## *A STRUCTURAL VAR APPROACH TO CORE INFLATION AND ITS RELEVANCE FOR MONETARY POLICY*

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## Introduction

When measures of core or underlying inflation are discussed, several measurement techniques are often referred to. Simplifying somehow, three major approaches can be distinguished. A first approach tries to remove from headline inflation, measured on the basis of the CPI, the component that is judged to be of a temporary nature and therefore veils the "true" or underlying (core) trend of inflation. This component is considered as noise. Traditionally the noise is removed on an *ad hoc* basis either by a smoothing technique or by the so called "zero weighting" technique, which gives a zero weight to those components of the CPI which are thought to be the source of the noise. Examples of measures of core inflation such as these are the well-known CPI excluding energy and seasonal food, or the CPI excluding changes in indirect taxes. In practice, these measures are very often used, probably because they are easy to calculate and are, from the point of view of the user, relatively transparent. However from a theoretical angle, they have the disadvantage that the selection of the removed components is made on a purely arbitrary basis.

A second approach emphasises the fact that inflation, which is a monetary phenomenon, should measure the increase of the *general* price level. However, in practice this is done using the CPI, which is a weighted average of prices of *individual* goods and services. Consequently, the CPI measures the increase in the general price level, as well as the changes in *relative* prices resulting from sectoral developments. According to Bryan and Pike (1991) "*the relative price "noise" has to be disentangled from the inflation signal*". They suggest that this can be done by using the *median* consumer price change instead of the increase of the CPI, which corresponds to the weighted *mean* of the price changes of individual goods and services. The median differs from the mean if the cross-sectional distribution of the price changes is skewed. Along the same lines, Bryan and Cecchetti (1994) propose the use of the weighted median or a 15 p.c. trimmed mean. They find that these measures of core inflation have a higher correlation than the CPI with past money growth, and provide better forecasts of future inflation. Ball and Mankiw (1995) relate the skewness of the cross-sectional distribution of individual price changes to the existence of menu costs in a model where price

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adjustment is costly, and they use measures of this skewness as indicators for aggregate supply shocks. Bryan, Cecchetti and Wiggins (1997) view this skewness as a statistical sampling problems. Roger (1995) provides an extensive discussion of the weighted median as a measure of core inflation in New Zealand, while Shiratsuka (1997) applies this concept to Japan. Roger (1997), confronted with a high degree of chronic right skewness in the data for New Zealand, introduces the idea of asymmetrical trimming. Of European central banks, it is the Bank of England which publishes the median and the trimmed mean on a regular basis in its Inflation Report.

Finally, the third approach to underlying inflation, which was proposed by Quah and Vahey (1995), defines core inflation as "*that component of measured inflation that has no medium to long-run impact on real output*". Incorporating the vertical long-run Phillips curve explicitly in this definition of core inflation, it is, in contrast to the previous approaches, based on economic theory. A bivariate structural VAR in output growth and the acceleration of inflation is used to extract core inflation from measured CPI inflation. This system is assumed to be driven by two independent types of disturbance. The first disturbance - the core shock - has no impact on real output in the long-run. The second disturbance - the non-core shock - is not restricted at all. This allows them to test whether the non-core shock has permanent effects on inflation or not. The non-existence of important long-run effects of the non-core shock on inflation is seen as a crucial element in a successful identification. A similar bivariate approach is presented in Fase and Folkertsma (1997). Blix (1995), Dewachter and Lustig (1997) and Gartner and Wehinger (1998) expand this approach to a trivariate SVAR, in order to incorporate a monetary shock as well. They find, in general, that there is little difference between the core inflation measure resulting from the bivariate VAR and the one resulting from the trivariate VAR.

In this paper we will concentrate on the issue of the conceptual definition of core inflation which is, from a theoretical point of view, of relevance for central bankers. A theoretical model is therefore discussed in Section 1. The model is an application of the real business cycle methodology for an open economy with sticky prices and wages, and money in the utility function. Using this model, an attempt is made to give some indication of the optimal monetary policy reaction to the different shocks that hit the economy. One of the findings is that, in contrast to conventional wisdom, the optimal responses to a positive demand shock and to a negative supply shock are very similar, as is the case in Goodfriend and King (1997) and in Svensson (1998). It has also been found that no reaction to the direct impact on inflation resulting from an energy shock or similar shocks to flexible prices is the best option. However, if these shocks have, over and above their immediate impact on CPI, important second round effects, a monetary policy reaction is still desirable.

Section 2 presents SVARs for three economies: the USA, Germany and Belgium. Five structural shocks - an aggregate supply shock, an aggregate demand shock, a monetary shock, an exchange rate shock and an energy shock - are identified. This allows us to analyse whether the effect of these shocks on prices, as well as the historically observed reaction of the monetary authorities, is consistent with what was predicted by the theoretical model. Before doing so, the impulse responses of the Quah and Vahey approach - a bivariate VAR in output growth and the *change in inflation* - are compared with those of a bivariate VAR in output growth and *inflation*. This distinction seems to be crucial as in the first case, the shock that has permanent effects on output is interpreted as *the non-core shock*, having no long-run consequences for inflation, while in the second case, the shock with permanent output effects is identified as *the supply shock*, having permanent effects on output *and*, in the opposite sense, on prices. Subsequently, our VARs in output growth and inflation are extended by introducing the short-term interest rate, the exchange rate and the oil price as additional variables. These VARs confirm to a large extent the findings of the theoretical model, and more particularly the importance of the supply shock for prices and for the observed monetary policy reactions. Consequently, we suggest that it is not optimal to exclude the effects of supply shocks from the measure of core inflation.

The final section presents our conclusions.

## 1. Theoretical foundation for the conceptual definition of core inflation

In this section we try to provide a theoretical foundation for the definition of core inflation. The starting point of our argument is that core inflation should be judged according to its relevance for monetary authorities. As a consequence, core inflation is defined as the inflation information concept that is optimal for monetary policy purposes.

The observed inflation results from a diversity of exogenous shocks affecting the economy: supply, demand, cost-push, exchange rates, monetary shocks etc. The question then is whether monetary policy should react in the same way on inflation whatever the underlying cause of the inflation movement. If monetary policy is unable to offset inflation resulting from some type of a shock, or can only do so by incurring great cost in terms of some other criteria in the loss function of the central bank, one would expect that it would be better to subtract this inflation component from observed inflation in calculating an optimal "core inflation" concept.

### 1.1 Theoretical considerations

In the literature on inflation targeting, many suggestions are given concerning this issue. Several papers have indicated that for open economies, it could be preferable to use domestic inflation as an indicator or target for monetary policy above CPI inflation. Svensson (1998) illustrates that under a monetary policy regime with a "strict inflation objective", the use of CPI targeting reduces the variance of CPI inflation but increases the variance of other relevant variables (output, domestic price inflation, real exchange rate etc.) compared to a similar policy using domestic inflation as its objective. The reason for this is that monetary policy, under strict CPI-inflation targeting, relies heavily upon the direct exchange rate channel, and neglects the other exchange rate channels disturbing aggregate demand allocations and domestic output decisions. The use of domestic inflation instead of CPI inflation performs better, as it makes monetary policy less dependent on the short-term exchange rate fluctuations. The inclusion of output variability as a second argument in the objective function also results in a better performance for the variability of other macroeconomic concepts than strict CPI-inflation targeting, as it shifts the emphasis of monetary policy more towards the long-run domestic inflation tendency that is caused by output or capacity utilisation. The use of CPI- versus domestic-inflation targeting is also analysed by Conway et al. (1998) using simulations of the FPS model for New Zealand. They obtain similar conclusions by introducing different inflation concepts in the forward-looking reaction rule of the central bank.

Mayes and Chapple (1995) and Yates (1995) describe how certain shocks that are expected to result in simply temporary price level movements should be extracted out of the inflation measure that is used in the inflation targeting approach. This idea is also present in the theoretical analysis of Goodfriend and King (1997) and of King and Wolman (1998) where the optimal inflation (or price level) concept for monetary policy is defined as the sticky price component of inflation. The motivation here is that only sticky prices result in a misallocation of demand and supply decisions as marginal costs deviate unnecessarily from marginal benefit in these circumstances, and therefore have a negative effect on welfare. By eliminating any variability in the marginal cost and suppressing any need for changes in the sticky price level, monetary policy can maximise economic welfare of private economic agents.

These examples illustrate the importance of the inflation concept that is central to monetary policy decision making.

Svensson (1998) and Goodfriend and King (1997) also discuss the optimal policy reaction on different kinds of shocks. In these sticky price models, demand and supply shocks have similar consequences for monetary policy. In the case of a demand shock, monetary policy should react restrictively, reducing aggregate demand and eliminating inflation pressure coming from increasing marginal costs or higher capacity utilisation. That supply shocks should ask for similar reactions is surprising, and, in emphasising the conflict between the inflation objective and the output objective, conflicts with conventional wisdom. However, when output gap stabilisation enters the loss function instead of output stabilisation, this conflict disappears. Indeed, a negative supply shock, reducing productivity and increasing marginal costs, increases inflation pressure. A restrictive reaction of monetary policy will decrease this inflation pressure but also aggravate the output reduction. However, the output reduction should not necessarily be considered as negative in this case: output should follow production capacity, and the result of a restrictive monetary policy reaction implies a minimisation of the output gap variance. The minimisation of output gap variance or marginal cost stabilisation increases the efficiency of production decisions. In this way demand shocks and negative supply shocks have similar implications for monetary policy.

This conclusion contradicts the Quah and Vahey approach of core inflation: that approach is concentrated on subtracting the inflation component related to permanent output shocks. If this shock is interpreted as a supply shock[2], it does not seem optimal to exclude its effect from the core inflation measure. In a broader theoretical sticky-price model, both supply and demand shocks can have persistent, but not permanent, effects on inflation, as both work through the capacity gap or the marginal cost channel on prices.

### 1.2 Evaluation criterion

In practice, there are different approaches possible to illustrate the relevance of different inflation concepts for monetary policy. Such an evaluation can be based on a purely statistical argument: which inflation component is the optimal forecaster of future inflation? However such a statistical approach does not contain any information on the relative costs of the monetary policy actions trying to offset different inflation sources. In contrast, our theoretical approach will combine the information on the specific dynamic pattern of the different inflation shocks with the impact profile of a monetary policy reaction and show the outcome of the joint action on other relevant macroeconomic variables. Together this gives the necessary information to evaluate how optimal an effect a monetary policy reaction has on specific shocks.

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[2] Quah and Vahey (1995) interpret this shock as the "non-core" shock. Dewachter and Lustig (1997), as well as Gartner and Wehinger (1998) interpret the shock with permanent output effects explicitly as a supply shock. Blix (1995) uses the expression "technology shock", while Fase and Folkertsma (1997) describe this shock as "output shock".

The same argument applies to the historical measure of the empirical importance of different shocks in explaining the inflation process. Such information can be obtained by the statistical decomposition of the forecast error variance of VAR estimations. Such exercises show the importance of specific shocks in predicting inflation, and they also illustrate the contribution of these shocks to the observed interest rate movements. For certain shocks that were historically important to explain the inflation process, one should indeed expect that there has been some interest rate reaction on it. However all this information on past policy experiences does not mean that the observed behaviour was also the optimal reaction. The historical importance of certain shocks for inflation and interest rates therefore does not yield definite answers on the optimal definition of core inflation.

For this reason we start our analysis with a structural theoretical model that is able to illustrate the implications of different reaction functions of the central bank on its loss function. By executing stochastic simulations of the model for different types of shocks, we will compare the results for the objective function (or its possible arguments) of a strong and a weak reaction of monetary policy on the specific shocks. If a strong reaction of monetary policy on inflation caused by one type of shock results in a smaller variance of inflation, output and other economic variables, we conclude that this type of shock should certainly be retained in the core inflation definition. If on the other hand, the variance of the relevant variables increases when monetary policy reacts more strongly on the shocks, one should subtract this inflation component from observed series in the calculation of core inflation.

The outcome of this exercise depends of course on the specification of the structural model. We will therefore start with a brief description of the model that is used (see Kollmann (1998) and Smets and Wouters (1998) for a detailed discussion of a similar model).

### 1.3 A real business cycle model for an open economy

The model is an application of the real business cycle methodology for an open economy with sticky prices and wages. Households maximise a utility function over a finite life horizon with the following arguments: consumption of domestic and foreign goods, money and leisure. Consumption appears in the utility function relative to the time-varying external habit variable (see Campbell (1998)). Labour is differentiated over households so that there is some monopoly power over wages which results in an explicit wage equation and allows for the introduction of sticky nominal wages à la Calvo. Households allocate wealth over money, equity, domestic and foreign assets, which are considered as perfect substitutes, so that UIRP applies in the linear approximation. Firms produce differentiated goods and decide on labour, capital (with capital adjustment costs), capacity utilisation (following the approach of King and Rebelo (1998)) and prices, again according to the Calvo model. Prices are therefore set in function of current and expected marginal costs. These marginal costs depend on the marginal unit labour cost (average over the economy) and on the price of imported intermediate inputs, described further in the text as energy inputs, which are used in fixed proportions in the production process. The composite domestic good is an imperfect substitute for the foreign good, so that the real exchange rate is not constant over time.

The model is calibrated on the German economy as far as the economic structure is concerned, while other behavioural parameters are set at realistic values found elsewhere in the literature (see appendix for more details on the parameter choice). The linear approximation is solved using the forward simulator available in the Troll-software.

Following the papers of Svensson (1998), Rotemberg and Woodford (1997) and Goodfriend and King (1997), models that are based on dynamic microeconomic foundations for macroeconomic relations are now also becoming the standard tool for analysing monetary policy questions. The specific application, discussed in this paper, allows us to discuss some specific topics: the open economy problem (total versus domestic inflation), energy or broader commodity price shocks (either as intermediate input in the production process or as final demand component in consumption), and wage versus price stickiness (against the one price models lacking an explicit treatment of the wage formation process in the labour market).

### 1.4 Discussion of the theoretical impulse response functions of different types of shocks under two monetary policy reaction functions

Using the theoretical model we will discuss different kinds of shock: monetary policy shocks, productivity shocks, demand shocks, energy price shocks (either as intermediate input or as final consumption good), exchange rate shocks and cost-push shocks.

The impulse-response functions of these shocks on major macroeconomic variables (total inflation, domestic inflation, output, interest rates, real marginal costs, exchange rate etc.) are presented in Figures 1 to 7. These graphs are based on two reaction functions of monetary policy represented by a simple instrument rule for the interest rate as a function of CPI inflation:

$$r(t) = a * \pi(t) + b * r(t-1)$$

The value $a/(1-b)$ determines the strength with which monetary policy reacts on inflation shocks. Only rules with $a/(1-b) > 1$ fulfil the stability condition of the model and are considered in this exercise. Under the "weak" reaction rule the parameter $a$ is set at the value of 0.165 while $b$ is 0.85, so that the long-run reaction of the interest rate on inflation equals 1.1. This can be considered as a very neutral monetary policy that is only oriented towards a stable long-term real interest rate. Under the "strong" reaction rule, coefficient $a$ equals 0.45 and $b$ equals 0.85.

***a. monetary policy shock***: increase in the interest rate (autocorrelation 0.3)

The impulse-response function of a monetary policy shock is not a crucial issue in this paper. However the discussion of these effects gives some indication of the implications of the endogenous reaction of monetary policy through the instrument rule on other exogenous shocks.

The monetary shock in our model has persistent effects on output and inflation. These results contrast with the results of other sticky price general equilibrium models (i.e. Andersen (1998), Jeanne (1998)). The difference is explained by some typical characteristics of our model:

- the introduction of both sticky prices and sticky wages slows down the adjustment speed of the price system. We therefore do not need to assume unrealistically slow adjustment coefficients in the price equation as is typical for models that consider only sticky prices. The assumed reaction lag for both prices and wages (average one year reaction lag in our calibration) remains empirically acceptable;

- a second reason for the persistence of the effects results from the assumption of aggregate demand behaviour. The introduction of habit formation in the consumption process implies that aggregate demand reacts more smoothly to shocks. A slower reaction of output also moderates the reaction of marginal costs and therefore of prices;

- the introduction of a variable capacity utilisation reduces the short-run impact of output fluctuations on marginal costs. Higher output in the short-run is produced with a more intensive use of production capacity so that marginal productivity of labour declines less strongly and employment moves only slightly more than proportional with production. The fact that marginal costs behave in a less volatile manner also implies that the effect on domestic inflation is somewhat smoothed over time;

- the persistence is influenced negatively by the assumption of a finite labour supply elasticity. With indivisible labour and the resulting infinite labour supply elasticity, wage costs would react less on a restrictive monetary shock and the downward pressure on prices should weaken. However the same argument applies for other types of demand shocks and inflationary pressure will decrease in that case. The finite labour supply elasticity together with the sticky wage assumption are retained in the calibration for reproducing the traditional Phillips-curve effect in the model.

Figure 1 describes the impulse-response of a 0.25 point increase in the interest rate. The interest rate is expressed on a quarterly basis so that the interest rate shock corresponds with a one point increase in the normal rate expressed on a yearly base. The immediate impulse is dominated by the direct exchange rate reaction. The exchange rate illustrates the traditional overshooting behaviour. The result is a strong decline in import prices and in CPI inflation. The real appreciation and the high real interest rate decrease aggregate demand. Lower demand and production and cheaper energy inputs lower the marginal production costs of the firms and lead to a downward pressure on domestic prices. The economy gradually returns towards the steady state path, but the accumulation of wealth and net foreign assets during the first phase of the adjustment allows for a positive consumption effect afterwards. The lower net exports and real exchange rate appreciation form the counterpart of the higher foreign capital income in the current account.

Under the strong reaction rule, the interest rate shock will be less strong and persistent as will be the effects on inflation and output.

***b. demand shock:*** increase in the demand of the rest of world (autocorrelation = 0.9)

The impulse-response functions in Figure 2 show the results of an increase in the demand by the rest of the world that affects positively the exports of the economy considered (for a constant foreign price and interest rate level). Higher foreign demand increases domestic production and, as marginal costs increase with the higher capacity utilisation, domestic producer prices start to increase. Both the increased output (and income) and the improvement in the terms of trade stimulate domestic aggregate demand (both consumption and investment). Output and domestic inflation pressure is therefore further increased. Using the "weak" instrument rule for monetary policy (a=0.165) in terms of CPI inflation, monetary policy reacts by increasing the interest rate following the increase in total inflation. The increase in current and expected short-term interest rates, given the constant foreign rate, leads to an appreciation of the exchange rate. Both the interest and the exchange rate reaction reduce the increase of CPI inflation through the direct exchange rate effect and through the negative influence on aggregate demand and net exports and furthermore on marginal costs and the domestic inflation pressure on the sticky prices.

Using the "strong" instrument rule for monetary policy (a=0.45) in terms of CPI inflation, monetary policy reacts by decreasing the interest rate somewhat following the decline in total inflation. The exchange rate appreciation is stronger and more persistent than under a weak reaction rule. The stronger appreciation lowers import prices, and this effect more than compensates the initial weak positive effect of sticky domestic prices in the CPI. However after the initial jump in import prices, the domestic inflation process will become dominant and CPI inflation will turn positive, but by much less than under the weak policy scenario.

The difference between the results of the two interest rate rules illustrates that a stronger reaction rule of interest rates in terms of inflation does not necessarily lead to higher interest rate movements. On the contrary, private agents that recognise the central bank's reaction function will adjust their behaviour so that a higher stability of inflation is obtained not by larger swings in interest rates but by the adjustments in forward-looking behaviour. Of course, such a result is dependent on the assumed credibility of the monetary policy rule in the minds of private decision makers. By explaining that the main inflation concept which drives monetary policy explicitly takes into account the specific nature of different shocks, the recognition of the correct monetary policy by private agents can perhaps be strengthened, so that the results of policy actions will move towards the optimal result. The core inflation concept therefore probably has importance not only for the internal monetary policy evaluation, but also for the communication of the policy to the rest of the economy.

***c. supply shock:*** increase in productivity (autocorrelation = 0.95)

An increase in productivity increases the mark-up of firms as prices and wages react slowly to the productivity shock. This means that the real marginal cost decreases and, as a consequence, there is some gradual downward movement in domestic prices. The increased profitability increases investment and the positive wealth effect stimulates consumer expenditures. Net exports increase also, following the decline in the relative price of the domestic good. Under a weak interest rate reaction rule, the exchange rate depreciation will be limited and CPI inflation will decrease following domestic inflation.

With a strong interest rate reaction, the exchange rate depreciation is stronger and more persistent. Net exports increase further, stimulating production and domestic income. A smaller decline in inflation results in lower real interest rates and stimulates domestic demand. Output will therefore increase more quickly and persistently in this case, remaining closer to the expanded output capacity. As a consequence, real marginal costs decline somewhat less, so that domestic prices will also decrease less. CPI is further influenced by the stronger depreciation leading to higher import costs and nominal wages.

The remarkable differences between the short-run reactions of the interest rate in the two policy scenarios are explained by the strength of the direct exchange rate channel on CPI inflation. Once again this illustrates that the differences between the two scenarios is more than just a different reaction of the interest rate on an observed inflation movement. A stronger reaction rule, meaning a stronger emphasis and willingness of monetary policy to react to a specific type of shock, changes private sector behaviour. Forward-looking financial asset prices, such as the exchange rate, are most sensitive to such differences.

***d. energy price shock****:* increase in the energy price driven by a second order ARMA-process

Energy and other imported primary inputs influence the economy through two channels: directly, as final consumption goods, and indirectly, as inputs in the production process. To illustrate the different consequences of both channels, two model versions are considered. In the standard version, energy is considered as a pure intermediate input that only influences the domestic and CPI prices via the marginal production costs of firms. In an alternative version of the model, energy is treated exclusively as a final demand component that influences CPI directly. In both versions, energy prices are considered as flexible prices that reflect immediately the international market and exchange rate fluctuations.

In the version with energy as intermediate input, an energy price shock influences the economy basically as a supply shock (Figure 4). The marginal production costs of firms react positively to the energy price increase, at least during the first quarters illustrating the flexibility of energy prices compared to domestic costs. Lower profitability will have a negative effect on investment, and the terms of trade deterioration will have a negative wealth effect on private consumer expenditures. Lower economic activity and employment together with lower consumption, and the corresponding increase in the marginal value of wage income, both cause a decrease in the equilibrium real wage so that nominal and even real wages start moving downward. As illustrated in Figure 4, the decrease in the marginal unit labour costs will dominate the higher energy price after a few quarters. The forward-looking nature of the price-setting process implies that domestic prices start declining from the beginning, as the expected decline in wage costs more than compensates for the higher energy costs. Together with the absence of a direct effect of energy on CPI, these arguments explain the surprising negative effect on inflation and prices in Figure 4 under the weak reaction rule. Under a stronger interest rate reaction rule, there is a stronger depreciation in the short-term which will stimulate net exports and economic activity. The smaller loss in output implies a stronger increase in marginal costs and a more realistic inflation and price reaction (see Figure 4 under the strong reaction rule).

The results of an energy shock differ from these of a productivity shock although both can be considered as supply shocks. Two arguments explain the different results. A productivity shock has a relatively small impact on employment and the real wage reaction will therefore be weaker. With an energy price shock, real wages react more strongly as both consumption (and marginal value of wealth) and employment have a downward pressure on real wages. The real marginal cost should therefore be less sensitive to an energy shock than to a productivity shock, at least if the labour market functions correctly so that the real wage can adjust quickly towards its new equilibrium level. A second difference between energy price shocks and productivity shocks is situated in their impact on the current account and the exchange rate. A negative productivity shock causes a real appreciation of the exchange rate: lower exports coincide with an amelioration of the terms of trade. An increase in oil prices, however, means a deterioration of the terms of trade. In this way the terms of trade effect or the corresponding wealth effect reinforces the price increase of a negative productivity shock, while it works in the opposite direction for an oil price shock . Energy price increases, as far as they are considered as supply shocks, should not have strong effects on aggregate inflation, assuming that the labour markets adjust sufficiently towards the real equilibrium wage in the economy. Rotemberg and Woodford (1996) do indeed find a negative real wage effect for the US following an oil price shock.

Results are different for an energy price shock that directly (and exclusively) influences the final demand price (see Figure 5). Here CPI inflation increases directly, given the flexible price assumption for the consumption price of energy. Higher inflation implies an interest rate hike. Domestic prices, in contrast with the total price index, will start to decrease given the negative domestic aggregate demand effect resulting from the interest and wealth effects. A stronger interest reaction in this case causes not only a further fall in domestic demand, but also limits net exports through the temporary appreciation of the exchange rate. A more restrictive reaction on this temporal inflation shock causes an unnecessarily large downturn in economic activity and somewhat stronger fluctuations in domestic marginal costs.

It is a question which requires more empirical research as to whether oil shocks in the seventies caused unnecessarily strong declines in economic activity because of a monetary policy reaction which was too restrictive. The theoretical model explains a strong decline in economic activity following an oil shock for both weak and restrictive monetary policy reactions.

This result therefore indicates that shocks in flexible prices that affect the CPI index immediately, are no reason for monetary policy to react. These type of shocks should therefore be excluded from the core inflation concept. The result of the stochastic simulations will further illustrate this argument.

***e. exchange rate shock***: increase in the risk premium of the exchange rate (autocorrelation = 0.9)

The exchange rate effects the economy through different channels. It has a direct effect on the economy because it is responsible for adjusting import prices. In our model we assumed that the import prices were adjusted immediately with exchange rates. These import price increases have a further effect through the indexation of domestic costs and especially through the effect on wages. Exchange rates also effect the cost of imported energy inputs and through that channel influence the marginal production costs. The exchange rate influences relative prices and therefore the net exports. Finally the exchange rate exerts wealth effects on domestic demand, through the impact on the terms of trade.

In Figure 6, we present the impulse response function of a persistent exchange rate shock, that can be described as a shock in the risk premium on the domestic currency. The results of a purely temporal shock were very similar as far as the conclusions are concerned, and are therefore not presented here. A depreciation of the exchange rate increases CPI inflation directly through import prices. In doing so, CPI inflation typically shows a strong impact jump. The effect on domestic prices depends on the reaction of output and marginal costs. Domestic final demand decreases with higher real interest rates. Net exports on the contrary increase. Total demand is therefore only relatively weakly affected and the net effect depends on the reaction function of the central bank.

The comparison of the two reaction functions in Figure 6 indicates that a strong reaction on exchange rate shocks is preferable as far as prices are concerned. A strong reaction is able to diminish directly the exchange rate shock and its impact on CPI. Domestic prices and real marginal costs are also less strongly affected, but this has a cost in terms of lower economic activity. It is clear that the final outcome of this shock depends on the relative power of the different channels of the exchange rate on the rest of the economy: for instance the result will depend on the relative weight of the exchange rate in marginal costs against the weight in the CPI and on the size of the aggregate demand effects through the relative price elasticities. The outcome of the stochastic simulations will also depend on the particular calibration of the model.

***f. cost-push shock***: increase in the nominal wage equation (autocorrelation = 0)

Through the sticky reaction of nominal wages a one-period shock in the wage equation disappears only gradually over the next few quarters. Marginal costs of firms increase and domestic prices start to increase. Both domestic demand and net exports decline following the deterioration of profitability and competitiveness. Output will therefore decline also and this will reduce the marginal costs increase. A stronger reaction of monetary policy will increase the decline in aggregate demand and net exports (through the appreciation of the exchange rate). The decline in output will therefore be aggravated but this will stabilise marginal costs and domestic prices, and, together with the appreciation, also CPI inflation. These results point to the conflicting nature of pure cost-push shocks for monetary policy if output and inflation variance are central in the loss function. However, if output capacity is defined as the output level that corresponds with a steady state inflation rate (or price level), there is no longer a conflict with such an output gap concept in the loss function, instead of the output.

### 1.5 Results of the stochastic simulations

Table 1 summarises the results of the stochastic simulations. For each type of shock we run two stochastic simulations, one for each policy reaction function: a simulation with a weak reaction of the interest rate on the inflation process ($a$=0.165, $b$=0.85) and an alternative scenario in which the central bank reacts strongly to the inflation disturbances ($a$=0.45, $b$= 0.85). The table presents, for a list of variables, the relative standard deviation expressed as the standard deviation resulting from a strong reaction rule divided by the standard deviation resulting from a weak reaction rule. A value smaller than one therefore illustrates that the standard deviation of a variable is smaller under the stronger reaction function. We prefer to show a list of variables instead of the results for a specific loss function that combines the separate components.

The results illustrate that for a typical demand shock, the standard deviations of all variables considered decrease, with a stronger reaction of the central bank on the inflation resulting from this type of shock. This result indicates that it is optimal for the central bank to react strongly on the inflation component resulting from demand shocks. The demand shock component of inflation should therefore be an important element of the core-inflation measure.

The results for the simulation with supply shocks are somewhat more complicated. Inflation variance, both total and domestic inflation, decreases when monetary policy reacts more strongly. Output variability however increases, but this measure is of less importance in this context as the production capacity changes so that the output fluctuations can be optimal. The fact that these fluctuations are optimal is evidenced by the reduction in the real marginal cost fluctuations. This measure illustrates how efficient inputs are used in the production process: an optimal use of production capacity means that the marginal cost of inputs equals the marginal return of output. As positive productivity shocks increase marginal productivity of labour, the real marginal cost will decrease, unless real producer wages adjust sufficiently flexibly to follow the productivity shock. Sticky nominal wages and prices however prevent an immediate adjustment of real wages, which can be considered as an inefficiency in the production process. Therefore it would be more efficient to have a stronger expansion of output so that marginal productivity should decrease while real wages increase more quickly. As a result, the real marginal cost can remain constant. Hence it is optimal for the central bank to decrease the interest rate, stimulating economic activity and accelerating the necessary adjustment process in the economy.

The results for energy price shocks, in the version where energy is an input in the production process, are some way between these of supply shocks and demand shocks. The strong wealth effects of energy price shocks explain why it is less costly to offset the price effects of energy price shocks compared to pure supply shocks. The result implies that monetary policy should react on commodity price shocks which mainly affect the intermediate input costs of firms.

If the energy price shock only affects the final consumption price, it is less clear whether the central bank should intervene. The results in Table 1 show that a strong reaction can indeed minimise the effect on the CPI, but is rather neutral for domestic inflation, and the result implies a somewhat stronger variability in output and real marginal costs and especially in interest rates. It is therefore questionable whether the small gain in CPI inflation variance is worth the extra variance in the other relevant variables.

The impact of exchange rate shocks on prices can also be offset by a stronger monetary policy reaction. The remarkable decline in the variance of domestic inflation and real marginal costs illustrates that the inflation shocks resulting from exchange rate effects on imported intermediate inputs and second-round effects on wages, and subsequently on marginal costs, can be offset by a strong monetary policy reaction. The inconvenience of this strong reaction is the extra variability in demand components and aggregate production. This raises a similar evaluation problem as with supply shocks: higher costs of imported products are compensated by declining real wages in total marginal production costs. In this way the stabilisation of the real marginal cost, or of the mark-up, implies that the equilibrium output level, or the inflation-neutral capacity, shifts over time. The final evaluation depends again on the formulation of the objective function for monetary policy.

The positive conclusion for strong reactions on exchange rate shocks is not really in contradiction with the argument of Svensson (1998) that domestic-inflation targeting is preferable above strict CPI-inflation targeting. It is important in this discussion to stress the role of the exchange rate as a determinant of imported intermediate inputs prices and, via indexation of wages, of the marginal unit labour costs. Import prices and wage costs both induce domestic sticky prices to react. Both CPI- and domestic-inflation targeting will therefore react on exchange rate movements. However, models working exclusively with the output gap as the measure for cost pressures, following the Phillips curve approach, lack this important channel in the discussion. This illustrates the advantage of the microeconomically derived sticky-price setting relation above the traditional macroeconomic specifications.

The output effect of exchange rate shocks follows from the different impact of interest rate shocks and exchange rate shocks on respectively output and prices. In order to obtain the same price effect, interest rates have to have a stronger output effect compared to exchange rates. By responding more strongly to exchange rate shocks the effects on prices can be minimised, but this implies an overreaction in terms of output. The result indicates that monetary policy should look for an optimal reaction on exchange rate shocks, a problem related to the discussion on optimal MCI-weights.

The simulation results of pure wage shocks (cost-push shocks) illustrate again the possible conflict between different objectives of the central bank. Inflation can be stabilised in this case only at the cost of higher output variability. However, the relative standard deviation of the real marginal costs decreases somewhat. The result is therefore comparable to the productivity shock. A further argument in favour of a strong reaction lies here in the influence on future wage negotiations: rational behaviour will try to prevent the pure loss-situation that results from systematic central bank actions on unrealistic wage-deals.

Summarising the results, we can say that the distinction between demand and supply shocks as sources of inflation fluctuations is not of crucial importance for monetary policy, unless the variability of output as such is considered an important element in the objective function. For shocks originating from the rest of the world, the reaction should depend on how they affect the economy. Shocks that are limited to flexible prices which are part of the final consumption basket do not ask for a strong reaction, at least if the central bank has a broader objective function than strict CPI-inflation targeting. The use of the direct exchange rate mechanism to offset these shocks causes too many real effects in the rest of the economy. The same argument probably applies for shocks in domestic flexible prices and also for indirect tax shocks. If foreign price shocks disturb mainly the intermediate input costs of firms, the reaction of monetary policy will depend on whether other domestic costs components react sufficiently flexibly to offset the effects on marginal costs.

The final decision regarding the optimality of the reaction depends on the choice of the evaluation criteria. A correct specification of the loss function of the central bank in terms of inflation and output gap will result in similar conclusions as the microeconomic efficiency argument, which favours constant marginal costs so that sticky prices do not have to change. However different arguments are also possible. Following the approach of Rotemberg and Woodford (1997), the final choice will depend on the relative variability of the arguments that appear in the utility functions of households. Using one particular utility specification, their approach can be reduced to the inflation and output gap variance. But using a traditional utility function, the variance of consumption and employment should get more attention (especially if the utility function contains a habit persistence term). Furthermore, the optimal monetary policy will also depend on the relative cost of average inflation against the benefit of increased room for stabilisation policies, given the constraint that interest rates must remain positive. As long as there is no definite answer on the concept of optimal monetary policy, the choice of the optimal target and instrument rules is also open.

Drawing definite conclusions on optimal policy behaviour in open economies is also difficult because of the complexity of the transmission channels. The results obtained in this paper are certainly dependent on the model choice and the specific calibration. This applies not only to the role of the foreign prices and exchange rate shocks, but also to the relative importance of price versus wage rigidity, and to the implications of more complicated instrument rules. The theoretical model is able to analyse the implications of all these assumptions, but empirical estimation of the model is a necessary step, before one can draw definite conclusions from this exercise and lay down practical guidelines.

## 2. SVARs for the USA, Germany and Belgium

In order to illustrate the findings of the theoretical model, SVARs in output growth, inflation, the short interest rate, the change in the exchange rate and the change in the international oil price were estimated. Before presenting the results of these VARs, we want to highlight the fact that our specification differs from the specification proposed by Quah and Vahey. This is done in paragraph 2.1, while paragraph 2.2 presents the results of the VARs with five variables.

### 2.1 What enters the VAR: inflation or the change in inflation ?

Quah and Vahey (1995) estimate a bivariate VAR in output growth and the change in measured inflation. As measured inflation, defined as the 12 month change of the CPI, is integrated of order one, the change in inflation enters the VAR instead of inflation itself. It is assumed that this bivariate VAR is driven by two independent disturbances: the core shock, having no long-run impact on output, and the non-core shock. Core inflation is that component of measured inflation that results from the core shock. In other words, core disturbances affect prices and are output-neutral in the long-run, in line with the long-run vertical Phillips curve hypothesis. To identify both shocks, it is sufficient to impose one restriction, more precisely the fact that the core shock has no long-run impact on output. The long-run impact of the non-core shock on inflation is not restricted, nor do Quah and Vahey prescribe how quickly the core shock becomes output-neutral. Both aspects can be determined freely by the data, allowing them to test the validity of the imposed identification scheme.

Bivariate VARs of this type have been estimated for the USA, Germany and Belgium. Since it was preferable to perform this exercise on monthly data, the log of industrial production was used as the real output variable, while inflation corresponds to the 12 month change in the log of the CPI. Both variables finally entered the VAR as changes compared with the values of the previous month. The estimation covers the period from January 1972 to August 1998. Twelve lags were included, as well as a set of seasonal dummies.

The impulse responses of output (Y) and measured inflation (Pi) are, for each of the three economies considered, shown in the upper row of graphics in the Figures 8 to 10. The broken lines plotted around these responses represent bootstrapped 10 p.c. confidence intervals. The impulse responses are in several ways similar to those obtained by Quah and Vahey (1995) for UK-data. Indeed, the non-core shock is much less important for inflation than the core shock, and its long-run impact on inflation is not significantly different from zero, although a significant short-run impact of this shock exists for US inflation. The core shock very quickly becomes output-neutral in Germany, while this takes longer in Belgium (about 1 year) and in the USA (about 20 months). These findings are also illustrated by the forecast error variance decomposition shown in the upper row of graphics in the Figures 11 to 13.

However, if inflation is defined as the one month change in the log of the CPI and this (stationary) variable enters the VAR, the results of a similar identification scheme are quite different, as is shown in the lower part of Figures 8 to 10. It should be noted that in this case impulse responses for prices (P) are obtained. The shock with permanent output effects is important for prices too, even in the long-run. Having an influence on prices in the opposite sense as on output, this shock shows the same characteristics as the supply shock in the model of Section 1 and is therefore interpreted as such. The second shock is interpreted as a demand shock, including the response to a monetary shock. By extending the VAR in the next paragraph, a separate identification of the demand shock and the monetary shock will be possible. The forecast error variance decomposition for these VARs is reported in the lower row of graphics in the Figures 11 to 13. These figures indicate that in our VAR-specification the supply shock is definitely more important for prices than the corresponding core shock identified by Quah and Vahey. In Germany nearly 25 p.c. of the forecast error variance at all horizons is due to the supply shock. In Belgium this is nearly 40 p.c. at all horizons. In the USA, the influence of the supply shock is even more important. For the shorter horizons nearly 75 p.c. of the forecast error variance is due to the supply shock and this remains nearly 40 p.c. at the longer horizons. For Germany and Belgium the contributions of the supply shock are similar to those reported in Gartner and Wehinger (1998) for bivariate VARs in output growth and inflation, with quarterly GDP data.

The difference between the two approaches is also illustrated in Figure 14, where the impulse responses for prices resulting from our VARs have been recalculated as 12 month differences. As a result, they can then be compared on a direct basis with the impulse responses from the Quah and Vahey approach. Again, a more important effect on inflation is obtained in our approach. This difference is not only observed in the short-run, but appears to be rather persistent. Given these differences we prefer to continue with our specification of the VAR in the remaining part of this paper. The characteristics of the supply shock presented in the previous section, where a negative supply shock and a positive demand shock have similar effects on prices supports our view. This approach is not in contradiction with the long-run vertical Phillips curve, as supply shocks shift this curve to the left or to the right. Moreover, in several other papers - for instance that of Smets (1997) - VARs similar to ours which combine output growth and inflation rather than output growth and the change in inflation, have been published, and gave a fair description of the economies studied.

Summarising this paragraph, the Quah and Vahey approach was abandoned because it was feared that, by excluding what they call the core shock, important supply shock effects on inflation would be disregarded. Perhaps this is the reason why Dewachter and Lustig (1997), applying the specification proposed by Quah and Vahey, find that the differences between measured inflation and their core measure are very persistent.

### 2.2 Extending the VARs with a monetary shock, an exchange rate shock and an energy shock.

The bivariate VARs presented in the previous paragraph were progressively extended to include a monetary shock, an exchange rate shock and an energy shock. Extensions with a monetary shock were also presented in Blix (1995), Dewachter and Lustig (1997) and Gartner and Wehinger (1998). Given the openness of two of the examined economies (Germany and Belgium), the exchange rate was incorporated in the VARs. Finally, by analogy with the model of the previous section and taking into account the importance of changes in the oil price during the estimation period, an energy shock was considered. The results of the VARs with three variables (including a monetary shock) and with four variables (including a monetary and an exchange rate shock) are not reported here. However, they confirm the importance of the supply shock for prices. Finally, VARs in output growth, inflation, the short-term interest rate, the change in the exchange rate and in the international oil price were estimated for the period from January 1972 to August 1998. All exchange rates are expressed as units of domestic currency per unit of foreign currency. Hence, an increase of the exchange rate indicates a depreciation of the domestic currency.

The five disturbances driving this VAR were identified as follows. The demand shock, the monetary shock and the exchange rate shock do not have long-run effects on output. As a result, only the supply shock and, if the data reveal this, the energy shock can have permanent output effects. The monetary and the exchange rate shock were disentangled from the demand shock by restricting their contemporaneous impact on output to zero. This restriction, proposed by Gali (1992), is based on the so-called outside lag, indicating that monetary innovations do not have an immediate effect on aggregate demand. Following Smets (1997), the exchange rate shock is distinguished from the monetary shock, using the relative weight of the exchange rate in the short-run reaction function of the central bank. However, estimating these weights was beyond the scope of this paper. Instead, ad hoc assumptions were made. Finally, four additional restrictions are necessary to identify the five shocks successfully. These were provided by the assumption that the four domestic innovations do not have a contemporaneous effect on the oil price.

### *a. United States*

In the VAR for the United States the exchange rate vis-à-vis the German mark was taken into account, whereas it was assumed that there is no weight on exchange rate stabilisation in the short-run reaction function of the monetary authorities. This assumption was also used by Eichenbaum and Evans (1995).

The impulse responses reported in Figure 15 show that an increase in the oil price (E) has a permanent effect on consumer prices (P) and on output (Y). The monetary authorities do not react strongly to an oil shock, as short-term interest rates (R) are nearly not increased. As was the case in the bivariate VAR discussed earlier, a positive supply shock coincides with an important downward effect on prices. The extended specification of the VAR did not change this conclusion but allows us to see how the monetary authorities react to a supply shock. They seem to have taken the downward effect on prices into account, as a positive supply shock was accompanied by a decrease of the short interest rate, although it was not possible to estimate this effect very precisely. On the contrary, they increase the short-term interest rate in the case of a demand shock, that increases output in the short-run and prices permanently. A positive demand shock has consequently similar effects on prices and on the monetary policy reaction as a negative supply shock. This evidence suggests that the monetary authorities try to diversify their answer to output fluctuations according to the type of shock that is at the origin and, consequently, aim at output gap stabilisation rather than output stabilisation.

A monetary shock leads, after some months, to a significant reduction of output and to a gradual fall in consumer prices. The dollar exchange rate (S) appreciates vis-à-vis the German mark when interest rates are increased. Finally the exchange rate shock does not have important effects on the American variables, highlighting the closed character of the US economy. The forecast error variance decompositions will be discussed later, in comparison with the results for Germany and for Belgium.

### *b. Germany*

In the case of Germany, the exchange rate vis-à-vis the dollar is considered and it is assumed that there is some weight on exchange rate stabilisation in the short-run reaction function of the monetary authorities. Evidence of this was found in Clarida and Gertler (1997). Smets and Wouters (1998) estimate a 0.25 weight. However, Smets (1997) estimated a SVAR, using the zero weight hypothesis. In the VAR presented here a weight of 0.125 was assumed, since with this weight, uncovered interest rate arbitrage holds approximately for the impact effect. The impulse responses are reported in Figure 16, while Figure 17 shows the impulse responses if a zero weight on exchange rate stabilisation is assumed.

An oil price hike increases German consumer prices but has, in contrast to the US, no significant impact on German output. The reaction of the monetary authorities to an oil price shock was nearly zero. A positive supply shock has an important downward effect on consumer prices, evidence that was also revealed by our bivariate VAR. Moreover, the German monetary authorities react strongly on a positive supply shock by lowering the short-term interest rates. This reaction is stronger than in the case of the US and is also estimated more precisely. The strength of this reaction may result from the importance that the Bundesbank traditionally attaches to the outcome of wage negotiations in Germany. Wage increases are, in the absence of a typical cost push shock in the estimated VAR, presumably captured by the shock that was identified as a supply shock. A positive demand shock increases the price level and leads to an interest rate hike. In the German VAR it was also observed that a positive demand shock has similar consequences for prices and for the monetary policy reaction as a negative supply shock.

A monetary shock in Germany decreases output after some months and has a gradual downward effect on prices. The German mark tends to appreciate against the dollar when German interest rates are increased, although it has not been possible to estimate this effect precisely. The effects of an exchange rate shock - a depreciation of the German mark - on output and on consumer prices are very limited, as they are counterbalanced by the increase of short interest rates resulting from the assumption that the Bundesbank reacts to exchange rate movements. In an alternative scenario, where the German monetary authorities do not react contemporaneously to exchange rate innovations there are some more pronounced effects on output and consumer prices. In that case the effects of a monetary shock on prices and on output are also more pronounced. However, this identification scheme shows a depreciation of the exchange rate when interest rates are increased.

### *c. Belgium*

The Belgian VAR is slightly different from those previously discussed. As the Belgian monetary policy is an exchange rate policy aiming to stabilise the exchange rate against the German mark, this exchange rate, as well as the short-term interest rate differential vis-à-vis Germany (instead of the Belgian interest rate) entered the VAR. Given that policy, it is clear that exchange rate stabilisation must be important in the short-term reaction function of the Belgian monetary authorities. In recent years, exchange rate stabilisation was the only objective of the central bank. In the seventies and the eighties the exchange rate policy was less ambitious and a depreciation against the German mark could not be prevented. On average, a weight of 0.75 p.c. was assumed. This corresponds to the weight that Smets (1997) estimated for France, a country that has an exchange record that is similar to that of Belgium. Impulse responses for Belgium are presented in Figure 18.

An increase in the oil price permanently shifts consumer prices to a higher level. Its negative impact on output is more pronounced than in Germany, but less than in the US. The impact on consumer prices is however the biggest of the three countries considered. This is illustrated in Figure 19, where the impulse responses of consumer prices to an energy shock have been recalculated as the 12 month change in prices (inflation). The difference between Belgium and Germany is striking, and results presumably from the indexation of Belgian wages on the CPI. As a consequence, the direct effect of an energy shock was followed by important second-round effects.

In Belgium supply shocks also have an important effect on prices which is the opposite of that of a positive demand shock. These findings are similar as in the case of the US and Germany. However, given the exchange rate policy, these shocks did not lead to important reactions on the part of the monetary authorities. In contrast, they tend to react strongly to a foreign exchange rate shock, which can be interpreted as a change in the market perception of the risk premium leading to a depreciation. The fact that the effect of the foreign exchange shock on the exchange rate is significant on impact, but not in the long-run, indicates that the central bank was sometimes successful in defending the exchange rate. We interpret these exchange rate shocks as periods of increased tension in the ERM. Given their temporary nature, the uncertainty about their final effect on the exchange rate and taking the accompanying increase of domestic interest rates into account, output is nearly not affected by an exchange rate shock and the result for prices is unclear. A positive monetary policy shock - an increase in the interest rate differential with Germany - leads to an appreciation of the Belgian franc. Obviously, all the monetary policy shocks of this type that were observed in the past worked in the opposite direction, more particularly each time a decrease in the interest rate differential coincided with a devaluation of the ERM parity vis-à-vis the German mark. These observed monetary shocks - a decrease in the interest rate differential, accompanying a change in the ERM parity - tend to expand output moderately in the short-run and increase prices permanently.

### *d. Forecast error variance decomposition for consumer prices and for short interest rates*

Figure 20 shows the relative importance of each of the structural shocks for consumer prices. This figure confirms to a large extent the conclusions about the importance of the supply shock made earlier on the basis of the bivariate exercise. For the US and Germany the supply shocks account for about 40 p.c. of the forecast error variance at longer horizons and this measure tends to be significantly different from zero for both countries. Compared to the bivariate VAR the contribution of the supply shock increased for Germany and decreased for the US. For Belgium the contribution of supply shocks became less important than in the bivariate case, presumably as a result of the identification of the energy shock that accounts for about 25 p.c. of the long-run forecast error variance for prices. Disregarding the supply shocks, aggregate demand shocks and energy shocks were important for US inflation, while the monetary and foreign exchange shocks were relatively important for Germany. The relative weight of these two shocks depends evidently on the specification of the German model.

The case of Belgium merits some special attention, as in this country the effect of the energy shocks on consumer prices was more pronounced than in the two other economies and significantly different from zero. It indicates that a possible core inflation measure which eliminates the effect of oil price shocks must be interpreted carefully. If only the direct effect on consumer prices is excluded, this measure may be useful as a supplementary indicator of inflation. Indeed, the theoretical model of the previous section showed that a monetary policy reaction to the direct effect was not desirable. Moreover many oil price movements in the recent past were of a temporary nature. However, if an energy shock has important second round effects, a reaction seemed justified. These second round effects worked in the typical Belgian context of the seventies and the early eighties in the opposite sense than in the theoretical model. Given the automatic wage indexation, real wages in Belgium appeared to be very inflexible and the oil price shocks became the driving force behind the increase in inflation that took place at that time. Recently the vulnerability of the Belgian economy to oil price increases has been reduced by introducing the so-called "health index" instead of the total CPI as the reference for the wage indexation mechanism. This "health index" does not take the price changes for oil products into account.

Figure 21 shows that supply shocks also contributed to a large extent and in a significant way to the forecast error variance of the German short-term interest rate, although the impact effect of the two monetary innovations taken together is more important. The demand shock represents some 20 p.c. of the forecast error variance, while the energy shocks were not important in explaining the German short interest rates. For the short-term interest rates in the US, the monetary shock is definitely the driving force at shorter horizons, while the demand shock is important at longer horizons. Nevertheless, some 25 p.c. of the forecast error decomposition is accounted for by the supply shock. The fact that the Belgian short-term interest rate differential vis-à-vis Germany is mainly driven by the exchange rate shock results directly from the exchange rate policy of the monetary authorities. Consequently, the other shocks, including the supply shock, are less important to explain the interest rate *differential* with Germany. However, this does not mean that supply shocks were not important for the Belgian interest rate *level,* as these shocks, which are, given the cointegration of Belgian and German output, to a large extent common to both countries, may have influenced Belgian interest rates through their effect on German rates.

## 3. Conclusion

In this paper, a real business cycle model for an open economy and SVARs for the US, Germany and Belgium are presented, in order to study the underlying sources of inflation movements, both from a theoretical and from an empirical point of view. An examination has been made of whether the monetary authorities should diversify their policy response, according to the type of structural shock that is at the origin of the observed inflation. It has been argued that the core inflation concept should incorporate those components of measured inflation that are caused by structural shocks which ask for a monetary policy reaction, while the effects of shocks that do not justify a monetary policy reaction should be removed from the core inflation measure. As such, the core measure should represent the information concept on inflation that is optimal for monetary policy purposes.

The theoretical and the empirical approach both lead to the following conclusion. Positive demand shocks and negative supply shocks have important and similar effects on inflation, as they pass through the same channel. The monetary policy reaction to these shocks should be identical. The empirical part indicates that this has been the case, in particular in Germany. Hence, the core inflation measure should incorporate the effects on inflation of the demand shock, as well as those of the supply shock. This tends to contradict the Quah and Vahey approach, that excludes from measured inflation the effect of the shock that has permanent output effects.

Shocks of flexible prices are less important for monetary policy purposes and should, as far as their direct effect on CPI inflation is concerned, be removed from the core measure. However, if these flexible price shocks have important indirect effects a monetary policy reaction seems to be justified, as is evidenced by the significant impact that the energy shocks have had on Belgian inflation. This result goes into the direction of the traditional approach to core inflation, whereby flexible prices, such as energy or seasonal food prices, are removed from headline inflation. However, this approach has the disadvantage that the choice of the removed component is made on an arbitrary basis. The core inflation measures proposed by Bryan and Pike (1991) and by Bryan and Cechetti (1994), may overcome this problem as discretionary judgement is eliminated when the removed components are selected.

Table 1

Summary of stochastic simulations [1]

Relative standard deviation for a list of selected macro-economic variables
strong interest rate instrument reaction rule versus weak interest rate instrument rule [2]
for inflation driven by different types of shocks

| | supply shock | demand shock | energy shock as input in production | energy shock as consumption good | exchange rate shock | cost-push shock |
|---|---|---|---|---|---|---|
| CPI inflation | 0.39 | 0.42 | 0.47 | 0.75 | 0.56 | 0.53 |
| domestic inflation | 0.47 | 0.26 | 0.18 | 1.02 | 0.25 | 0.83 |
| exchange rate | 0.42 | 0.40 | 0.40 | 0.87 | 0.50 | 0.41 |
| interest rate | 0.28 | 0.41 | 0.54 | 2.04 | 0.80 | 1.32 |
| | | | | | | |
| output | 1.08 | 0.66 | 0.84 | 1.12 | 1.67 | 1.28 |
| employment | 0.87 | 0.64 | 0.82 | 1.14 | 1.79 | 1.29 |
| consumption | 1.05 | 0.86 | 0.94 | 1.04 | 1.29 | 1.21 |
| investment | 1.16 | 0.58 | 0.85 | 1.12 | 1.86 | 1.39 |
| export | 1.10 | 0.98 | 1.16 | 0.94 | 0.94 | 1.35 |
| import | 1.07 | 0.99 | 0.97 | 1.01 | 1.12 | 1.22 |
| | | | | | | |
| real consumption wage | 1.05 | 0.79 | 0.92 | 1.01 | 1.35 | 0.97 |
| nominal wage | 0.24 | 0.16 | 0.33 | 1.10 | 0.22 | 0.79 |
| CPI price level | 0.07 | 0.11 | 0.11 | 0.62 | 0.15 | 0.26 |
| | | | | | | |
| real marginal cost | 0.83 | 0.44 | 0.72 | 1.13 | 0.38 | 0.93 |

1. the standard deviations are calculated as averages over ten simulations for 120 quarters each and dropping the first 20 observations
2. the two instrument rules are

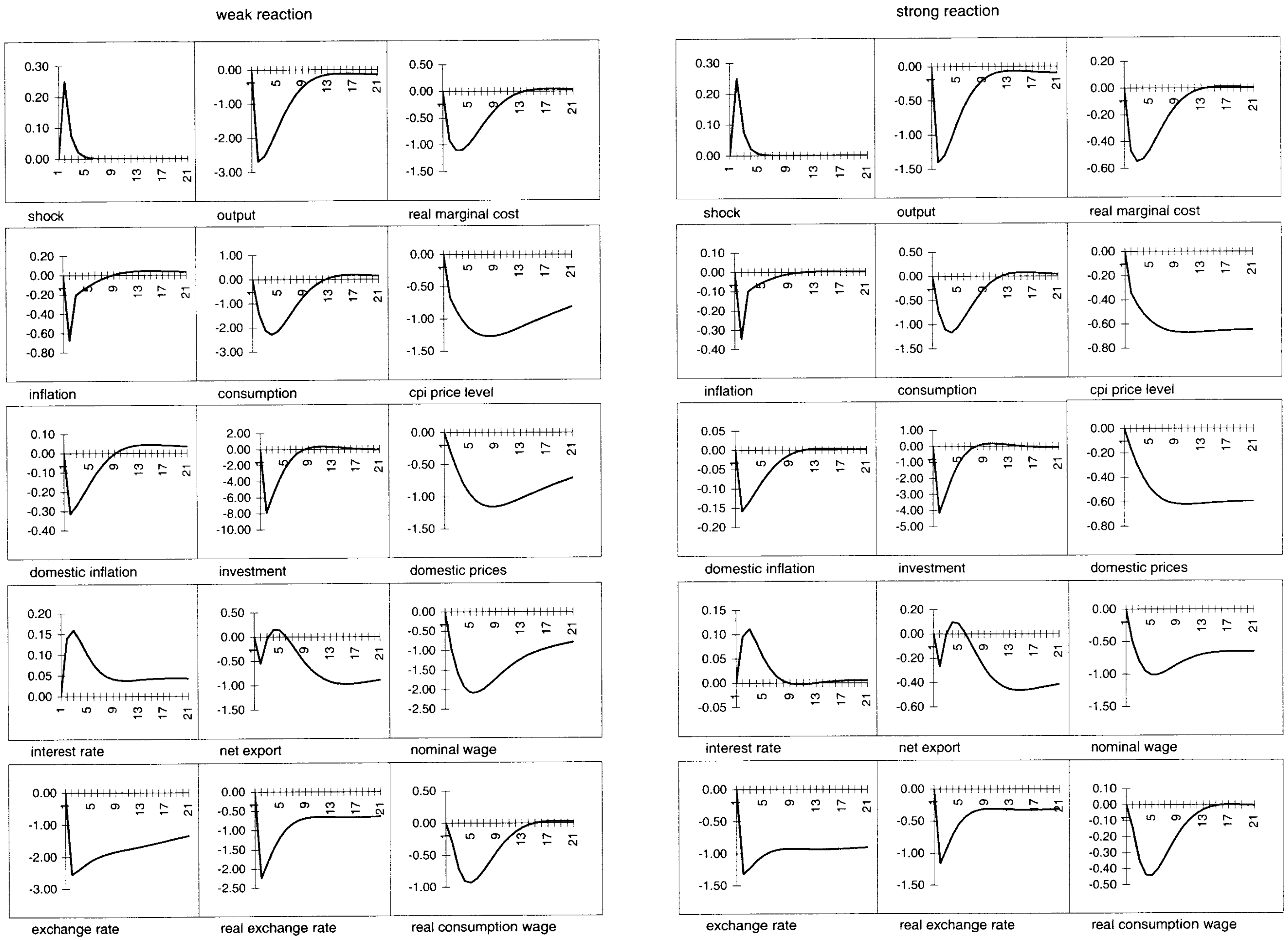
$r(t) = 0.165*\pi(t)+0.85*r(t-1)$

$r(t) = 0.450*\pi(t)+0.85*r(t-1)$

a relative standard deviation smaller then one implies that the standard deviation was smaller under the strong reaction rule

Figure 1 Impulse-response functions for a monetary policy shock (25 basispoint increase in interest rate[1] - autocorrelation 0.3)

weak reaction — strong reaction




[1] interest rate expressed on a quarterly basis, inflation calculated as a percentage quarter to quarter change in the price level

Figure 2

Impulse-response functions for a demand shock (increase in ROW demand - autocorrelation 0.9)

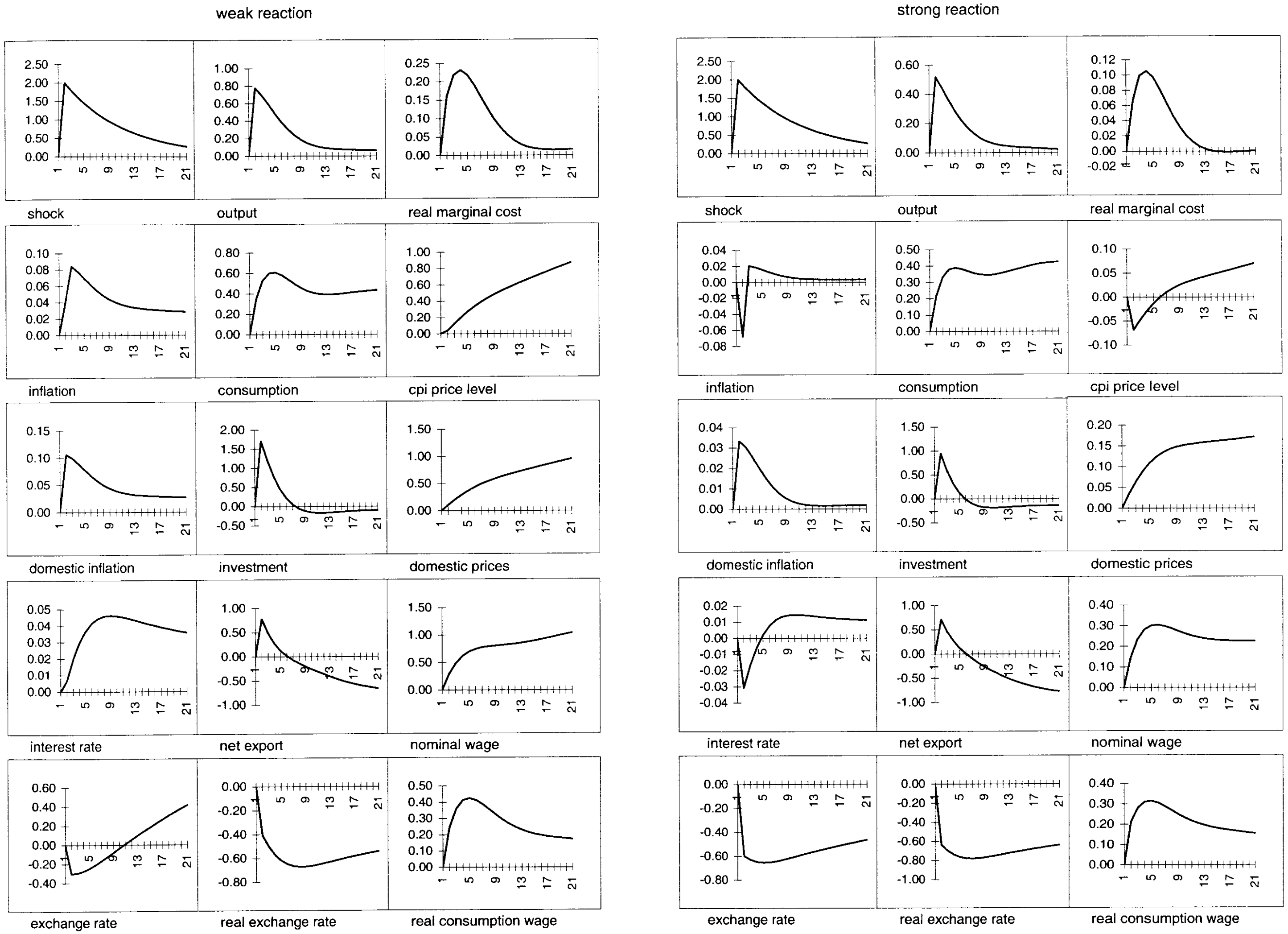


Figure 3 Impulse-response functions for a supply shock (increase in productivity - autocorrelation 0.95)

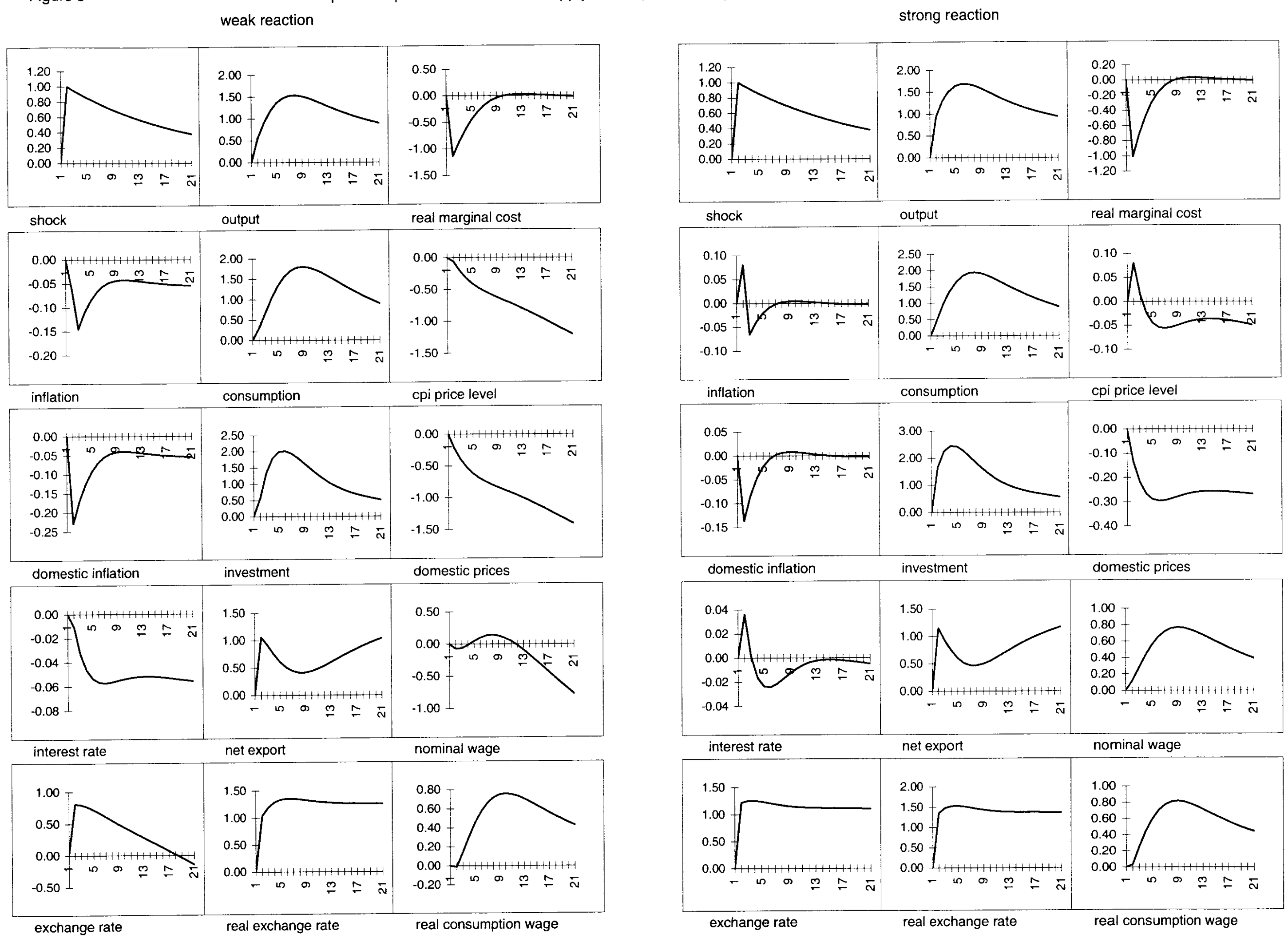


Figure 4 Impulse-response functions for an energy price shock : energy as intermediate input (second order autocorrelation (1.5,-0.55))

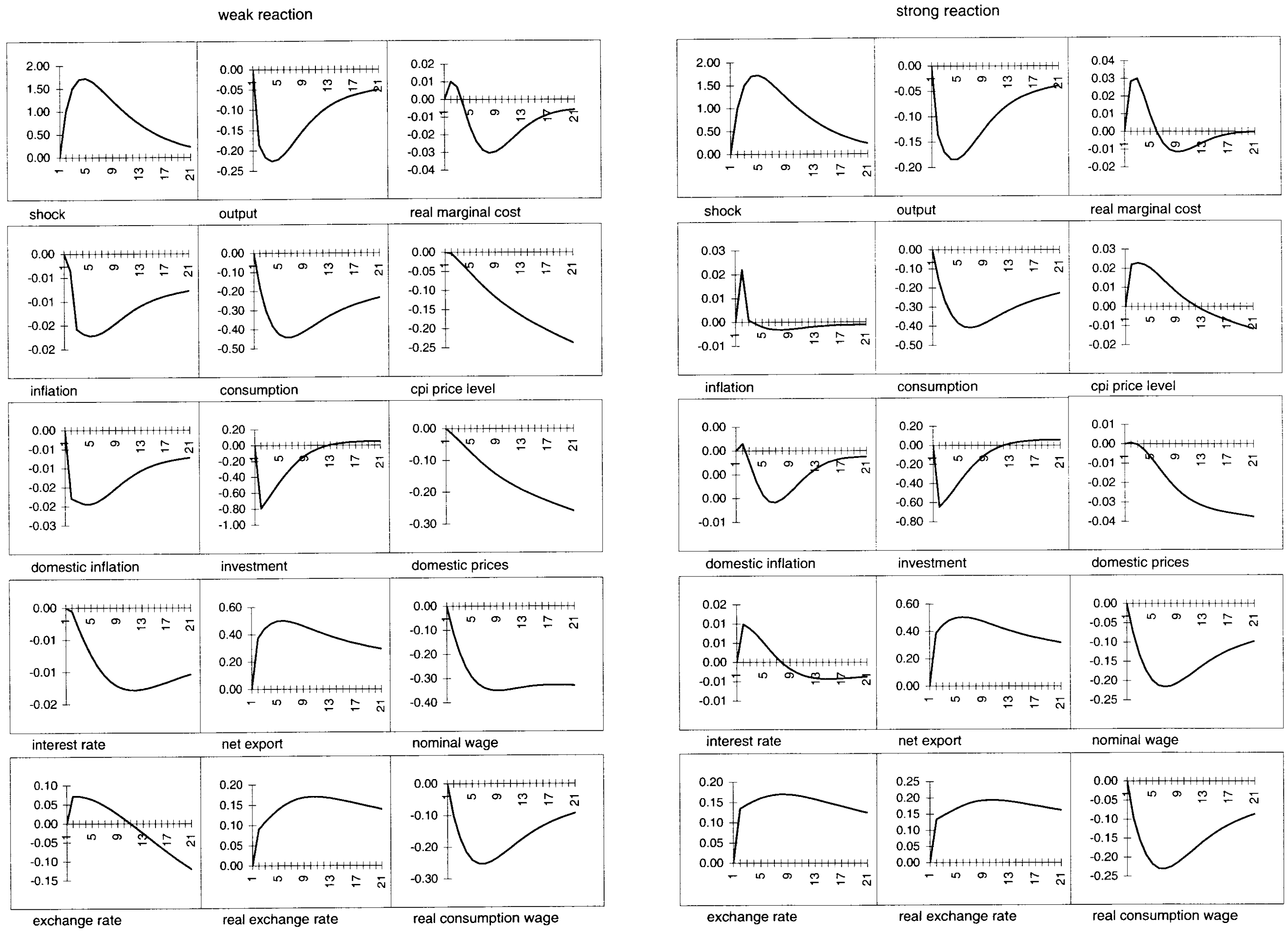


Figure 5 Impulse-response functions for an energy price shock : energy as final consumption good (second order autocorrelation (1.5,-0.55))

weak reaction strong reaction

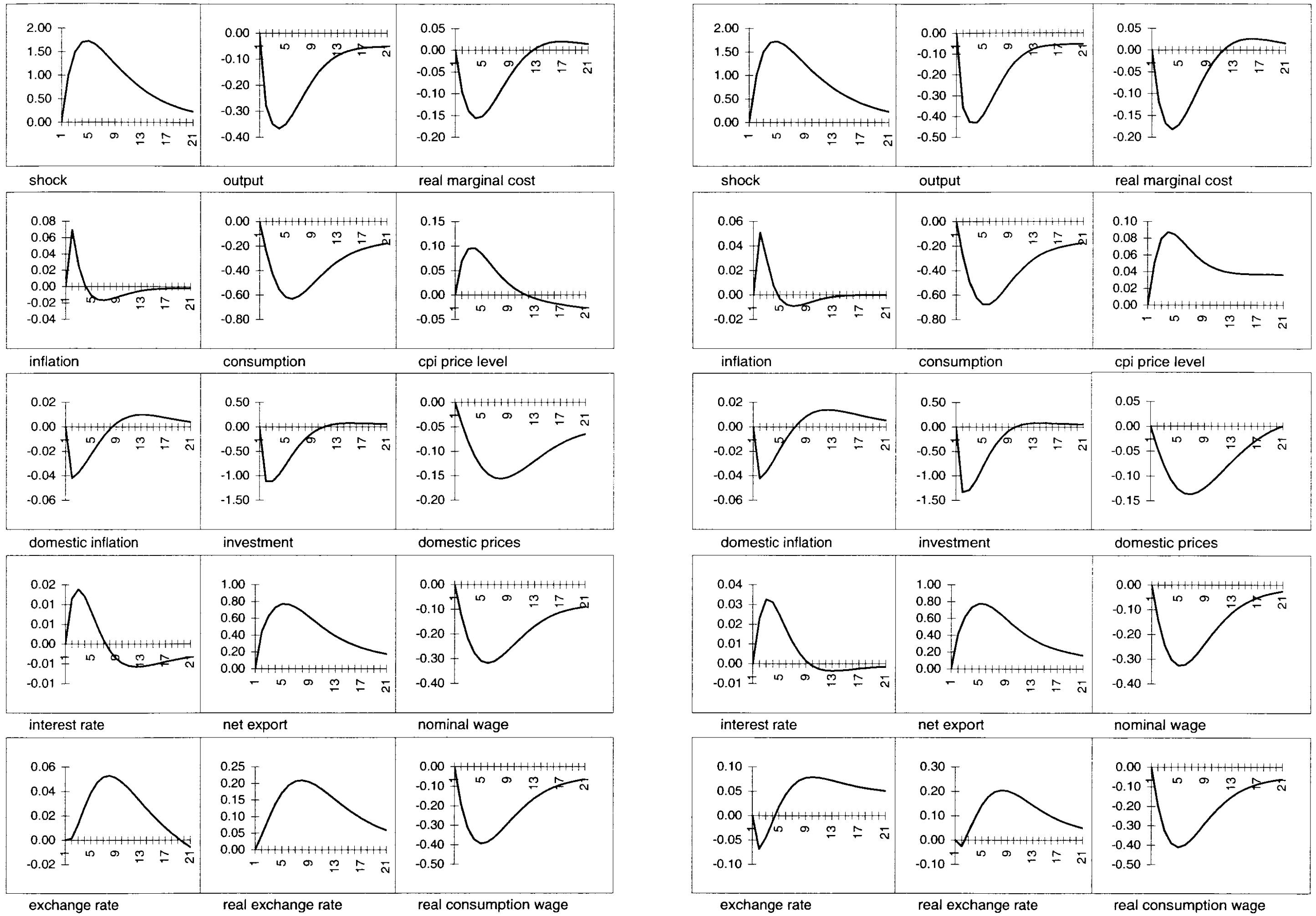


Figure 6 Impulse-response functions for an exchange rate shock (increase in risk premium - autocorrelation 0.9)

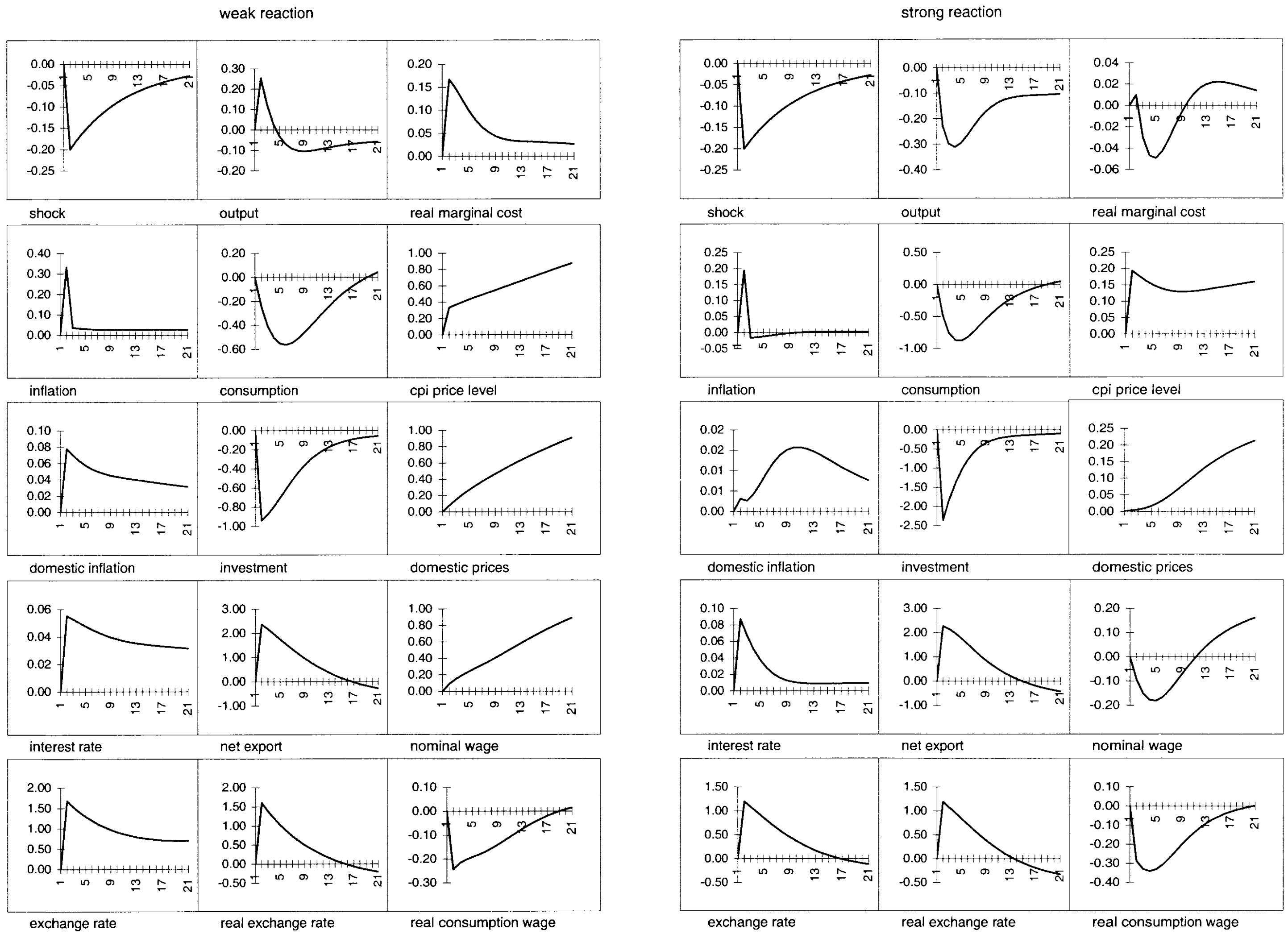
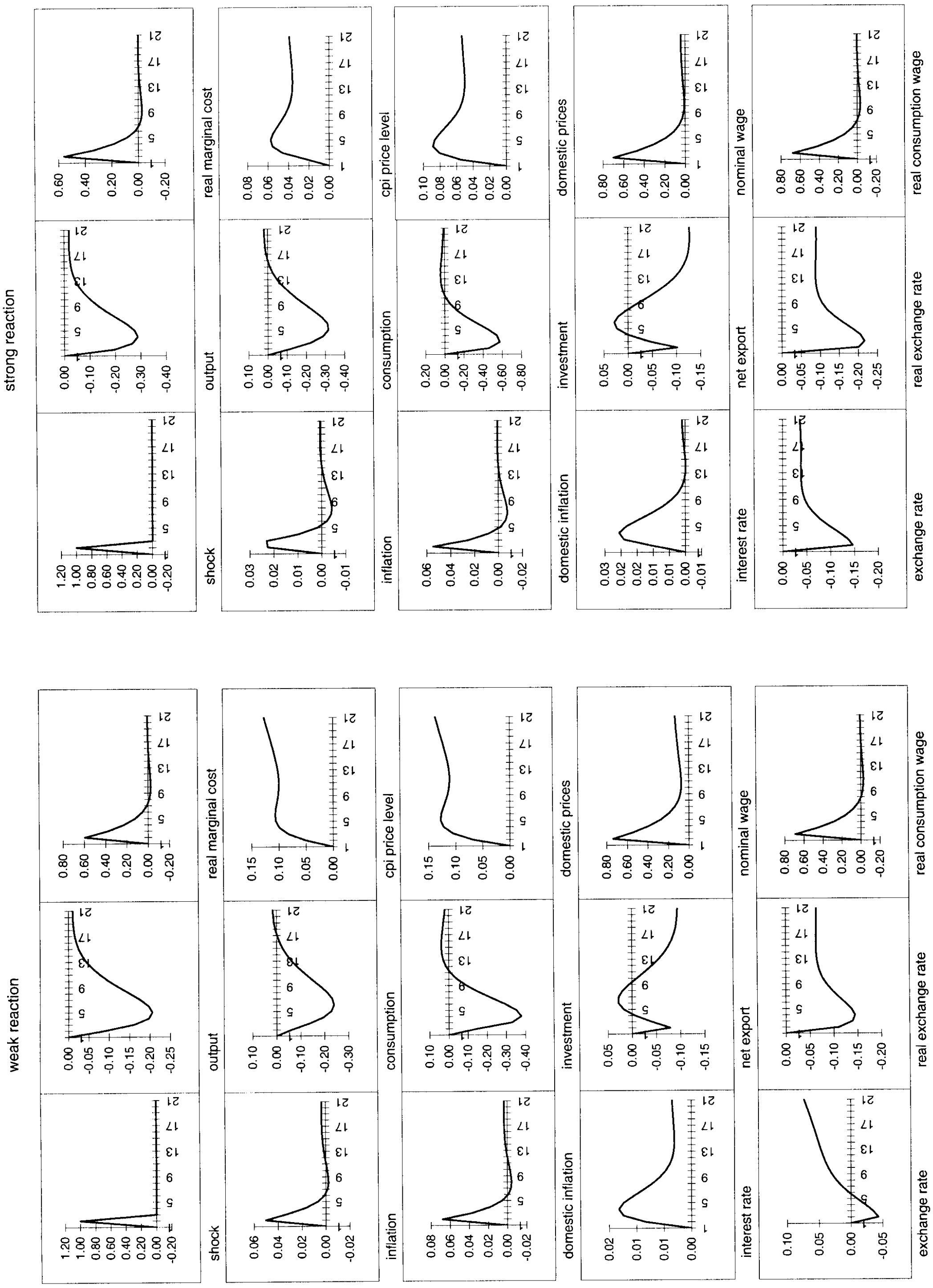


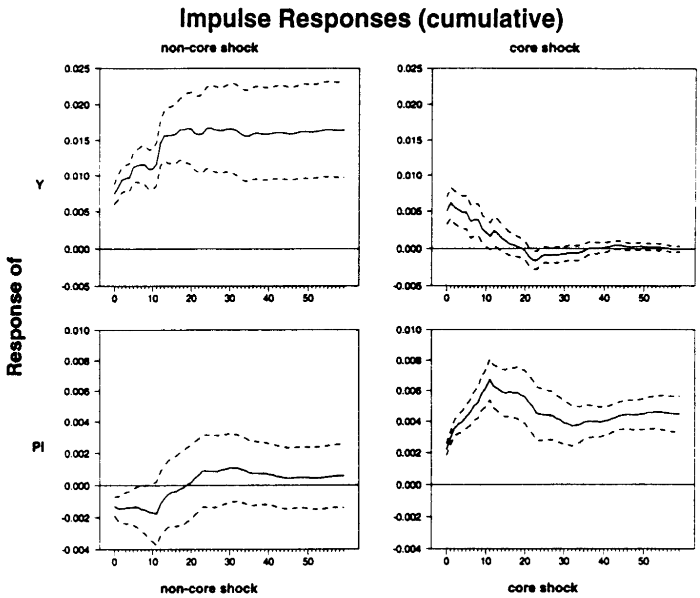
Figure 7

Impulse-response functions for a cost-push shock (wage increase shock)

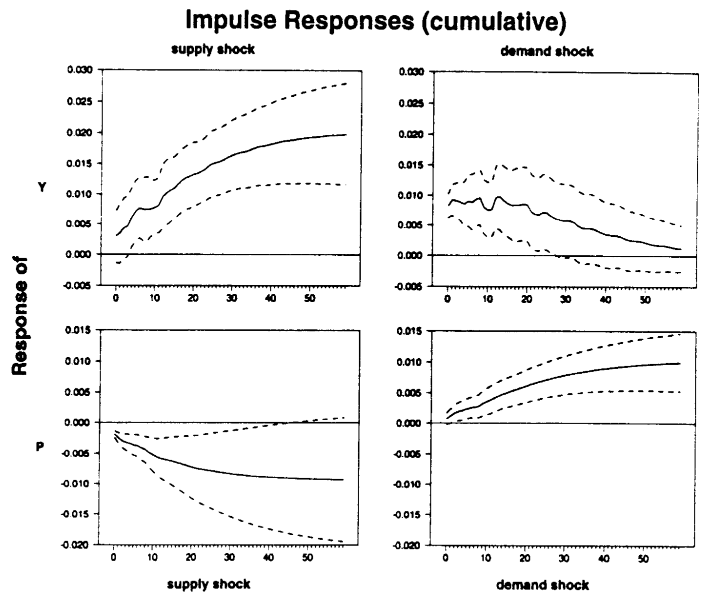


# USA : IMPULSE RESPONSE IN A BIVARIATE VAR WITH

## 1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION




## 2. OUTPUT GROWTH AND MEASURED INFLATION

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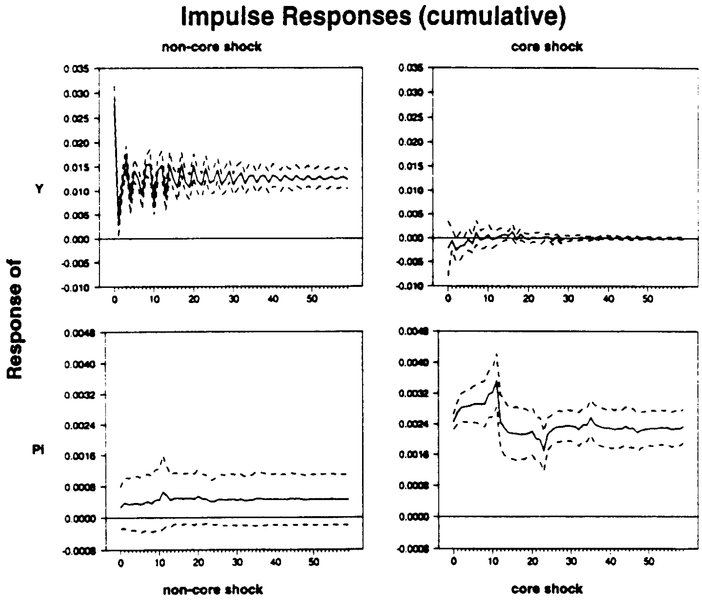
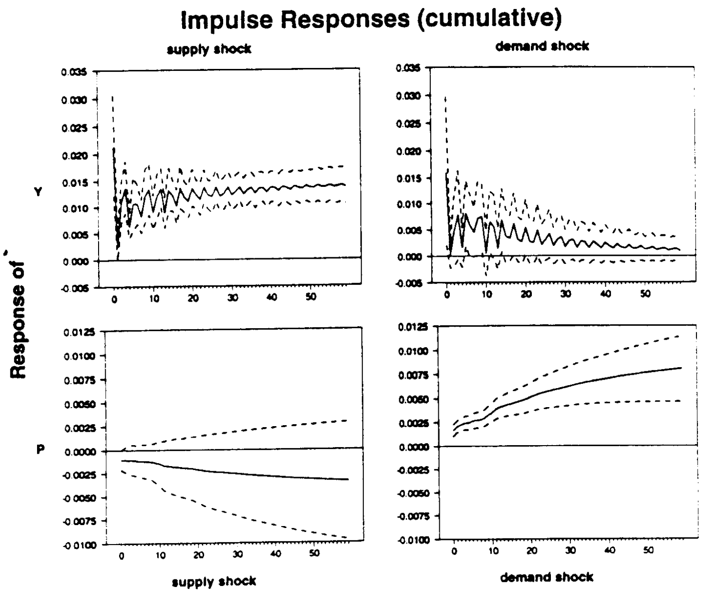
# GERMANY : IMPULSE RESPONSE IN A BIVARIATE VAR WITH

## 1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION




## 2. OUTPUT GROWTH AND MEASURED INFLATION

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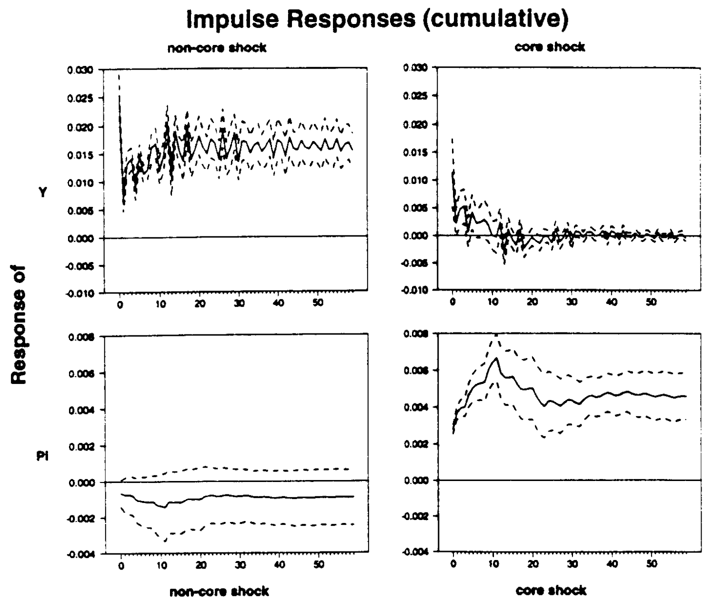
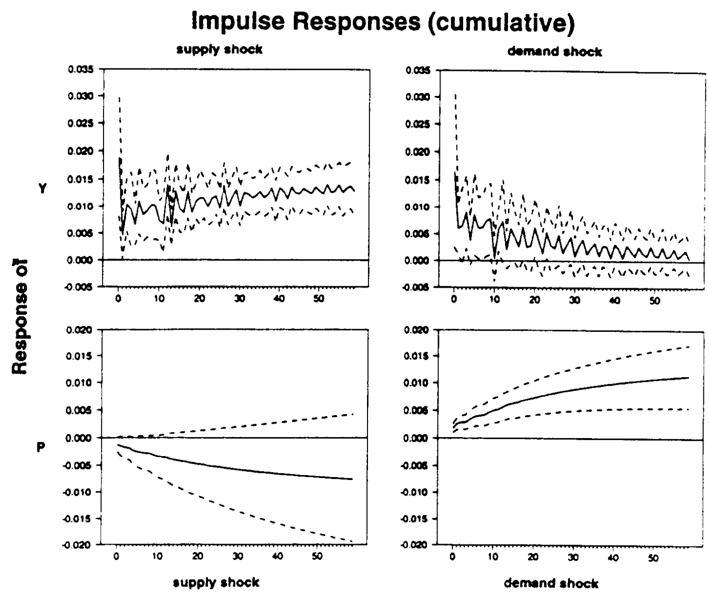
# BELGIUM : IMPULSE RESPONSE IN A BIVARIATE VAR WITH

## 1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION



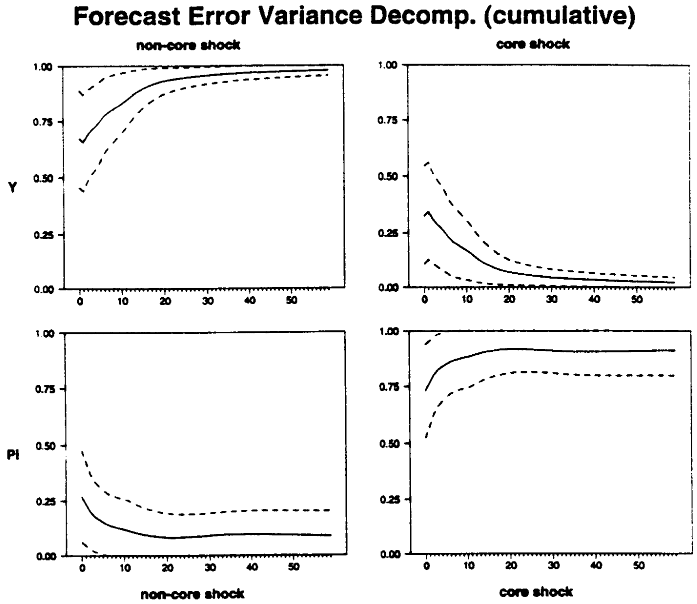

## 2. OUTPUT GROWTH AND MEASURED INFLATION




GRAF 2VAR.doc

## USA : FORECAST ERROR DECOMPOSITION IN A BIVARIATE VAR WITH

### 1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION




### 2. OUTPUT GROWTH AND MEASURED INFLATION

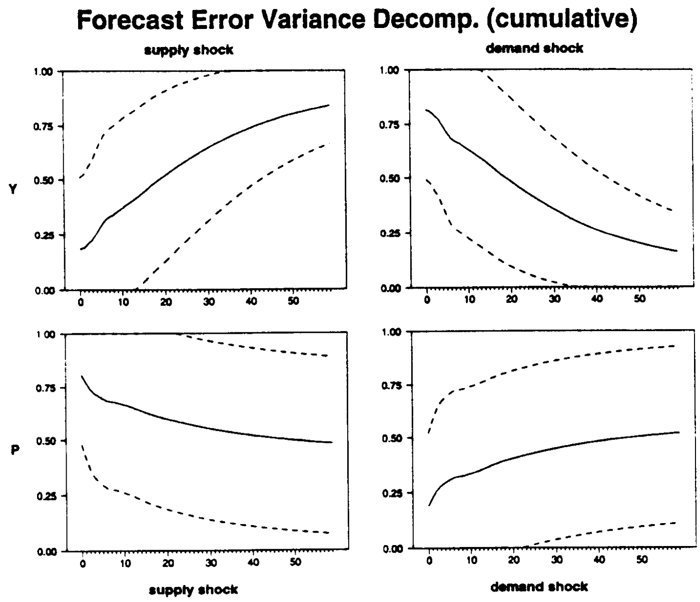
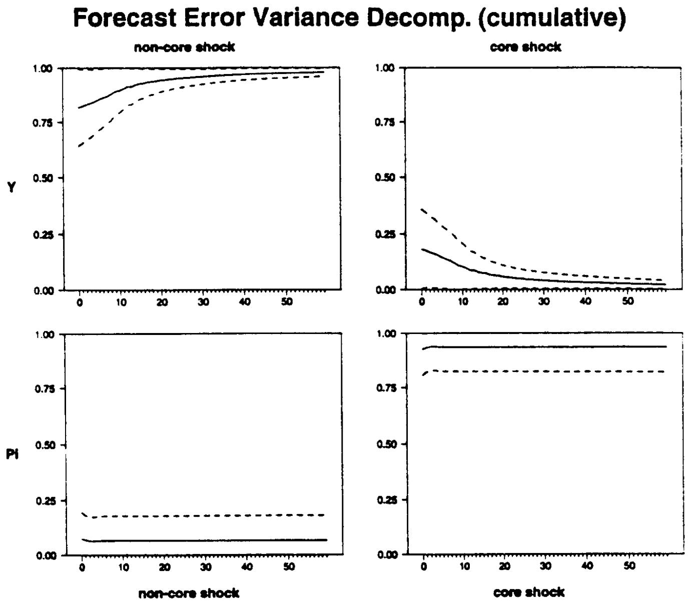


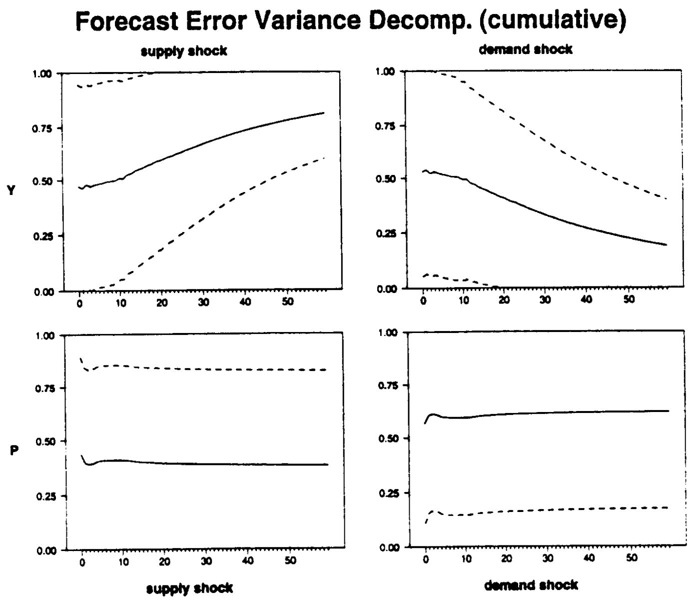
Figure 12

**BELGIUM : FORECAST ERROR DECOMPOSITION IN A BIVARIATE VAR WITH**

**1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION**

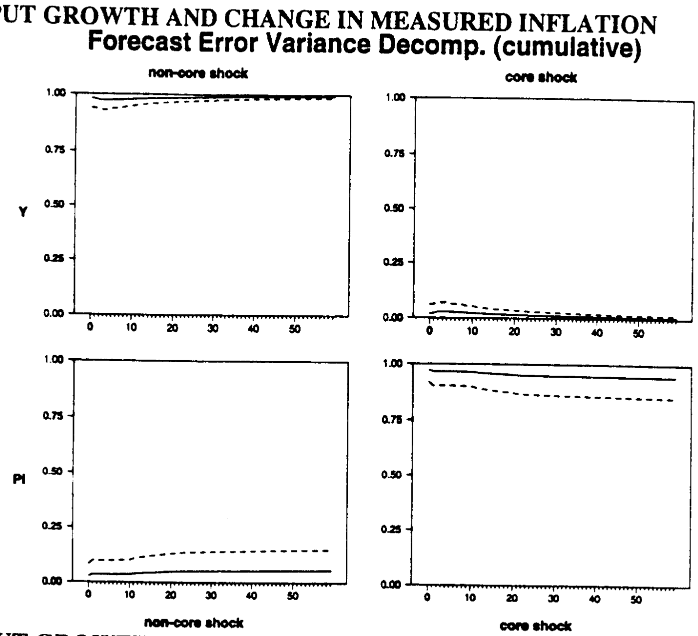



**2. OUTPUT GROWTH AND MEASURED INFLATION**



## GERMANY : FORECAST ERROR DECOMPOSITION IN A BIVARIATE VAR WITH

### 1. OUTPUT GROWTH AND CHANGE IN MEASURED INFLATION




### 2. OUTPUT GROWTH AND MEASURED INFLATION

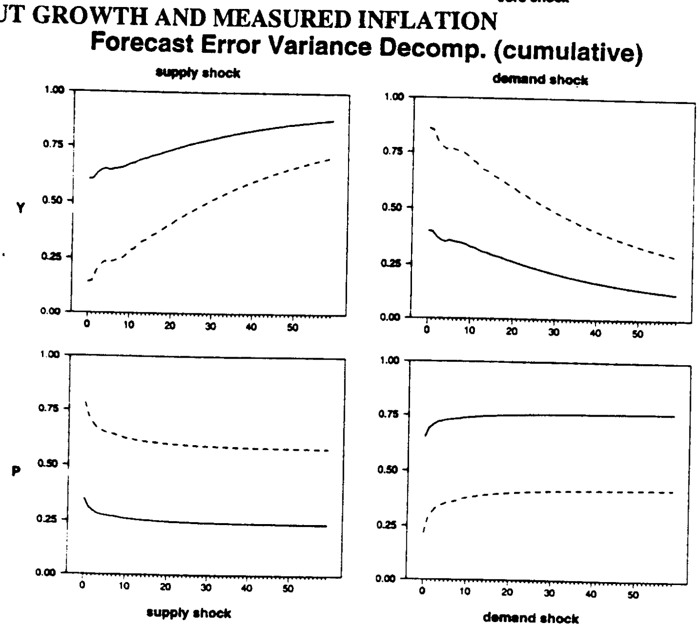
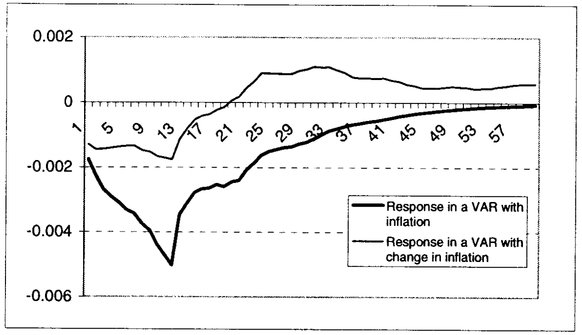


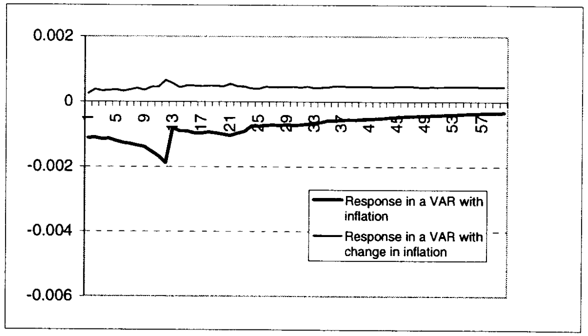
Figure 14

**CONSEQUENCES OF THE VAR SPECIFICATION FOR THE IMPULSE RESPONSES OF A SUPPLY SHOCK ON INFLATION**

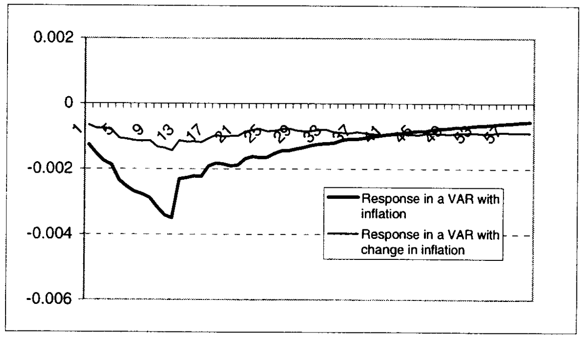
**USA**



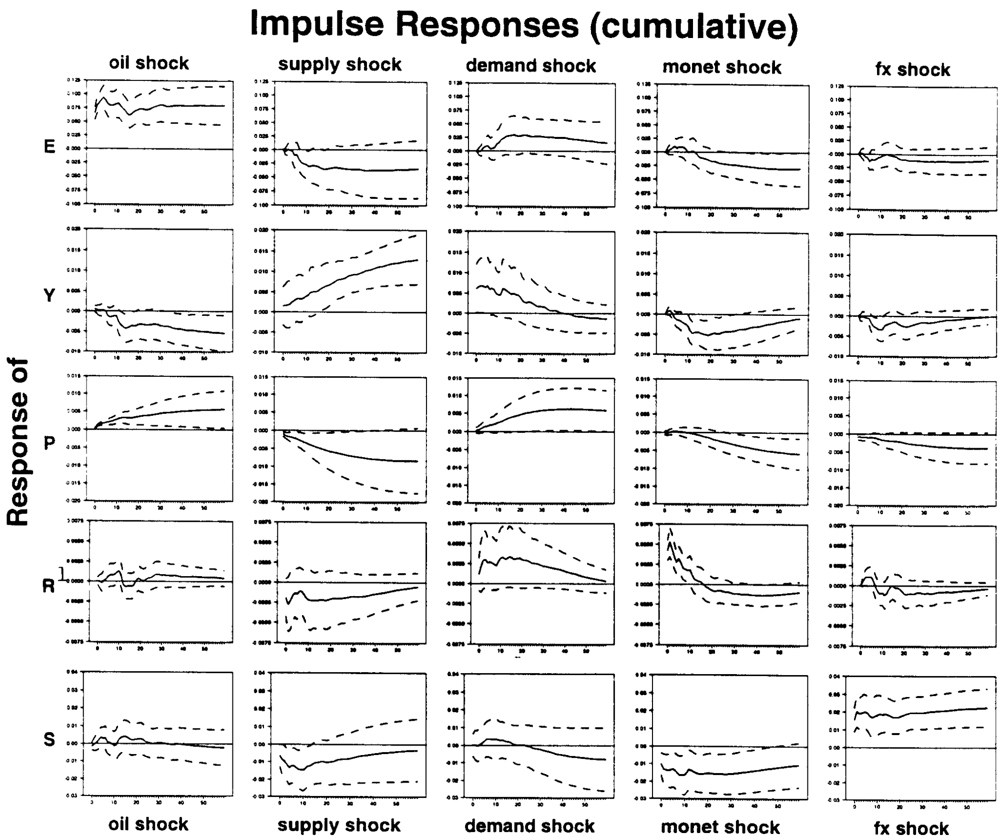

**GERMANY**




**BELGIUM**



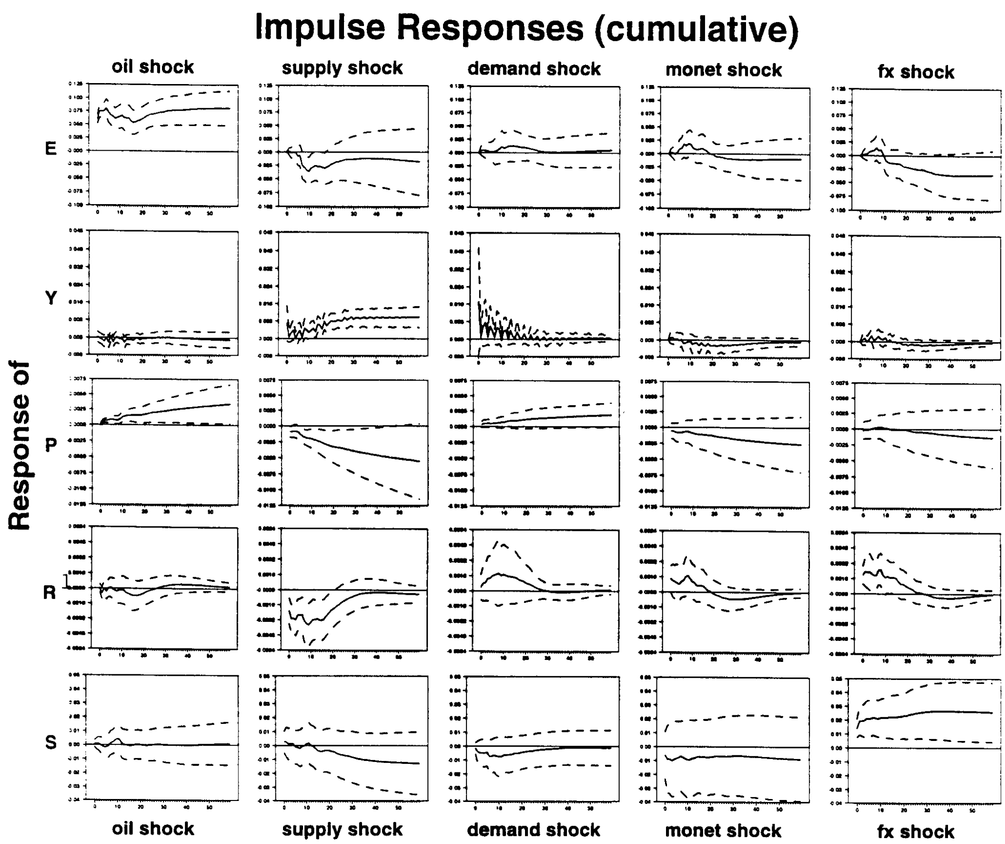
**A SVAR WITH 5 VARIABLES : USA**




1 Not cumulative.

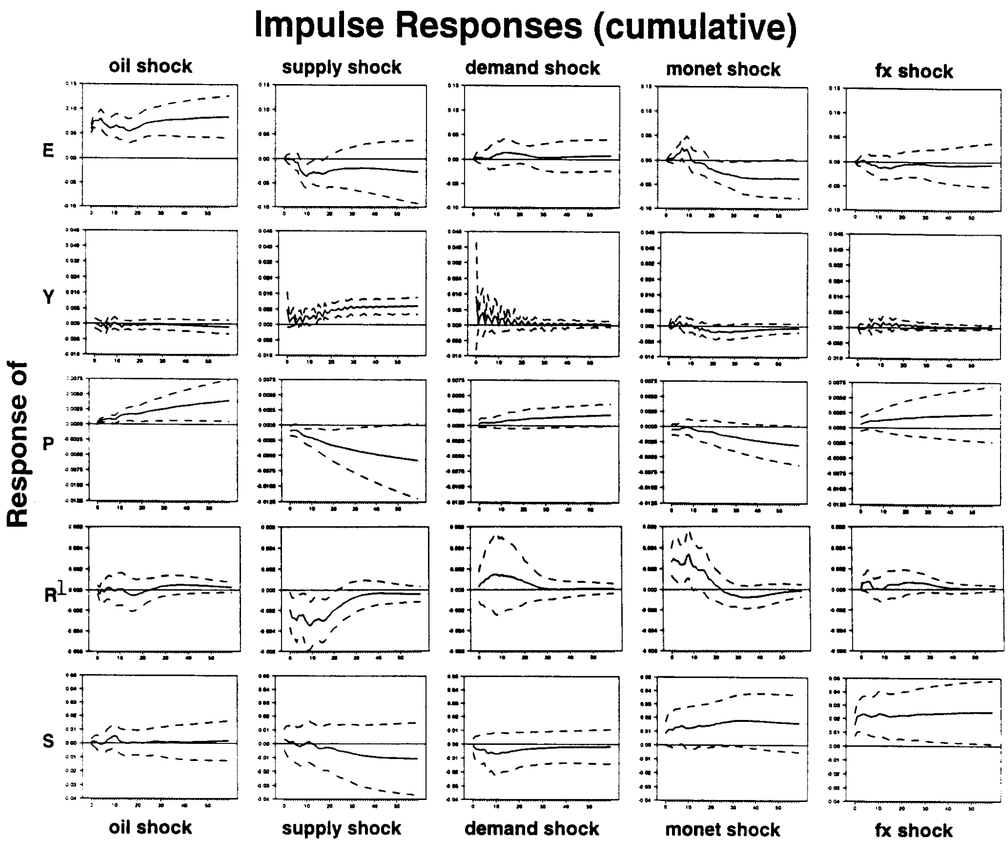
Figure 16

**A SVAR WITH 5 VARIABLES : GERMANY WITH SOME WEIGHT ON EXCHANGE RATE STABILISATION**



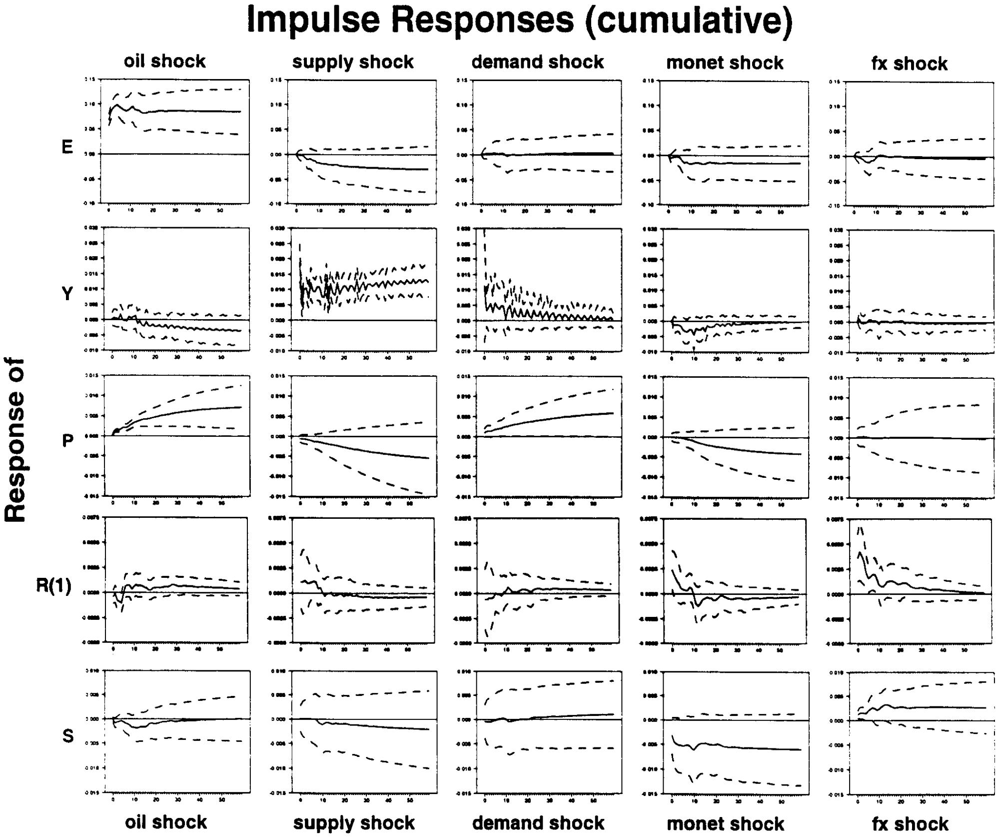

1 Not cumulative.

**A SVAR WITH 5 VARIABLES : GERMANY WITHOUT WEIGHT ON EXCHANGE RATE STABILISATION**




1 Not cumulative.

**A SVAR WITH 5 VARIABLES : BELGIUM USING THE BEF-DEM EXCHANGE RATE AND THE INTEREST RATE DIFFERENTIAL VIS-A-VIS GERMANY**




(1) Short-term interest rate differential vis-à-vis Germany. Not cumulative.

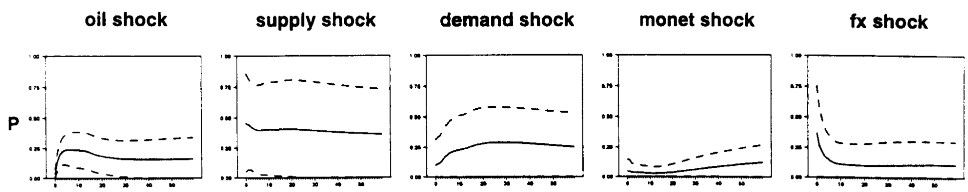
Figure 19


IMPULSE RESPONSES OF AN ENERGY SHOCK ON INFLATION (12 MONTH CHANGE IN CPI)
Belgium
Germany
USA
0.003500
0.003000
0.002500
0.002000
0.001500
0.001000
0.000500
0.000000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59

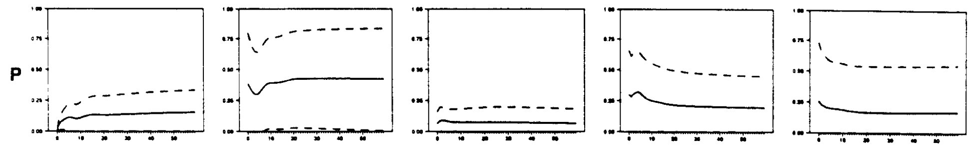
Figure 20

## FORECAST ERROR VARIANCE DECOMPOSITION FOR CONSUMER PRICES

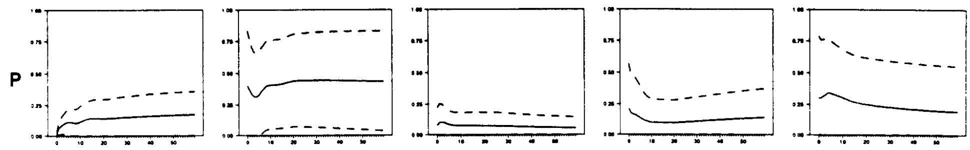
### 1. USA



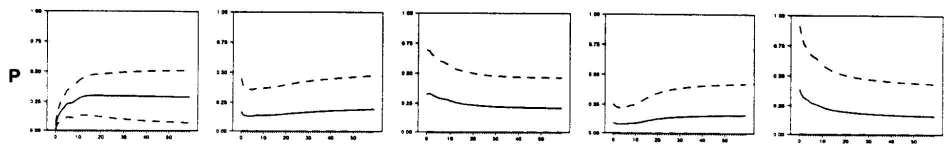

### 2. Germany, with some weight on exchange rate stabilisation




### 3. Germany, without weight on exchange rate stabilisation

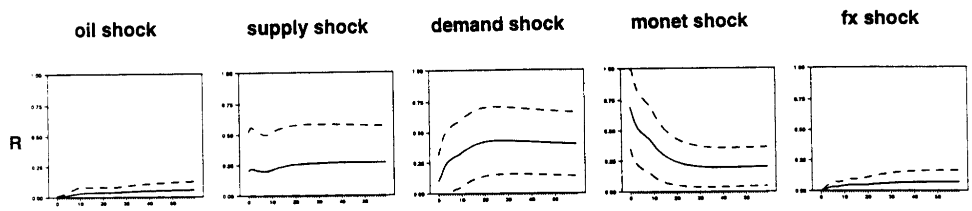



### 4. Belgium

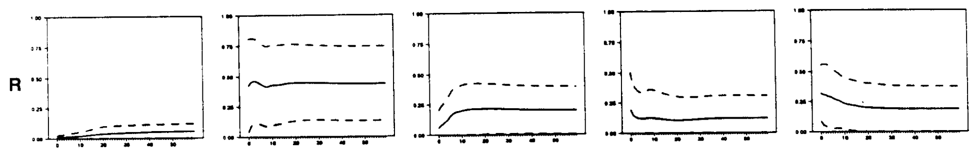


## FORECAST ERROR VARIANCE DECOMPOSITION FOR SHORT INTEREST RATES

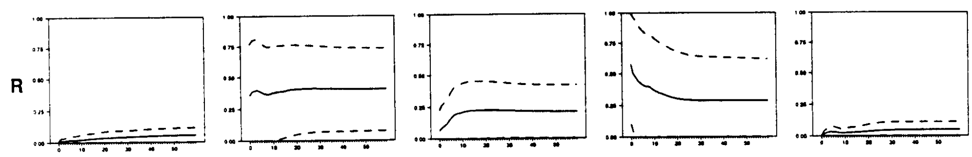
**1. USA**



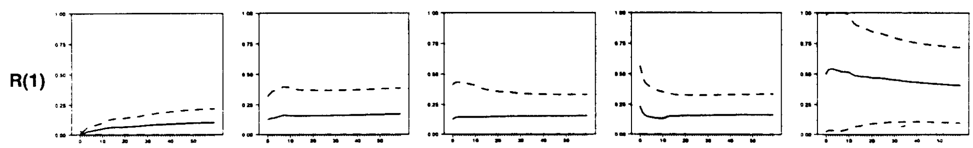

**2. Germany, with some weight on exchange rate stabilisation**




**3. Germany, without weight on exchange rate stabilisation**




**4. Belgium**




(1) Short term interest rate differential vis-à-vis Germany.

## Appendix: parameterisation of the theoretical model

In the standard simulation of the theoretical model the following values for the coefficients are assumed. The share of capital is set at 0.35 and the parameter for the cost of capital adjustment is 10. The parameter determining the marginal cost of higher capacity utilisation (King and Rebelo (1998)) is set at 0.1. In the utility function, we set the coefficient of relative risk aversion at 1. The habit variable moves with consumption lagged one period with a coefficient equal to 0.8. The macroeconomic labour supply elasticity with respect to real wages is 0.5.

The structure of final demand is given by the following steady-state assumptions: final import/gdp = 0.15, energy import/gdp = 0.10, export/gdp = 0.25, consumption/gdp = 0.58, investment/gdp = 0.22, government expenditures/gdp = 0.20, public debt/gdp = 2.4 and net foreign assets/gdp = 0.4. The discount factor $\beta$ is set at 0.99, the rate of depreciation is 0.02 and capital/gdp ratio is 11.0. The import and export price elasticity is set at 0.75.

In order to get a specification in which monetary expansions result in persistent effects on real growth and inflation, we set the probability of price and wage changes at 0.2 which falls within the acceptable region of empirical estimates. In this case the average duration for a fixed price and wage contract is equal to (1 - 0.2)/0.2 or four quarters, which is comparable with one-year Taylor-type contracts. In similar models, King and Watson (1996) use a value of 0.1 for the price adjustment coefficient, whereas Gali and Gertler (1998) estimate a value of 0.2 in an empirical model for the US.

These parameters can reflect the economic structure of a large open economy such as Germany. The model is linearized around the steady state growth path. This results in a simple linear model that is solved numerically using the Troll software.

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