identification of technology shocks, see for instance, Dedola and Neri (2006).

In Marques (2008) the identification of the productivity and unemployment shocks assumes that the unemployment rate does not depend on productivity in the long run, given that $\delta = 1$ in the wage equation (the so-called Layard-Nickell condition). For a discussion, see Jacobson *et al.* (1997) or Layard and Nickell (1986).

¹⁹Note that the identification of the structural shocks assumes that the innovations have unit variances. In particular, the coefficient (i,j) of the long-run impact matrix measures the long-run effects on the i-th endogenous variable from a unit shock to the j-th trend innovation.

the EA, the elements of the lower-left 3×2 block of the matrix of the contemporaneous impacts are equal to zero, given that the restriction of weak-exogeneity of u , h and z was imposed on the matrix of the loadings (see, Fisher and Huh, 1999).

5.2 Wage and price dynamics

We now look at the impulse response functions with a special emphasis on real wages and wage and price inflation. The impulse response functions of model variables, as well as the responses of real wages, the labour share and wage and price inflation to the three permanent and the two transitory shocks are depicted in Figures 2 to 6²⁰.

Table 5 presents two measures of persistence for real wages, wage and price inflation for the US and the EA. These two measures are defined as the proportion of the total disequilibrium that dissipates in the two years after the shock, and the number of periods required for 99 percent of the total disequilibrium to dissipate. These measures appear as particularly suitable to evaluate how fast the impulse response functions approach the new long-run equilibrium level (see, for instance, Dias and Marques, 2005). We see the first measure as a simple way of quantifying the speed of reaction in the short-term, so that we will loosely denote it as "short-term persistence" and the second as a way to measure "long-run persistence". When the speed of adjustment to the new equilibrium is constant, the two measures will give the same message on the relative persistence of the shocks. However, when the speed of the responses varies throughout the convergence period, we will need to look at both measures to better characterize the adjustment process. For simplicity, we assume that all the adjustments have taken place by the very last period of the simulations (the 60th quarter)²¹.

²⁰The impulse response functions for the five original variables of the system are depicted together with 80 percent confidence bands.

²¹This in fact seems a reasonable simplifying assumption given the visual inspection of the impulse response functions in Figures 2 to 6. Note that our measure of persistence is not affected if the total adjustment occurs in less than the assumed 60 periods.

5.2.1 Permanent import price shock

Figure 2 depicts the impulse responses to a permanent positive import price shock in the US and the EA, which is identified by the condition that it has no long-run effects on unemployment and productivity. As expected, given the property of long-run nominal homogeneity of the model, a permanent positive shock in import prices brings about a permanent increase in nominal wages and prices of the same magnitude in the long run. As a result, real wages, as well as the labour share remain unchanged. A noteworthy result is that the import price shock has a larger impact on prices (and wages) in the EA than in the US, in line with the estimated parameters of wage and price equations, which reflect the relative openness of the two economies.

As could also be expected, prices increase faster than nominal wages in the short run, so that real wages decrease during the first two years in the US and the first three years in the EA. In addition, the adjustment of real wages displays a very persistent hump-shaped response to this type of shock in both economies, particularly in the US. From Table 5, we can see that real wages emerge as clearly more persistent in the US than in the EA in the short-run following a permanent import price shock. In fact, in the first two years after the shock, only about 30 percent of the disequilibrium has dissipated in the US, compared to 60 percent in the EA. The higher short-term persistence of real wages in the US stems from the fact that, despite exhibiting a smaller long-run impact, both wages and prices react relatively slower during the first two years after the shock.

In the case of price inflation, the largest impact occurs almost contemporaneously in both economies. Interestingly, while in the US both wage and price inflation exhibit a strong short-term response, in the EA the largest impact on wage changes occurs only after 10 quarters and both wage and price inflation display a more sluggish response. From Table 5 we can see that after 2 years only 42 percent and 55 percent of the total disequilibrium of wage and price inflation has dissipated in the EA, compared to 80 percent in the US.

The apparent contradiction between the speed of adjustment of real wages on the one side, and wage and price inflation on the other, stems from the fact that the scalar measure of short-term persistence is largely affected by a stronger reaction of both wage

and price inflation in the US immediately after the shock. At longer horizons, the difference between the two economies partly fades away, but the number of periods required for 99 percent of the total disequilibrium to dissipate for wage and price inflation in the EA still remains slightly above that of the US.

5.2.2 Permanent unemployment shock

Figure 3 depicts the impulse responses to a permanent positive unemployment shock, which is identified by the condition that it has no long-run effect on productivity. As a result of the shock, real wages and the labour share decrease permanently to a lower equilibrium level. However, an unexpected permanent shock in unemployment seems to affect EA wages more significantly. The explanation for this result might be found in the response of import prices and in the unemployment rate itself. Although import prices increase permanently in the long run in both economies (eventually following a currency depreciation induced by higher unemployment), the reaction is stronger in the US, possibly due to higher sensitivity of the dollar to domestic conditions. In addition, the unemployment rate levels off at a higher level in the EA, eventually reflecting greater institutional rigidity of the labour market (see, for instance, Abbritti and Weber, 2008, and Peersman and Robays, 2009). As a consequence, prices rise more markedly in the US economy relatively to the EA, and partially offset the effect of higher unemployment on wages in the long run, which remain virtually unchanged.

In the short run, labour productivity temporarily increases and unemployment temporarily falls in the US leading to a rise in nominal wages. Given the sluggish response of prices in the short-term, real wages increase in the first year after the shock, resuming a downward trend afterwards. This contrasts with the short-term behaviour of real wages in the EA, which start declining immediately after the shock, reflecting the increase in prices. As a result, in the short-run real wages adjust somewhat slower in the US relatively to the EA. In fact, the proportion of the disequilibrium in real wages dissipated after 2 years is 50 percent in the US and 64 percent in the EA.

As regards wage and price inflation, both variables emerge as more persistent in the EA than in the US, especially at longer horizons. The full adjustment takes about 9 to 10 years in the US compared to about 12 years in the EA.

5.2.3 Permanent productivity shock

Figure 4 depicts the impulse responses to a permanent positive technology shock that shifts productivity in the long run and, by definition, may impact on the long-run level of all the variables of the model. In the context of our estimated model for the US, all productivity gains are absorbed by nominal wages in the long run ($\delta = 1$ in equation (9)). In contrast, in the EA changes in productivity have no long-run direct impact on wages, as $\delta = 0$ in equation (9). Thus, the effects of a productivity shock on wages and prices may be expected to differ markedly between the two economies. From Figure 4 we find that this is indeed the case, especially where prices are concerned. The long-run response of nominal wages is similar in both models, although slightly more pronounced in the case of the US given the estimated long-run wage equation. In what concerns prices, a permanent productivity shock in the US causes a decline of import prices in the long run which combined with lower unit labour costs (stemming from a stronger reaction of productivity relatively to wages) translates into a decrease of consumer price level in the long run. In the EA, there is a permanent increase in the equilibrium price level brought about by a positive reaction of import prices to the productivity shock²². The labour share rises in the US (but not significantly so) and declines in the EA due to different relative magnitudes of the long-run effects on real wages and productivity. This appears to be consistent with data that indicate a broadly stable labour share in the US and a downward trend in the EA during the period under analysis.

²²The final effect on import prices (in domestic currency) may be thought of as depending on the relative importance of two channels with opposite effects. The exchange rate channel, which could be expected to bring about a decrease in import prices through a currency appreciation and the foreign price channel, which could be expected to increase import prices through higher import demand brought about by a rise in economic activity. The results suggest that the first channel seems to be stronger in the US, while in the EA the second one seems to predominate.

As regards the persistence of the responses, real wages emerge as more persistent in the EA than in the US. It takes almost 12 years for the full adjustment to take place in the EA, compared to about 10 years in the US.

An unexpected positive shock in productivity has a temporary positive impact on wage inflation in both economies, but brings about a symmetric reaction of price inflation (it declines in the US and rises in the EA), in line with the behaviour of nominal wages and consumer prices. The long-run adjustment of wage and price inflation is somewhat faster in US than in the EA (it takes between 8 and 10 years in the US and between 10 and 11 years in the EA).

Overall, in terms of long-run persistence, wage and price inflation appear as more persistent in the EA than in the US, in the face of the three permanent shocks, especially so in the face of unemployment and technology shocks. The evidence for real wages is not so clear-cut as their relative persistence depends on the type of shock hitting the economy. EA real wages emerge as more persistent following permanent unemployment and productivity shocks, but somewhat less persistent in the face of an import price shock.

5.2.4 Transitory wage and price shocks

We now take a brief look to the two transitory shocks (see Figures 5 and 6). The interpretation of these shocks is not as intuitive as that of the permanent shocks because their identification is not so well grounded on economic theory. In our model, a transitory wage shock may stem from changes in social security contributions, exogenous increase in the bargaining power of the employees (due, for instance, to changes in employment protection legislation), changes in some institutional features of the labour market (replacement ratio or reservation wage) or exogenous changes in demand, while a temporary price shock may stem from an exogenous mark-up change or from indirect taxes or interest rate shocks. Furthermore, recall that the weak-exogeneity restrictions imposed for unemployment, productivity and import prices in the model for the EA implies that the contemporaneous impact of the two transitory shocks on those variables is

null for this economy. All these facts may help to explain why the shocks have different implications in the US and the EA, calling thus for different interpretations.

In the EA, the effects of the transitory positive wage shock look very much like the expected effects of a transitory positive demand shock. In fact, from Figure 5 we see that the temporary increase in nominal wages is associated with a temporary decrease in unemployment that lasts for about 3 to 4 years and a temporary increase in domestic and import prices. Overall, this shock may be seen as evidence that transitory demand shocks create a negative short-run relation between real wages and unemployment. In the US, in contrast, the effects of the shock seem more in line with the expected effects of, for instance, an increase in wages brought about by an exogenous change in the bargaining power of the unions. In fact, the transitory wage increase is associated with a temporary increase in unemployment and a temporary decrease in domestic and import prices. Overall, this shock gives rise to a positive short-run relation between real wages and unemployment.

As regards the transitory price shock, its effects in both economies look very much like the possible consequences of a monetary policy shock (unexpected increase in the interest rate) with the so-called liquidity effect. In fact, from Figure 6 we see that in the very short run (first quarter) there is an increase in inflation and a decrease afterwards. Such a shock is also accompanied in both economies by temporary increase in unemployment (due to a decrease in demand) and a temporary decrease in productivity. The reaction of import prices is, however, different in the US and the EA. While in the US import prices increase (due possibly to a currency depreciation brought about by higher unemployment and lower productivity), in the EA import prices temporarily decrease (possibly due to a currency appreciation brought about by higher interest rates). Overall, real wages temporarily decrease in both economies, but while the decrease is very short-lived in the EA it emerges as very persistent in the US.

The effects of the transitory wage shock on real wages, wage and price inflation die out quickly in the first years after the shock (two years after the shock more than 70 percent of the disequilibrium has dissipated in both economies for real wages and wage inflation), but, in some cases, the effects of the price shock emerge as significantly

persistent. Overall, the long-run persistence of the two shocks in both economies is not significantly lower than that of the permanent shocks, reflecting the fact that, after the first years, the adjustment of the variables slows down significantly, thus prolonging the duration of the shocks.

5.3 Sources of wage and prices fluctuations

Forecast-error variance decompositions allow us to investigate how important were the different shocks in accounting for the observed fluctuations in wages and prices at the different horizons during the sample period.

As expected, the two transitory wage and price shocks explain the largest amount of the variation in the corresponding variables forecast errors up to 4 quarters, whereas permanent shocks play a more predominant role at longer horizons (see Table 6).

In the sample period, import price shocks emerge as the main driver of EA price developments at the business cycle horizons, being responsible for approximately 60 percent of the variation of prices' forecast errors. This is not the case for the US, where only 15 percent of the variation in prices' forecast errors is attributable to this kind of shocks.

Unemployment shocks emerge as the most important origin of wage fluctuations at the business cycle horizon, accounting for about 40 percent of the variation in wages' forecast errors in the two economies. The role in explaining price dynamics is also relevant, with a significant fraction of the variation in the corresponding forecast errors being attributable to this kind of shocks (17 percent in US and 26 percent in the EA).

The permanent productivity shock explains a considerable amount of the variation in forecast errors of prices and, to a lesser extent, of wages in the US (around 60 and 30 percent, respectively), but plays a minor role in EA developments (only around 10 percent of the forecast error variance of wages and prices is attributable to this kind of shocks).

Summing up, very short-term wage and price dynamics stemmed mainly from transitory shocks to wages and prices, respectively. At the business cycle horizon, variation in the forecast errors of wages is attributable mainly to unemployment shocks, whereas

variation in the forecast errors of prices is attributable mainly to productivity shocks in the US and import price shocks in the EA. To a lesser extent, unemployment shocks also contributed to explain price fluctuations in both economies. Finally, the comparison of the main sources of wage and price fluctuations between the two economies suggests that productivity shocks played a much more important role in the US than in the EA, while the opposite is true for import price shocks.

6 Accounting for the main differences between the US and the EA: some robustness checks

According to the results presented in the previous section, wage and price inflation emerge as less persistent in the US compared to the EA in the face of the three permanent shocks. In this section we carry out some robustness checks in order to see whether this finding is likely to stem from the use of different sample periods and/or different model specifications rather than from structural dissimilarities between the two economies.

In order to assess whether the use of different model specifications and/or of different sample periods play an important role in explaining the main differences documented in this paper, we estimate a new model for the EA using the same period as for the US (1993q1-2007q4), and including the quarterly change in the price of oil lagged one period as an exogenous regressor²³. This way we get two models that are strictly comparable, as far as the specification and sample period are concerned.

For the new EA model, the cointegration tests still suggest the existence of two cointegrating vectors. The coefficient of the unemployment rate in the long-run wage equation does not change significantly but the coefficient of import prices increases vis-à-vis the one obtained in equation (16) above. Importantly, the main qualitative features of the responses to the permanent shocks do not change and the conclusions of section 5 about the relative persistence of the two economies still hold²⁴. If anything, the long-run

²³The new cointegrating VAR model includes three lags of the endogenous variables and a dummy variable, which equals 1 in 1999q1, and is zero otherwise.

²⁴As could be expected some significant changes occur as regards the contribution of the shocks for the observed fluctuations in wages and prices, given the sample dependence of the relative importance

persistence of wage and price inflation in the EA in the new model emerges as somewhat higher (especially so for the import price and productivity shocks), thus increasing the difference vis-à-vis the US economy²⁵.

In the context of our theoretical model for wages and prices, we believe that the main differences concerning the persistence and characteristics of the responses to the shocks may be traced to some macro and micro structural differences between the two economies, among which, international openness, institutional rigidity of the labour market, as well as price and wage setting practices, may be expected to play a prominent role.

The different degree of openness implies that import price shocks have significantly different implications for the two economies. On the one hand, import price shocks are expected to have stronger direct long-run impact on the EA, given the larger share of imports in total GDP in this economy, which is reflected in the significantly larger coefficient associated with import prices in the estimated long-run price equation. On the other hand, the higher openness of EA is also expected to imply larger effects stemming from some shocks usually associated with globalisation (imports of final goods, outsourcing of the production of intermediate goods), with implications on the labour market. For instance, a smaller bargaining power of the unions or immigrant employees has been used to help explaining the strong decreasing trend exhibited by the labour share in some EA countries (see, for instance, Bentolila *et al.*, 2008, for Spain, and European Commission (2007) for the OECD countries), which is a way of explaining why, in the EA,

of the shocks. In particular, the contribution of import price shocks in explaining price developments in the EA at business cycle frequencies appears now significantly reduced and productivity shocks emerge as playing a more important role. This comes hardly as a surprise, because the importance of import price shocks in the model for the EA for the 1989q1-2007q4 period was strongly dependent upon its contribution during the first years of the sample, which were now removed from the estimation period. This is particularly visible from the forecast errors historical decomposition (available upon request). For similar reasons, unemployment shocks play now a less important role (and import price shocks and productivity shocks a more important one) in accounting for wage fluctuations.

²⁵In order to see whether the use of the price of oil in the two models could be distorting the main conclusions documented in the paper on the relative persistence of the shocks, we also estimated a model for the US without the price of oil, and compared the results to the ones obtained for the EA in the model used in section 5. Again we find that the conclusion about the relative persistence of the shocks between the two economies does not change (if anything, the long-run persistence of wage and price inflation in the US emerges as somewhat smaller for the different shocks, thus increasing the difference vis-à-vis the EA).

Detailed output of these models is available from the authors upon request.

workers have not been able to absorb a significant proportion of productivity gains²⁶. This, as we have seen, emerges in our model as an estimated coefficient of productivity in the long-run wage equation, which is not statistically different from zero ($\delta = 0$ in equation (15)). In strong contrast, the evidence for the US suggests that wages have been able to completely absorb productivity gains in the long run. In fact, the estimated $\delta = 1$ in equation (17) for the US is consistent with the evidence in Feldstein (2008), who shows that in this economy the rise in compensation per employee has been very similar to the rise in productivity. Similar evidence can be seen in European Commission (2007), where the US emerges as the country where the labour share exhibits a close to stationarity long-run behaviour, in contrast to the EA and Japan, for which the labour shares display a decreasing trend during the last twenty years or so.

As regards the institutional rigidity of the labour market (involving, for instance, employment protection, firing and hiring costs), the evidence in the existing literature suggests that the US labour market is more flexible compared to the EA, thus allowing a faster adjustment to shocks hitting the economy (see, for instance, Abbritti and Weber, 2008 and Peersman and Robays, 2009).

Finally, as mentioned in the introduction of this paper, the US and the EA also differ as far as price and wage setting practices are concerned. Using comparable data sets of quantitative micro data on consumer prices, Dhyne *et al.* (2006) find that the estimated monthly frequency of price changes is around 15 percent in the EA and 25 percent in the US. In turn, the average duration of a price spell ranges from 4 to 5 quarters in the EA and from 2 to 3 quarters in the US²⁷. These results on quantitative data are consistent with evidence from survey data. In fact, according to Fabiani *et al.* (2006), the median frequency of price changes is one year in the EA, lower than the estimated 1.4 price changes a year in the US obtained in Blinder *et al.* (1998)²⁸. Empirical evidence

²⁶The existence of skilled-biased technological progress is also suggested as an alternative to globalisation to explain the decreasing labour share in most OECD countries. The existence of such skilled-biased technological progress increases the income share of skilled workers but lowers the share of the unskilled workers, as the latter are substituted by capital (see European Commission, 2007).

²⁷See also Bills and Klenow (2004) and Klenow and Kryvstov (2008) for the US.

²⁸Altissimo *et al.* (2006) notice that the lower frequency of price changes in the EA cannot be explained by differences in consumption structure, as EA consumption is characterised by a larger share of food products (which change prices frequently) and a smaller share of services (with less frequent

for nominal wages is not as extensive as it is for prices. Nevertheless, recent evidence based on survey data suggests that nominal wages in the EA are changed less often than prices. In fact, according to Druant *et al.* (2009) around 60 percent of the firms change base wages once a year and 26 percent less frequently, implying an estimated average duration of wage spells of about 15 months. Even though there is no comparable evidence for the US, it is usually accepted in the literature that wages in the US are less rigid than in the EA (see, for instance, Altissimo *et al.*, 2006, Peersman and Robays, 2009).

Thus, overall, our finding of a larger persistence of wage and price inflation in the EA compared to the US appears consistent with the above micro evidence for both economies on wage and price setting practices, as well as on the institutional rigidity of the labour market, which suggest greater wage and price stickiness in the former. In turn, the relative inflation persistence documented in this paper is also consistent with the evidence found in the literature based on time series models with aggregate price data, which suggests that persistence of price inflation in the EA might be larger than in the US (see, for instance, Levin and Piger, 2004, Gatzinski and Orlandi, 2004, or Altissimo *et al.*, 2006).

7 Conclusions

This paper investigates wage and price dynamics in the United States (US) and the Euro Area (EA) assuming an economy where wages are determined through a bargaining process and prices are set by imperfectly competitive firms. The analysis is conducted within a structural vector error-correction model (SVECM) where two separate cointegrating relationships for wages and prices are identified by imposing the long-run restrictions implied by the theoretical model. Against this background, we identify three permanent shocks (labelled as import price, unemployment and productivity/technology shocks) and two transitory shocks (labelled as wage and price shocks). By definition, the permanent shocks are allowed to have significant long-run effects on some (or all)

price changes). Thus, the difference in the frequency of price changes would be even larger if both economies shared the same consumption structure.

the variables of the system as opposed to transitory shocks that do not affect the model variables in the long run.

Following an import price shock, we find that wages and prices rise more significantly in the long run in the EA than in the US, in line with the international openness of both economies. However, given the homogeneity property of the model, real wages and the labour share remain unchanged in the long run. This is not the case in the face of an unemployment or a productivity/technology shock. The unemployment shock implies a permanent decrease of real wages and of the labour share in both economies, but the productivity shock has different implications for the labour share in the long run. In fact, the labour share decreases in the EA and slightly increases in the US. This stems mainly from the fact that in the EA wages only absorb a small proportion of productivity gains whereas in the US they are completely absorbed.

Overall, in the long run, wage and price inflation emerge as more persistent in the EA than in the US in the face of the three permanent shocks, especially so for the unemployment and productivity shocks. This finding on the relative persistence is robust to the changes in the models' specifications and in the estimation period entertained in the paper. The evidence for real wages is not so clear cut, as the relative persistence depends on the type of shock. EA real wages emerge as more persistent following permanent unemployment and productivity shocks, but somewhat less persistent in the face of an import price shock.

Following a permanent unemployment shock it takes around 10 years for real wages and 12 years for wage and price inflation for 99 percent of the disequilibrium to dissipate in the EA. For the US, the corresponding figures are 8 to 9 years for real wages and 9 and 10 years for wage and price inflation, respectively. After an unexpected permanent productivity/technology shock, it takes about 12 years for the full adjustment to take place in real wages and between 10 and 11 years in wage and price inflation in the EA, compared to approximately 10 years and between 8 and 10 years in the US, respectively. In the face of a permanent import price shock, it takes about 11 years for the full adjustment in wage and price inflation to take place in the EA, slightly more than in the US.

The larger persistence of wage and price inflation in the EA compared to the US, as documented in this paper, appears consistent with the micro evidence for both economies on wage and price setting practices and on the institutional rigidity of the labour market, which suggest greater wage and price stickiness in the former. In turn, the relative inflation persistence is also consistent with the evidence found in the literature based on time series models with aggregate price data, which suggests that persistence of price inflation in the EA might be larger than in the US.

For the sample periods of the two main models estimated in the paper, the relative importance of the sources of wage and price fluctuations differs significantly for the two economies. At the business cycle horizon, import price shocks emerge as especially important for price dynamics in the EA while productivity/technology shocks appear to have been the main driver of prices in the US. Wage dynamics were mainly determined by unemployment shocks in both economies, but a significant role was also played by productivity/technology shocks in the US and by import price shocks in the EA.

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TABLE 1 - Unit Root Tests

US				
<i>w</i>	<i>p</i>	<i>u</i>	<i>h</i>	<i>z</i>
ADF(0)=-3.00	ADF(6)=-1.63	ADF(2)=-2.55	ADF(0)=-2.11	ADF(1)=-0.49
Δw	Δp	Δu	Δh	Δz
ADF(0)=-7.26	ADF(3)=-3.66	ADF(1)=-2.78	ADF(0)=-9.28	ADF(0)=-4.74
EA				
<i>w</i>	<i>p</i>	<i>u</i>	<i>h</i>	<i>z</i>
ADF(3)=-4.86	ADF(3)=-3.00	ADF(5)=-1.32	ADF(4)=-1.19	ADF(8)=-3.07
Δw	Δp	Δu	Δh	Δz
ADF(2)=-1.99	ADF(2)=-1.89	ADF(4)=-3.10	ADF(3)=-4.88	ADF(4)=-4.81

Note: ADF(k) stands for the Augmented Dickey-Fuller test with k lags, where k is the smallest number of lags that ensures that the residuals do not exhibit significant autocorrelation. The critical values for *w*, *p*, *h* and *z* (model with a time trend) are around -4.11 (1%) and -3.48 (5%). The critical values of the test for *u*, Δw , Δp , Δu , Δh and Δz (test with a constant) are -3.53 (1%), -2.90 (5%) and -2.57 (10%);

TABLE 2 - Cointegration Trace Tests

Rank	US	EA				
	Trace test (a)	Corrected trace test(b)	Corrected trace test(c)	90% quantile	95% quantile	99% quantile
0	87.45***	84.15***	71.15**	64.74	68.68	76.37
1	50.38**	47.24**	41.12	43.84	47.21	53.91
2	21.98	27.13*	25.74	26.70	29.38	34.87
3	5.10	12.83	12.75	13.31	15.34	19.69
4	0.01	1.96	1.53	2.71	3.84	6.64

Note: ***, ** and * mark significance at 1%, 5% and 10% respectively;
 (a) Trace test that allows for the presence of an exogenous stationary variable
 (b) Small sample corrected trace test using the Reinsel-Ahn correction (Cheung and Lai, 1993);
 (c) Small sample corrected trace test using the Bartlett correction factors (Johansen, 2002);

TABLE 3

Contemporaneous matrix of the structural VAR model for the US

<i>Equation</i>	ξ_w	ξ_p	ξ_u	ξ_h	ξ_z
<i>w</i>	0.002899 (0.000379)	0	0.000676 (0.000950)	-0.001546 (0.0007192)	0.000468 (0.000665)
<i>p</i>	-0.000218 (0.000301)	0.001506 (0.000233)	-0.000359 (0.000354)	0.000090 (0.000423)	0.001054 (0.000340)
<i>u</i>	0.007791 (0.003179)	0.010345 (0.003434)	0.007288 (0.006647)	0.009243 (0.005437)	-0.012768 (0.003723)
<i>h</i>	-0.000950 (0.000653)	-0.001567 (0.000696)	0.003578 (0.000793)	0.000738 (0.002074)	0.001529 (0.000806)
<i>z</i>	-0.004449 (0.001831)	0.007063 (0.001960)	0.001859 (0.004269)	-0.007809 (0.001949)	0.003194 (0.002302)

Long-run matrix of the structural VAR model for the US

<i>Equation</i>	ξ_w	ξ_p	ξ_u	ξ_h	ξ_z
<i>w</i>	0	0	-0.000743 (0.000752)	0.003134 (0.002837)	0.001248 (0.000264)
<i>p</i>	0	0	0.002633 (0.001542)	-0.004450 (0.005044)	0.001248 (0.000264)
<i>u</i>	0	0	0.010323 (0.005207)	-0.009263 (0.014006)	0
<i>h</i>	0	0	0	0.004555 (0.003343)	0
<i>z</i>	0	0	0.025583 (0.012977)	-0.038947 (0.044968)	0.001248 (0.000264)

TABLE 4

Contemporaneous matrix of the structural VAR model for the EA

<i>Equation</i>	ξ_w	ξ_p	ξ_u	ξ_h	ξ_z
<i>w</i>	0.003009 (0.000249)	0	-0.000042 (0.000370)	0.000277 (0.000359)	-0.000297 (0.000357)
<i>p</i>	0.000122 (0.000163)	0.001388 (0.000115)	0.000788 (0.000269)	0.000159 (0.000353)	0.000869 (0.000237)
<i>u</i>	0	0	0.009225 (0.001492)	-0.002320 (0.003586)	-0.004509 (0.001881)
<i>h</i>	0	0	-0.000650 (0.000873)	0.002593 (0.000317)	-0.000407 (0.000519)
<i>z</i>	0	0	0.01160982 (0.004432)	0.005948 (0.005160)	0.016976 (0.002892)

Long-run matrix of the structural VAR model for the EA

<i>Equation</i>	ξ_w	ξ_p	ξ_u	ξ_h	ξ_z
<i>w</i>	0	0	-0.006560 (0.002717)	0.001570 (0.002793)	0.003243 (0.000683)
<i>p</i>	0	0	-0.000818 (0.001365)	0.001226 (0.001018)	0.003243 (0.000683)
<i>u</i>	0	0	0.036575 (0.012590)	-0.002192 (0.013936)	0
<i>h</i>	0	0	0	0.002677 (0.000431)	0
<i>z</i>	0	0	0.008798 (0.003181)	0.005133 (0.003416)	0.003243 (0.000683)

TABLE 5 - Persistence of wages and prices

	Δw		Δp		$w - p$	
	US	EA	US	EA	US	EA
Share of total disequilibrium dissipated after 8 quarters						
Permanent import price shock	0.80	0.42	0.80	0.55	0.28	0.60
Permanent unemployment shock	0.58	0.25	0.65	0.40	0.50	0.64
Permanent productivity shock	0.54	0.63	0.58	0.64	0.55	0.44
Transitory wage shock	0.90	0.87	0.83	0.59	0.73	0.72
Transitory price shock	0.57	0.48	0.85	0.75	0.34	0.51
Number of quarters required for 99 % of the total disequilibrium to dissipate						
Permanent import price shock	42	44	40	43	43	40
Permanent unemployment shock	41	48	37	47	35	41
Permanent productivity shock	39	42	35	42	41	47
Transitory wage shock	29	34	40	41	44	38
Transitory price shock	45	44	36	40	38	46

TABLE 6

Forecast error variance decomposition at the business cycle frequencies^(a)				
	Wages		Prices	
	US	EA	US	EA
Permanent import price shock	0.15	0.24	0.15	0.57
Permanent unemployment shock	0.41	0.40	0.17	0.26
Permanent productivity shock	0.31	0.12	0.63	0.10
Transitory wage shock	0.10	0.20	0.01	0.01
Transitory price shock	0.03	0.03	0.04	0.07

(a) Average contribution of each shock in the 12th, 16th and 20th quarter.

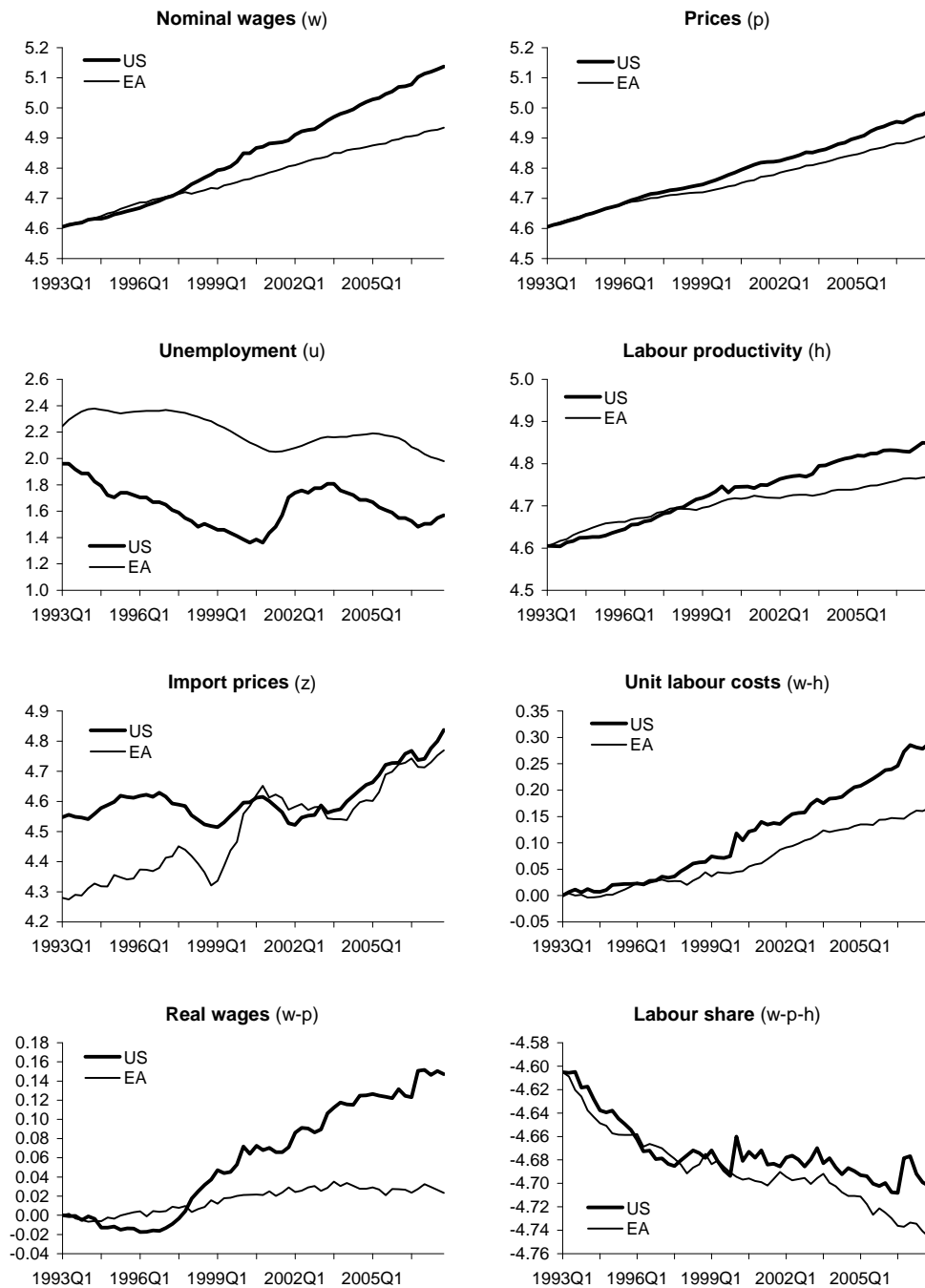


Figure 1: The data in logs

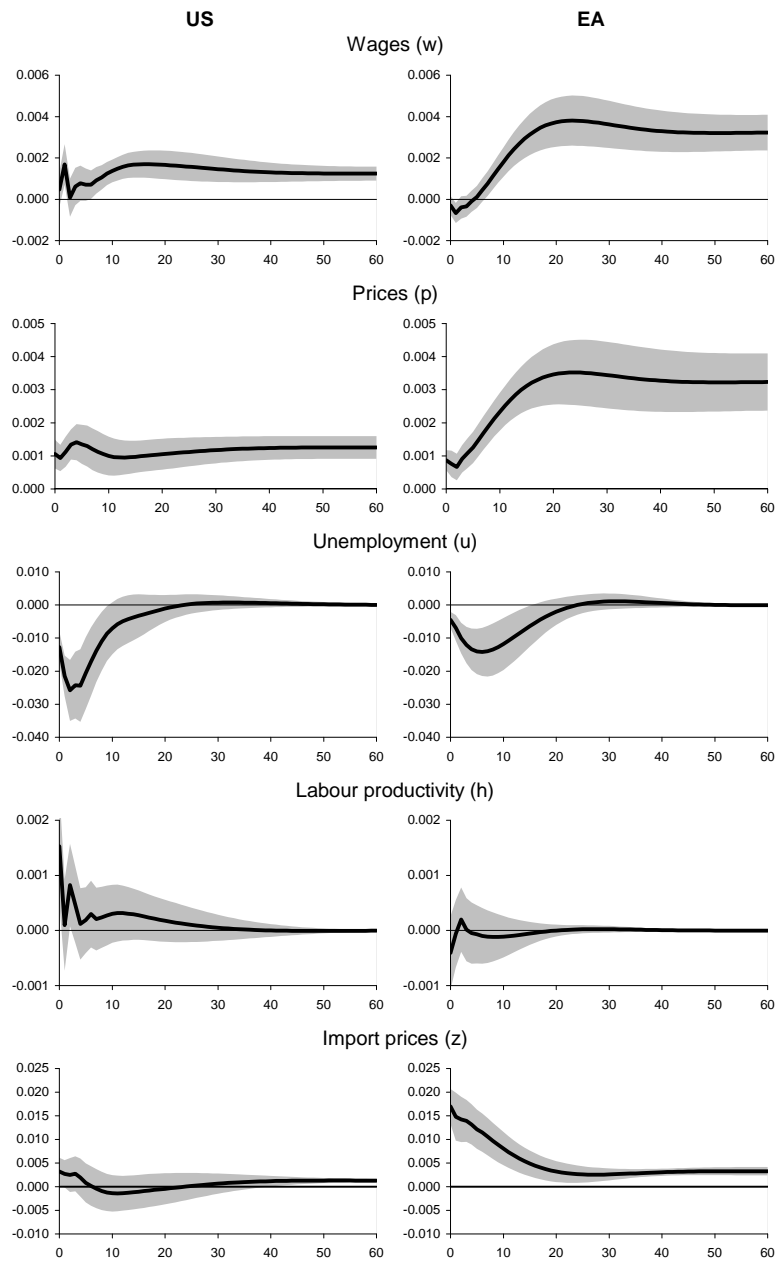


Figure 2: Responses to a permanent import price shock

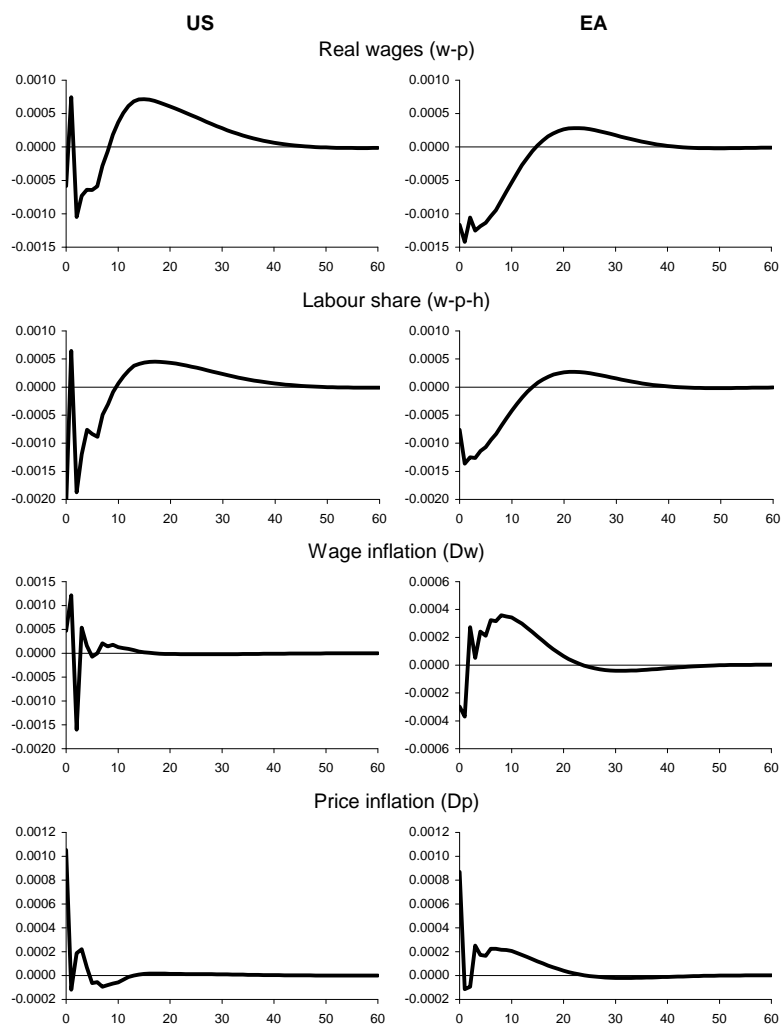


Figure 2: (cont.) Responses to a permanent import price shock

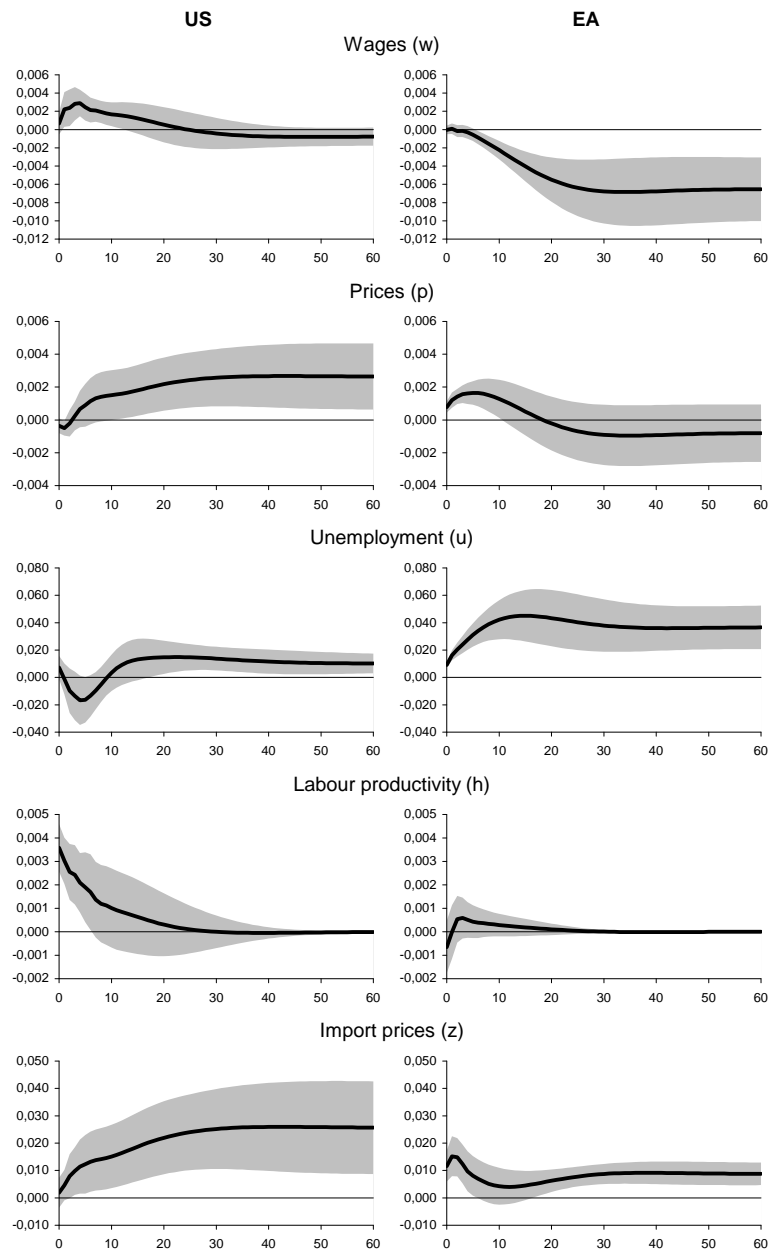


Figure 3: Responses to a permanent unemployment shock

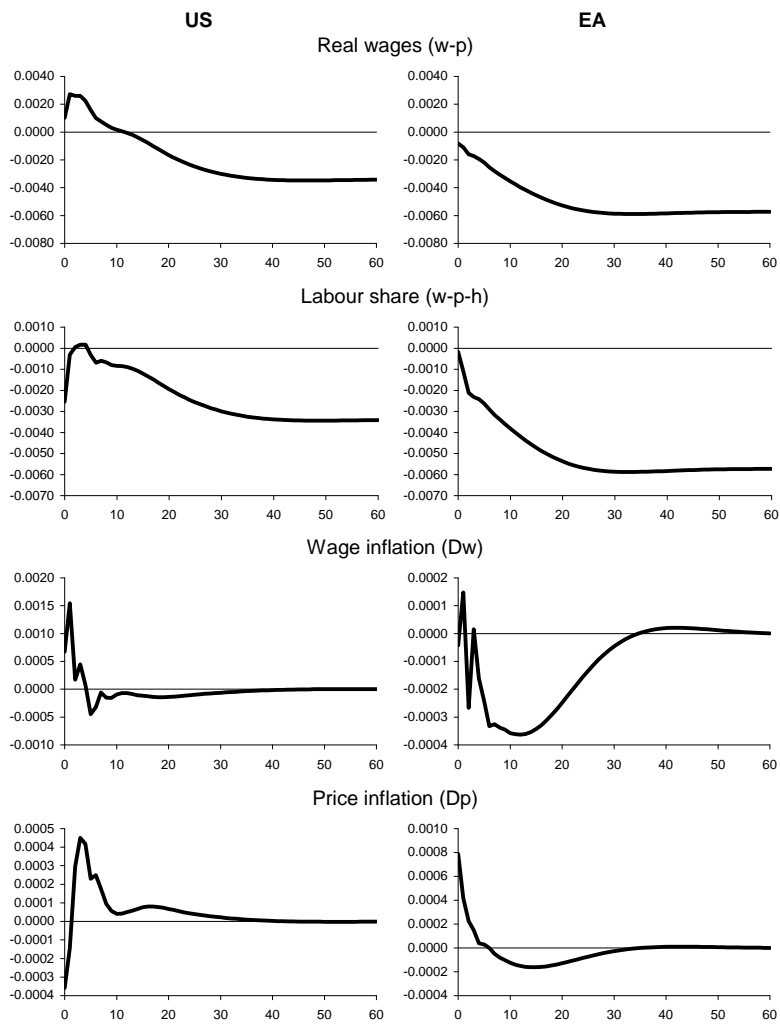


Figure 3: (cont.) Responses to a permanent unemployment shock

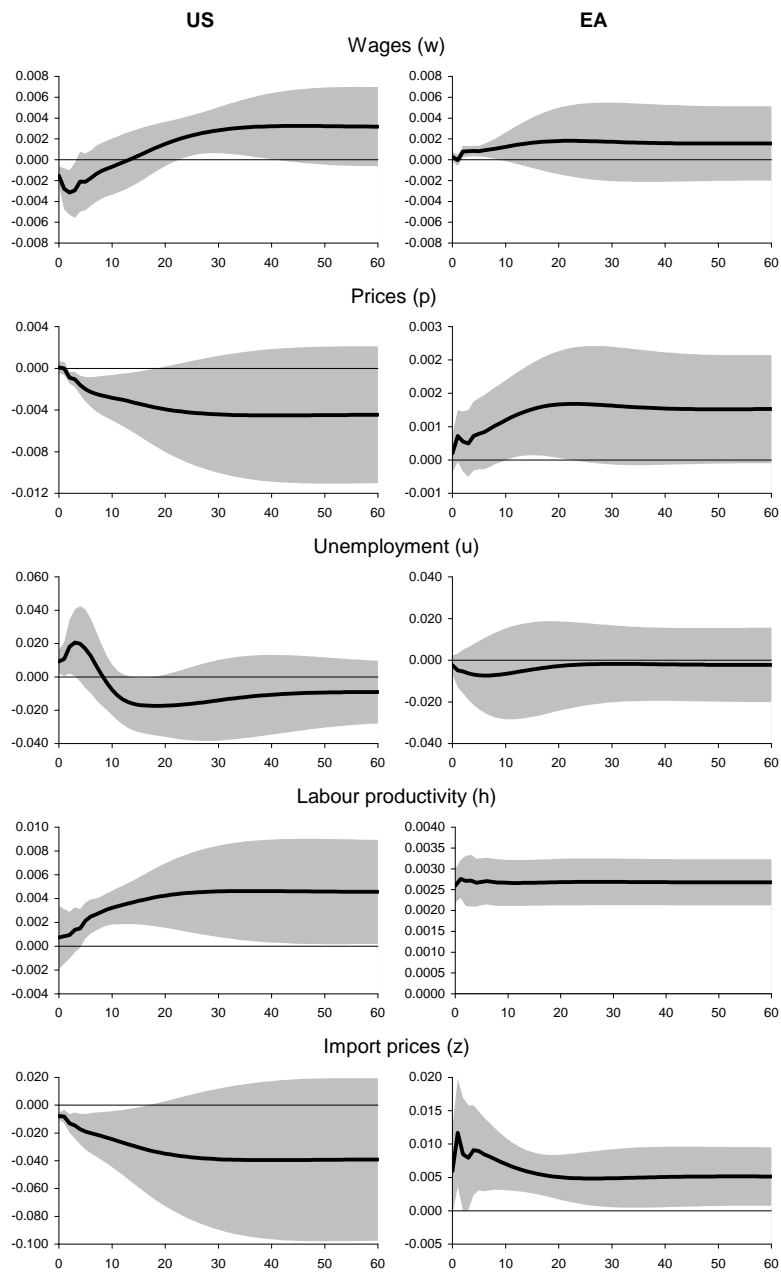


Figure 4: Responses to a permanent productivity shock

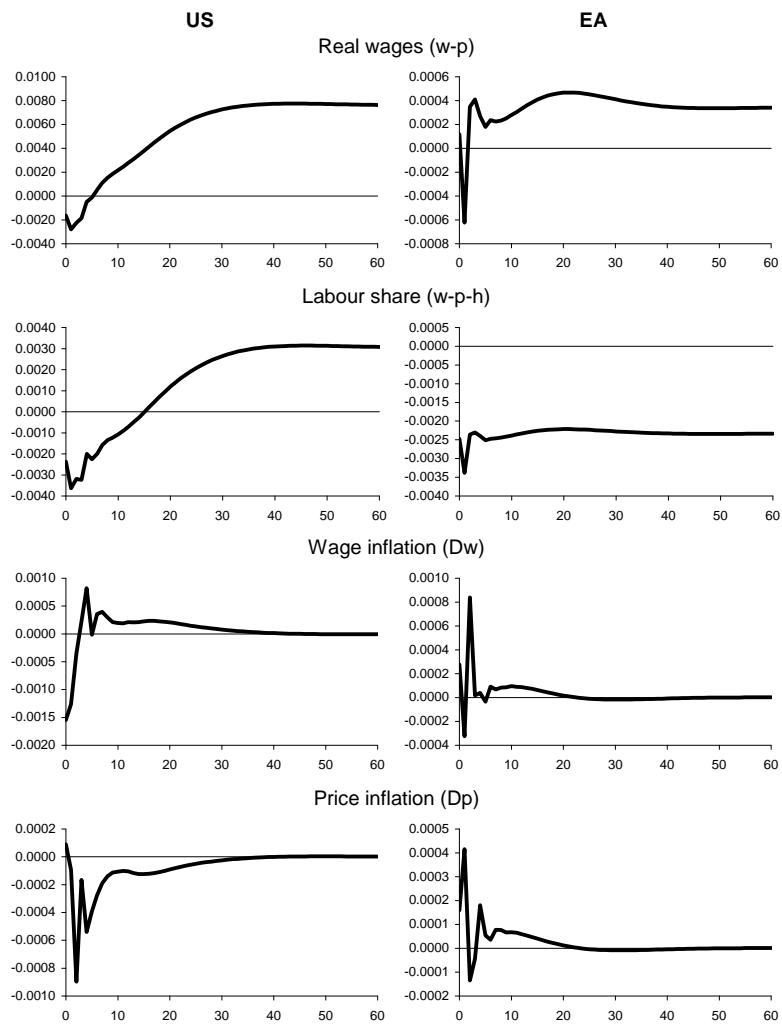


Figure 4: (cont.) Responses to a permanent productivity shock

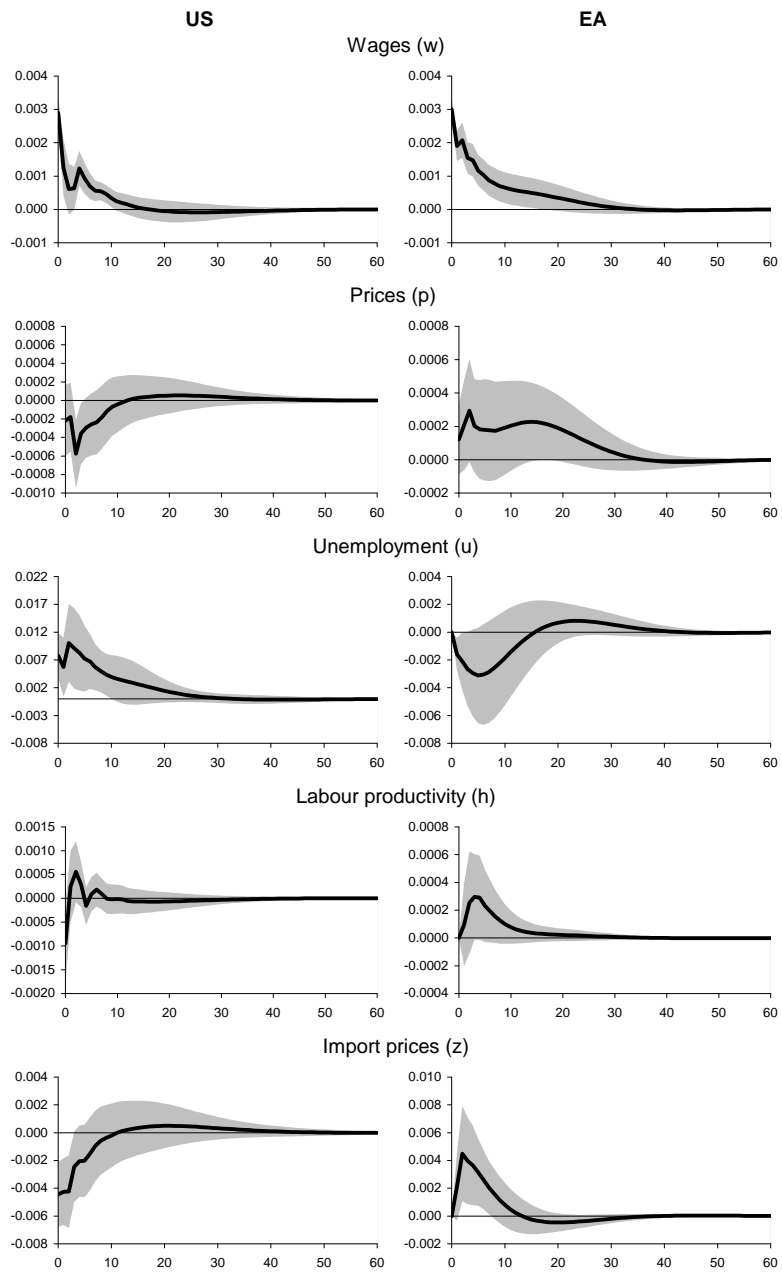


Figure 5: Responses to a transitory wage shock

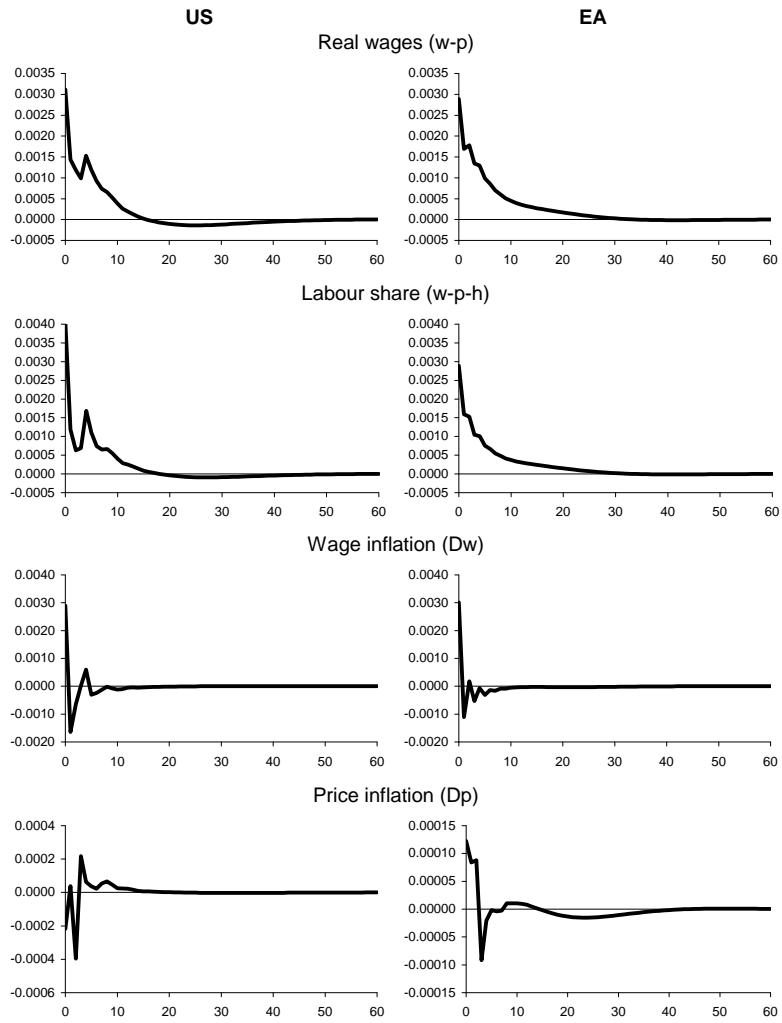


Figure 5: (cont.) Responses to a transitory wage shock

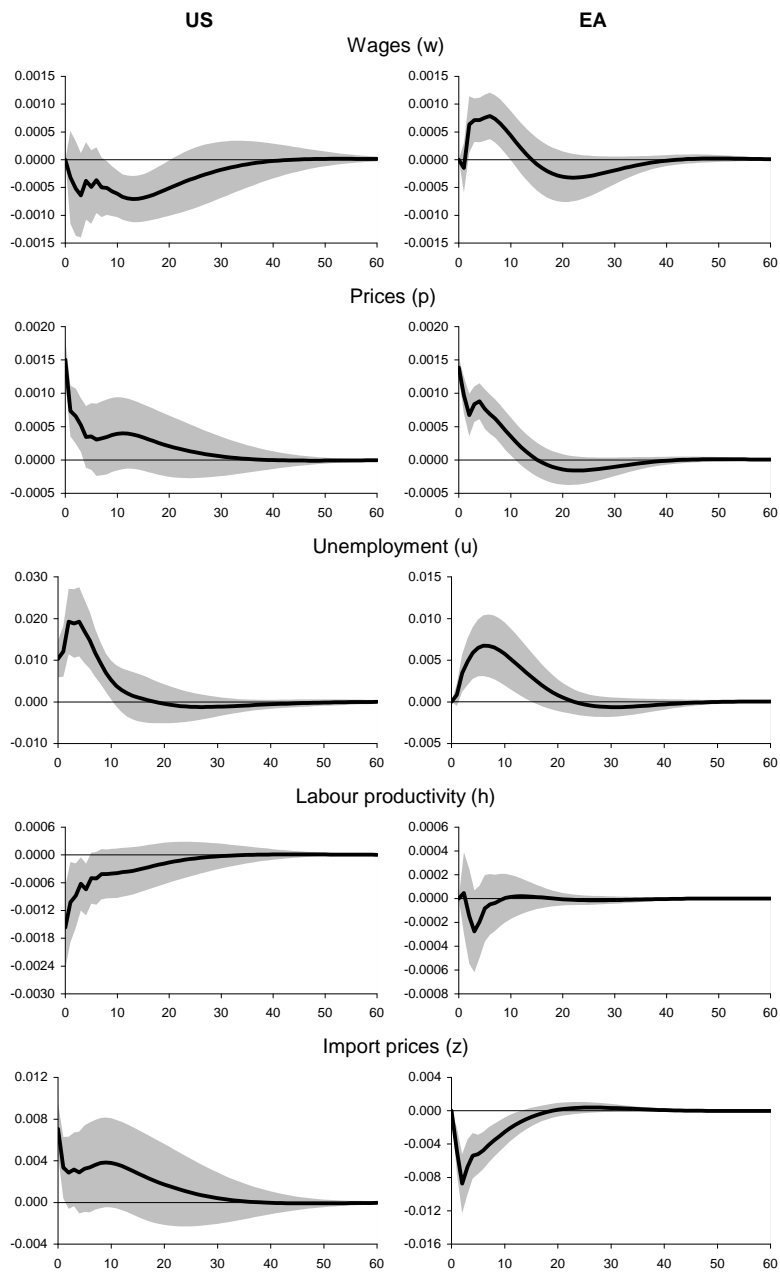


Figure 6: Responses to a transitory price shock

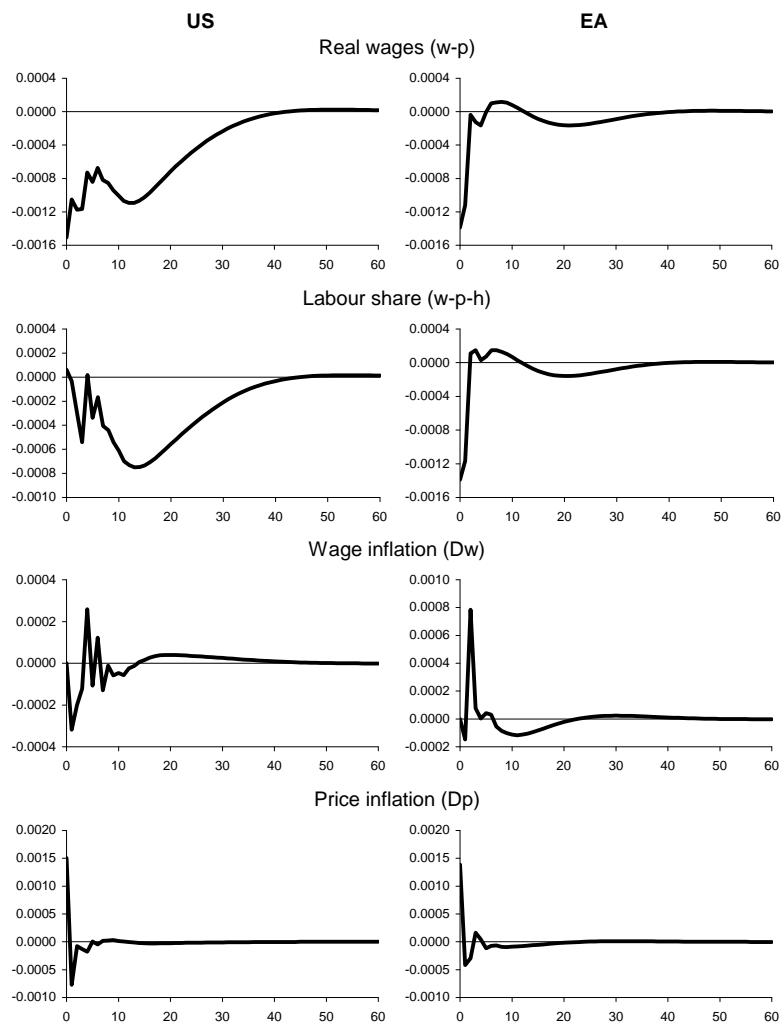


Figure 6: (cont.) Responses to a transitory price shock

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