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Economic Fluctuations in a Small Open Economy – Real versus Nominal Shocks

Abstract:
This paper analyses the role of real and nominal shocks in explaining business cycles in a small open economy like that of Norway. In particular, we study the sources behind real exchange rate fluctuations since the collapse of the Bretton Woods agreement. Imposing long run restrictions implied by economic theory on a structural vector autoregression (VAR) model containing GDP, unemployment (or price), real wage and the real exchange rate, four structural shocks are identified; Velocity (or monetary), fiscal, productivity and labour supply shocks. The model is also augmented to allow for oil price shocks.The identified shocks and their impulse responses are consistent with an open economy (Keynesian) model of economic fluctuations, and highlights the exchange rate as a transmission mechanism in a small open and energy based economy. Especially, I have found a plausible sequence of shocks (productivity shocks in the 1970s, velocity shocks in the mid-1980s, productivity and labour supply shocks in the late 1980s, and velocity and fiscal shocks in the early 1990s), which help to explain the evolution of GDP, unemployment, price, real wage and the real exchange rate. The results are robust to alternative specifications of the model and are stable over the sample.

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1. Introduction

A major focus of attention in macroeconomics in recent years, has been to identify the sources of economic fluctuations. It has been of particular concern to quantify the relative importance of real versus nominal shocks in the generation and propagation of business cycles. Initially, one of the motivations for doing so was to give relative credits to either the traditional demand driven Keynesian models, where monetary shocks have real effects due to the presence of market imperfections like nominal rigidities (see e.g. Fisher 1977, and Phelps and Tayler 1977), or the Real Business Cycle (RBC) approach, which attribute all (short and long run) variability in output to real as opposed to monetary factors (see e.g. Kydland and Prescott 1982).

However, the distinction between the RBC and the New-Keynesian theory no longer hinges on whether money can be a source of business cycles or not. Today many RBC models will argue that money can have some role as a driving force for the short run fluctuations in the economy, by introducing for instance sticky prices into the equilibrium models (see e.g. Yun 1996, and the references cited there).[1] On the other hand, many of the models that build on the heritage from the Keynesian tradition, will now agree with the RBC proponents about the long run neutrality of money (see e.g. the panel discussion by Blanchard 1997, Blinder 1997, Eichenbaum 1997, Taylor 1997, and Solow 1997). Disagreement nevertheless remains as to what constitutes most of the short run movements in economic activity, and the New Keynesians would say aggregate demand, whereas the RBC school would say aggregate supply (i.e. technology).

This paper focuses on the relative ability of real and nominal shocks to explain business cycles in Norway. To do so, I specify a structural vector autoregression (VAR) model, and, without imposing strong economic beliefs, identify nominal and real shocks through assumptions about the long run impacts of these shocks on the variables in the model (cf. Blanchard and Quah, 1989). As the direct measure of these shocks is difficult, it motivates the use of a VAR model, where, rather than specifying the impulses that correspond to the different policies, a set of equations are instead specified that characterise the different polices. The VAR approach is also particularly useful for the purpose of this paper, as it allows us to decompose the variation in a set of variables to the relative contribution of the different underlying shocks.

The key (long run) identifying assumption used here to distinguish between the nominal and real shocks, asserts that in the long run the level of output will be determined by real shocks. Hence, there is a full employment (natural) level of output that can only change with the real factors in the economy. As discussed above, this type of long-run identifying restriction is consistent with most models of macroeconomic fluctuations, but at the same time allows us to discriminate between the different schools of thought based on the short run implications of the model. In particular, although the nominal shocks are restricted so that they have no permanent effects on output, the speed of adjustment is left unrestricted, so that it may be instantaneous (as in the New Classical models with rational expectations) or slow (as in some Keynesian models with a relatively flat short run supply schedule).

In the (benchmark) VAR model specified here, I will allow for two nominal shocks (velocity and fiscal shocks) and two real shocks (productivity and labour supply shocks). Neither of the nominal shocks can

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[1] Exceptions to this would be some proponents of the rational expectations school, where money does not have a real effect even in the short run as prices adjust immediately to nominal shocks.

have a long run effect on the level of real output (nor unemployment). To separate the two nominal shocks and the two real shocks from each other, we need to assume something about the effects they have on the other variables in the model. The choice of variables should then be such that they capture the likely transmission mechanisms of the different shocks in the system.

There is an ongoing debate about the "appropriate" transmission mechanisms of the various shocks. Many studies of the effects of policy shocks in a small open economy have generated puzzling dynamic responses in a set of aggregated macroeconomic variables, puzzles that may appear due to an identification of the shocks that is inappropriate for such economies (see also Cushman and Zha 1997). For instance, in an open economy with flexible exchange rates and perfect capital mobility, a positive monetary shock that increases output will not only work via the interest rate channel, but will also have additional effects via the exchange rate (as the reduced interest rate will depreciate the exchange rate, improve the current account and thereby increase output). Studies that fail to take account of this channel, may typically misrepresent the importance of monetary shocks as a driving force of the business cycle.

In addition, for a resource rich country like Norway, a dominant energy sector can also have affects on the domestic economy via the exchange rate. Especially, a resource discovery may give rise to wealth effects that appreciate the exchange rate. This may squeeze the tradeable sector, a phenomenon that has been termed the "Dutch Disease" in the economic literature. To allow both the nominal and real shocks to also influence the domestic economy through an exchange rate channel, I therefore include the real exchange rate into the model. A second goal of the paper will be to study explicitly the sources behind the real exchange rate fluctuations in Norway, since the collapse of the Bretton Woods fixed exchange rate regime in the early 1970s.

The choice of the real exchange rate in the VAR model is also important as it allows me to separate a velocity (or a monetary shock) from the other nominal shocks, by assuming that the monetary shock can have no long run effect on the real exchange rate (see also Clarida and Gali 1994).[2] This is consistent with most models of short run exchange rate variability but long run purchasing power parity. In particular, the Dornbusch (1976) overshooting model explains short run real exchange rate volatility with sticky prices and monetary disturbances.

To distinguish the two real shocks from each other, the real wage is included into the model. Productivity (or labour demand) and labour supply shocks are then identified by assuming that only productivity shocks can affect the real wage in the long run. This is implied by a Solow growth model with a fixed savings rate and a constant-returns-to-scale production function (see the discussion in Gamber and Joutz 1993). In particular, a change in the labour supply will lead to an equal percentage change in the capital stock. The real wage will at first fall, but as the capital stock reaches its steady state level, the real wage increases back to the original level. As emphasised above, I place no restrictions on the effect of the productivity and labour supply shock on the real exchange rate, as I do not want to rule out any long run effects from the supply side on the real exchange rate.

To sum up, the VAR model estimated here consists of four variables; Real GDP, the rate of unemployment, the real wage and the real exchange rate. These four variables will then be sufficient to identify the four structural shocks; Velocity, fiscal, productivity and labour supply shocks. Neither velocity nor fiscal shocks can have long run effects on the level of GDP, the rate of unemployment or the real wage. In addition, velocity shocks have no long run effects on the real exchange rate. Productivity

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[2] In the remaining discussion I will use the terms velocity and monetary shocks interchangeably.

and labour supply shocks are both allowed to have a permanent effect on output and the real exchange rate, but only productivity shocks can affect the real wage in the long run. The choice of variables and the restrictions imposed on the VAR model, will be motivated by an economic model below.

Note that as emphasised above, no specific policy variable like monetary policy is included in the model. Instead, a velocity shock is identified through the effects it has on a set of target (or key macroeconomic) variables. There are several reasons for this. First, recent VAR studies of monetary policy have failed to come up with a consensus about what is the appropriate measure of monetary policy. For instance, whereas Bernanke and Blinder (1992) argue that the federal funds rate is a powerful indicator of monetary policy, Gordon and Leeper (1994), Bernanke and Mihov (1995) and Christiano, Eichenbaum and Evans (1996), focuses on monetary policy derived from explicit models about base money, reserves and central bank operating procedures.[3] Second, monetary aggregates in many countries have been subject to large disturbances unrelated to the business cycles (i.e. financial and credit deregulations), making them uninformative about monetary policy. Third, monetary policy instruments may have changed over the years, hence it is difficult to find a consistent series to use over the sample (see also Jacobsen et al. 1997, for a similar argument). Finally, with the development of a more complex monetary system, the monetary authorities control of monetary aggregates has decreased over time, making them less appropriate as a measure of policy stance.

The benchmark VAR model specified here will be exposed to several robustness tests. First, I replace the rate of unemployment with the inflation rate, to (a) check whether the impulse responses remain invariant to this model specification, and (b) test for overidentifying restrictions by investigating the implied effects of the different shocks on prices (inflation).[4] Both models are then re-estimated over different periods, to see if they are stable over the sample. Finally, I introduce the real oil price into the model, to investigate whether oil price shocks have been important sources of business cycles in Norway.

The results confirm the conventional view about the existence of significant shocks with impulse responses consistent with a standard Keynesian theory on economic fluctuations, and highlights the exchange rate as a transmission mechanism in a small open and energy based economy. In particular, I have found a plausible sequence of shocks (productivity shocks in the 1970s, velocity shocks in the middle 1980s, productivity and supply shocks in late 1980s, and velocity and fiscal shocks in the early 1990s) which help to explain the evolution of GDP, the unemployment rate, the price, the real wage and the real exchange rate. The results are robust to alternative specifications of the model, and appear stable over different samples.

The paper is organised as follows. In section two I propose an open economy model that satisfies the identifying restrictions discussed here. Section three identifies the benchmark structural VAR, and in section four I trace out the impulse response and the variance decomposition to the identified shocks. Section five displays the response in the main aggregate variables to the shocks in each historical period. In section six, I test the robustness of the results, by performing some model variations and tests of sample stability. Section seven summarises and concludes.

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[3] See also Rudebusch (1996) who argues that VARs are not useful for measuring monetary policy.

[4] Faust and Leeper (1997) have argued that for long run restrictions to give reliable results, the aggregation of shocks in small models should be checked for consistency using alternative models.

2. An open economy model

The open economy (Keynesian) model presented here is a variant of a closed economy model put forward in Blanchard and Quah (1989), and consists of an aggregate demand function, a production function, a price setting behaviour, an equation describing wage setting behaviour, a labour supply schedule and a real exchange rate equation:

(1) $$y_t = m_t - p_t + d_t + \alpha\theta_t + \beta(e + p* - p)_t$$

(2) $$y_t = n_t + \theta_t$$

(3) $$p_t = w_t - \theta_t$$

(4) $$w_t = w \big| \left[E_{t-1} n_t = \bar{n}_{t-1} \right]$$

(5) $$\bar{n}_t = \gamma(w_t - p_t) + \lambda_t$$

(6) $$(e + p* - p)_t = \Delta m_t + \pi d_t + \delta\theta_t + \sigma\lambda_t$$

where y is the log of real output, θ is the log of productivity, p is the log of the nominal price level, w is the log of the nominal wage, m is the log of nominal money supply, e is the log of the nominal exchange rate, $p*$ is the log of the foreign price level, d reflects demand in the goods market (i.e. some form of fiscal innovation not captured by monetary changes), n is the log of employment, $\bar{n}$ implies the log of labour supply and λ is a labour supply factor. α, β, γ, π, δ and σ are coefficients. Δ is the difference operator, (1-L). The rate of unemployment is defined as $u = \bar{n} - n$.

Equation (1) states that aggregate demand is a function of real balances, demand in the goods market, productivity and the real exchange rate. Both productivity and real exchange rates are allowed to affect aggregate demand directly. I expect $\alpha>0$, as a higher level of productivity may imply higher investment demand. The sign on β reflects the joint effect of the real exchange rate on the total economy. Typically, one would expect $\beta>0$, as a depreciation (increase) of the real exchange rate induces a balance of trade improvement, via an expenditure switching.

The production function (2) relates output to employment and technology through a constant return Cobb-Douglas production function. The price setting behaviour (3) gives the nominal price as a mark up on wages adjusted for productivity. As in Blanchard and Quah (1989), wages are chosen one period in advance to achieve full employment in (4). However contrary to that study, the labour supply is now allowed to vary. In (5), labour supply increases with real wages and other supply factors.[5] I expect $\gamma>0$, as labour supply increases with a higher real wage.

Most economists believe in some variant of the purchasing power parity (PPP) as an anchor for long run real exchange rates. However, real exchange rates can deviate from the PPP in the short run, and can in fact be very volatile. Recently, empirical studies have also shown that real exchange rates are not only very volatile in the short run, the speed of convergence to PPP in the long run is extremely slow (see

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[5] A similar representation was presented in Dolado and Lopez-Solido (1996), although they also introduced a labour supply discouragement factor into (5).

Rogoff 1996). How is it possible to reconcile the enormous short term volatility of real exchange rates with the very slow rates at which these shocks seem to disappear? The persistent deviation from PPP casts doubt on the Dornbusch (1976) open macroeconomic (overshooting) model, that explains short run real exchange rate volatility with sticky prices and monetary disturbances. Instead, long run deviation from PPP suggests the influence of real shocks with large permanent effects. The fact that many empirical studies do not reject the hypothesis of a unit root in the real exchange rate (see e.g. Serletis and Zimonopoulos 1997), also supports the argument that the variations in real exchange rates are attributed to permanent shocks.

Equation (6) suggests a function for the real exchange rate that encompasses *both* the short term volatility and the long run deviations from purchasing power parity. In particular the real exchange rate is a function of changes in money supply, fiscal innovations and some fundamentals, represented here by productivity and labour supply factors. As will be seen below, PPP is preserved in the long run with respect to monetary changes, so that a monetary shock will increase the price and depreciate the exchange rate proportionally. This leaves the real exchange rate unchanged in the long run, as predicted by the Dornbusch overshooting model and the Mundell-Fleming model with flexible prices. The same models also predict that a fiscal expansion appreciates the real exchange rate (via an increase in the interest rate, a capital inflow and a balance of payment surplus), hence I expect $\pi<0$.

Productivity and labour supply are good proxies for the fundamentals in the economy, as they will determine the path of real output in the long run (cf. equation 11 below). The effects of the fundamentals on the real exchange rate depend on the sign of δ and σ. For a small oil producing country like Norway, the discovery of natural resources may have the same effects on the exchange rate as the introduction of a new technology, that changes relative prices and appreciates the real exchange rate in the long run, hence, $\delta<0$.[6] More specifically, a discovery of natural resources will increase natural wealth and raise demand. If the economy is operating at full employment (as Norway did in the early 1970s when the oil discoveries in the North Sea were made), the additional demand can only be met if the relative prices change in favour of foreign goods, so that the currency experiences a real appreciation (see e.g. Corden and Neary, 1982). The effect of a labour supply shock on the real exchange rate is more difficult to establish. A flexible price exchange rate model would typically predict that following a labour supply shock, the price level falls monotonically and the real exchange rate depreciates, hence $\sigma>0$.

The model is closed by assuming m, θ, λ and d evolve as random walks, driven by four serially uncorrelated orthogonal velocity (or monetary) shocks (ε^{VEL}), productivity (or labour demand) shocks (ε^{PR}), labour supply shocks (ε^{LS}) and fiscal shocks (ε^{FI}):

(7) $\qquad m_t = m_{t-1} + \varepsilon_t^{VEL}$

(8) $\qquad \theta_t = \theta_{t-1} + \varepsilon_t^{PR}$

(9) $\qquad \lambda_t = \lambda_{t-1} + \varepsilon_t^{LS}$

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[6] A related explanation for why supply side factors like productivity may appreciate the real exchange rate in the long run, is due to Balassa (1964) and Samuelson (1964). The Balassa-Samuelson hypothesis states that the real exchange rate may appreciate if there are exceptionally large difference between productivity growth in the traded and the nontraded sector. A rise in productivity in the traded goods sector will lead to a wage effect only (as prices are tied down by the world price level). With no corresponding increase in productivity in the nontraded sector, prices in the nontraded sector must rise (to match the higher wage level), appreciating the real exchange rate.

(10) $\quad\quad d_t = d_{t-1} + \varepsilon_t^{FI}$

Solving for Δy, u, $\Delta(w-p)$ and $\Delta(e+p^*-p)$ yields:

(11) $\quad \Delta y_t = (1+\beta)\Delta\varepsilon_t^{VEL} + (1+\beta\pi)\Delta\varepsilon_t^{FI} + (1+\gamma)\varepsilon_t^{PR} + (\alpha - \gamma + \beta\delta)\Delta\varepsilon_t^{PR} + \varepsilon_{t-1}^{LS} + \beta\sigma\Delta\varepsilon_t^{LS}$

(12) $\quad u_t = -(1+\beta)\varepsilon_t^{VEL} - (1+\beta\pi)\varepsilon_t^{FI} - (\alpha - \gamma + \beta\delta)\varepsilon_t^{PR} + (1-\beta\sigma)\varepsilon_t^{LS}$

(13) $\quad \Delta(w-p)_t = \varepsilon_t^{PR}$

(14) $\quad \Delta(e+p^*-p)_t = \Delta\varepsilon_t^{VEL} + \pi\varepsilon_t^{FI} + \delta\varepsilon_t^{PR} + \sigma\varepsilon_t^{LS}$

Equation (11) states that only productivity and labour supply shocks will affect the level of output, y_t, in the long run, as y_t will be given as accumulations of these two shocks. However, in the short run, due to nominal and real rigidities, all four disturbances can influence output. Neither of the shocks will have a long run effect on unemployment in (12). Only productivity shocks will affect the real wage in the long run in (13), whereas all shocks but the monetary shock can have a long run effect on the real exchange rate in (14).

What are the expected short term effects of these shocks? Following a positive monetary shock, the real exchange rate depreciates whereas output increases and the rate of unemployment is reduced temporarily. The larger is β, the more will the monetary shock work via the real exchange rate on output and unemployment.

A fiscal shock will appreciate the real exchange rate if π<0. The net effect on output (and unemployment) will depend on among other things the degree of capital mobility. In a world with perfect capital mobility and flexible exchange rates, the exchange rate may appreciate to such an extent that the trade balance will deteriorate, leaving output unchanged in the long run. However, given that βπ>-1, output will increase and unemployment falls temporarily.

Positive labour supply and productivity shocks will increase output, but the effects on the other variables will most likely differ. A labour supply shock increases the unemployment rate, and if σ>0, the real exchange rate depreciates (thereby offsetting some of the initial rise in the unemployment rate). A productivity shock will appreciate the real exchange rate. The rate of unemployment falls if the direct effect of increased productivity on real output (α) is larger than the positive effects of the productivity shock (via a higher real wage) on labour supply (γ) plus the negative effects of the productivity shock (via an appreciated real exchange rate) on output (βδ); α > γ-βδ.

In the next section, I will show how the model can be specified and identified empirically. As the model above is rather static, I will allow for more dynamics by introducing lags. Also, I let the equations (7) - (10) evolve as random walks with drift, i.e., I allow for a constant in all the equations in the VAR.

3. Identifying the Structural VAR

The analysis above suggests that by estimating a VAR model containing the four variables; real GDP, unemployment, real wage and the real exchange rate, the four structural shocks; velocity, fiscal,

productivity and labour supply shocks, can be identified. In the model above, GDP, real wage and the real exchange rate are nonstationary integrated, I(1), variables, (where stationarity is obtained by taking first differences), whereas the rate of unemployment is stationary I(0).[7] Denoting the real wage as $(rw = w-p)$ and the real exchange rate as $(s = e+p^*-p)$, and ordering the vector of stationary variables as $z_t = (\Delta rw_t, \Delta y_t, \Delta s_t, u_t)'$, the reduced form of z_t can be modelled as:

$$(15) \qquad \begin{aligned} z_t &= \alpha + A_1 z_{t-1} + \ldots + A_p z_{t-p} + e_t \\ A(L)z_t &= \alpha + e_t \end{aligned}$$

where α is a constant, $A(L)$ is the matrix lag operator, A_j refers to the autoregressive coefficient at lag j, $A_0 = I$ and e_t is a vector of reduced form serially uncorrelated residuals with covariance matrix Ω. As all the variables defined in z_t are stationary, z_t is a covariance stationary vector process. The Wold Representation Theorem implies that under weak regularity conditions, a stationary process can be represented as an invertible distributed lag of serially uncorrelated disturbances. The implied moving average representation from (15) can be found and written as (ignoring the constant term for now):

$$(16) \qquad z_t = C(L)e_t$$

where $C(L)=A(L)^{-1}$ and C_0 is the identity matrix. As the elements in e_t are contemporaneously correlated, they can not be interpreted as structural shocks. To go from the reduced form to the structural model, the elements in e_t must be orthogonalized by imposing a set of identifying restrictions. Assume that the orthogonal structural disturbances (ε_t) can be written as linear combinations of the Wold innovations (e_t), i.e. $e_t = D_0 \varepsilon_t$.[8] A (restricted) form of the moving average containing the vector of original disturbances can then be found as:

$$(17) \qquad z_t = D(L)\varepsilon_t$$

where $C_j D_0 = D_j$, or:

$$(18) \qquad C(L)D_0 = D(L)$$

The ε_t 's are normalised so they all have unit variance, i.e. $cov(\varepsilon_t)=I$. If D_0 is identified, I can derive the MA representation in (17) since $C(L)$ is identifiable through inversions of a finite order $A(L)$ polynomial. However, the D_0 matrix contains sixteen elements, and to orthogonalise the different innovations sixteen restrictions are needed. First, from the normalisation of $var(\varepsilon_t)$ it follows that:

$$(19) \qquad \Omega = D_0 D_0' .$$

There are $n(n+1)/2$ distinct covariances (due to symmetry) in Ω. With a four variable system, this imposes ten restrictions on the elements in D_0. Six more restrictions are then needed to identify D_0. These will come from restrictions on the long run multipliers of the $D(L)$ matrix.

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[7] The assumptions of stationarity are discussed and verified empirically below in section four.

[8] The assumption that the underlying structural disturbances are linear combinations of the Wold innovations is essential, as without it the economic interpretations of certain VAR models may change, see e.g. Lippo and Reichlin (1993) and Blanchard and Quah (1993) for a discussion of the problem of nonfundamentalness.

I first order the four serially uncorrelated orthogonal structural shocks defined in (7)-(10) as: $\varepsilon_t = (\varepsilon_t^{PR}, \varepsilon_t^{LS}, \varepsilon_t^{FI}, \varepsilon_t^{VEL})'$. The long run expression of (17) can then simply be written as:

$$
(20) \qquad
\begin{bmatrix} \Delta rw \\ \Delta y \\ \Delta s \\ u \end{bmatrix}_t
=
\begin{bmatrix}
D_{11}(1) & D_{12}(1) & D_{13}(1) & D_{14}(1) \\
D_{21}(1) & D_{22}(1) & D_{23}(1) & D_{24}(1) \\
D_{31}(1) & D_{32}(1) & D_{33}(1) & D_{34}(1) \\
D_{41}(1) & D_{42}(1) & D_{43}(1) & D_{44}(1)
\end{bmatrix}
\begin{bmatrix} \varepsilon^{PR} \\ \varepsilon^{LS} \\ \varepsilon^{FI} \\ \varepsilon^{VEL} \end{bmatrix}_t
$$

where $D(1) = \sum_{j=0}^{\infty} D_j$ indicate the long run matrix of D(L). Above I found that only productivity shocks can affect real wages in the long run, hence:

$$(21) \qquad D_{12}(1) = D_{13}(1) = D_{14}(1) = 0$$

Only productivity and supply shocks can affect output in the long run:

$$(22) \qquad D_{23}(1) = D_{24}(1) = 0$$

and all shocks except the monetary shock can affect the real exchange rate in the long run:

$$(23) \qquad D_{34}(1) = 0$$

No restrictions are placed on unemployment. However, if the rate of unemployment is stationary, no shocks will permanently change the unemployment rate. With these six long run restrictions, it is now easy to see that the matrix D(1) will be lower triangular, and I can use this to recover D_0.

The long run representation of expression (18) and (19) implies:

$$(24) \qquad C(1)\Omega C(1)' = D(1)D(1)'$$

(24) can be computed from the estimate of Ω and C(1). As D(1) is lower triangular, expression (24) implies that D(1) will be the unique lower triangular Choleski factor of $C(1)\Omega C(1)'$. Let E denote the lower triangular Choleski decomposition of (24), then D_0 can easily be obtained from:

$$(25) \qquad D_0 = C(1)^{-1} E$$

4. Empirical results

The data and their sources are described in appendix A. Below I first perform some preliminary data analyses, to verify whether I have specified the variables in accordance with their time series properties. To test whether the underlying processes contain a unit root, I use the augmented Dickey Fuller (ADF) test of unit root against a (trend) stationary alternative, and Zivot and Andrews' (1992) test of a unit root against the alternative hypothesis of stationarity around a deterministic time trend with a one time break that is unknown prior to testing (cf. table A1-A.2). For neither GDP, the real wage nor the real exchange rate, can I reject the hypothesis of I(1) in favour of the (trend) stationary alternative or the trend

stationary with break alternative. However, I can reject the hypothesis that real wage, GDP and real exchange rate are integrated of second order, I(2).

Based on the ADF test, I can not reject the hypothesis that unemployment is I(1). However, a plot of the unemployment rate suggests that it may be stationary until the late 1980s, when it shifted up to a higher level (see figure A.1). In fact, using the test by Zivot and Andrews (1992), I can reject the hypothesis that unemployment is I(1) in favour of the trend-break alternative. The break occurred in 1988Q2. This corresponds to the start of the severe financial crisis and recession in the Norwegian economy. In the remaining analysis I therefore de-trend the unemployment rate by removing the structural break prior to estimation.[9]

The lag order of the VAR-models are determined using the F-forms of likelihood ratio tests for model reductions as suggested by Doornik and Hendry (1994). Lag lengths between one and eight orders are considered. An initial set of lag reduction tests suggested that a model reduction to four lags could be accepted at the 5 pct. level (see table A.3). With four lags, I could reject the hypothesis of serial correlation and heteroscedasticity in each equation at the 5 pct. level. Non-normality tests indicate that there is evidence of an outlier in the real wage, possibly in 1973 (see figure A.4). Hence I include an intervention dummy that is 1 in 1973Q3, -1 in 1973Q4 and 0 otherwise in the equation for the real wage. However, experiments show that the empirical results are virtually unchanged whether I include the dummy in the model or not. Non-normality can now be rejected in all equations except the unemployment rate, at the one percentage level (see table A.4). Below we will se that focusing on the period prior to 1988, non-normality can also be rejected for the unemployment rate at the 5 pct. level.

Finally, testing for cointegration between GDP, the real wage, the real exchange rate and the (detrended) unemployment rate, using the Johansen (1988, 1991) procedure, I can conclude that none of the variables in the VAR models are cointegrated (see table A.7).[10] Hence, the nonstationary variables in the VAR model can be specified in accordance with equations (11) - (14) above. Note that the lack of cointegration implies that the non-stationary variables in the VAR are not driven by common stochastic trends, but by independent stochastic trends. That is, the real wage is driven by a productivity trend, real GDP is driven by both a productivity and a labour supply trend, whereas the real exchange rate can be driven by three stochastic productivity, labour supply and fiscal trends.

4.1. Impulse responses and variance decompositions

The cumulative dynamic effects (calculated from equation 17) of productivity, labour supply, fiscal and monetary disturbances on GDP, unemployment, the real exchange rate and the real wage are reported in figures 1-4. The figures presented here give the cumulative response in (the level of) each endogenous variable to a unit (innovation) shock, with a one standard deviation band around the point estimate, reflecting uncertainty of estimated coefficients.[11]

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[9] To allow for somewhat more flexibility, I let the structural break occur for two quarters, 1988Q2-1988Q3. A deterministic trend is also included in the regression as it comes out significant (although it is virtually flat before and after the break date).

[10] The trace test indicates that there may be one cointegrating vector. However, with the short sample used here (87 observations), the tabulated asymptotic critical values are only approximations. Adjusting for degrees of freedom as the sample is small, none of the tests indicate any evidence of cointegration.

[11] The standard errors reported are calculated using Mount Carlo simulation based on normal random drawings from the distribution of the reduced form VAR. The draws are made directly from the posterior distribution of the VAR coefficients. The standard errors that correspond to the distributions in the D(L) matrix are then calculated using the estimate of D_0.

The responses to the shocks are consistent with a conventional economic model as that presented in section two. A velocity shock has a positive impact effect on the level of GDP. The response of GDP thereafter declines gradually as the long run restriction bites, and after two years, the standard error bands include zero. The effect on the rate of unemployment is a mirror response to that on GDP, and unemployment falls temporarily. Consistent with Dornbusch's overshooting model, a velocity shock depreciates the real exchange rate, before it appreciates (overshoots) back to the long run equilibrium. A velocity shock has a small effect on the real wage, indicating essentially an acyclical behaviour. An acyclical (or weakly countercyclical) behaviour of the real wage, is consistent with a traditional view of business cycles driven by aggregate demand where wages are sticky.

Figure 1. Impulse responses: Velocity shocks

A) GDP

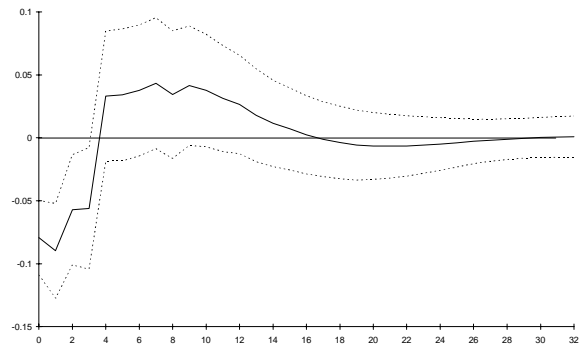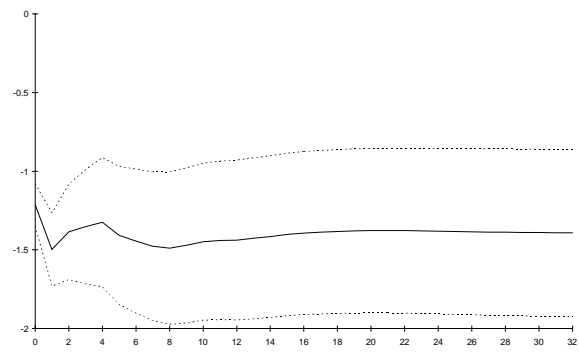B) Unemployment

C) Real exchange rates
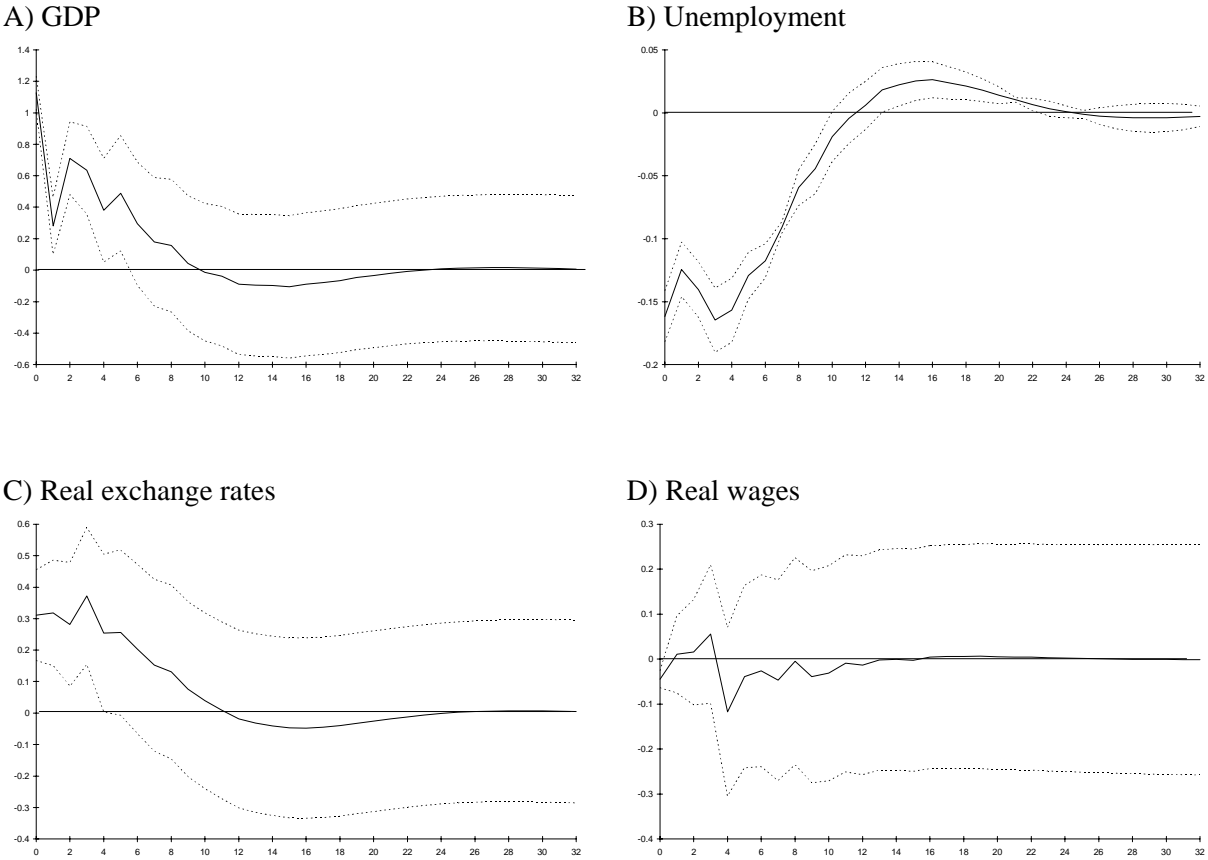
D) Real wages

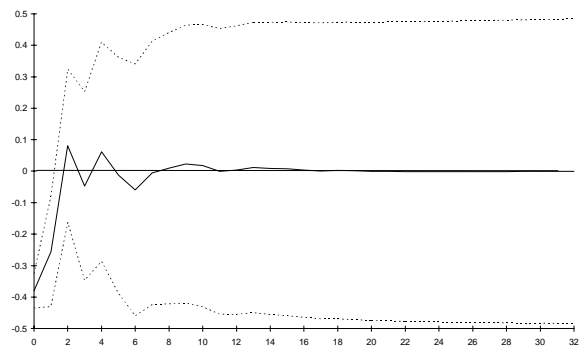**Figure 2. Impulse responses: Fiscal shocks**
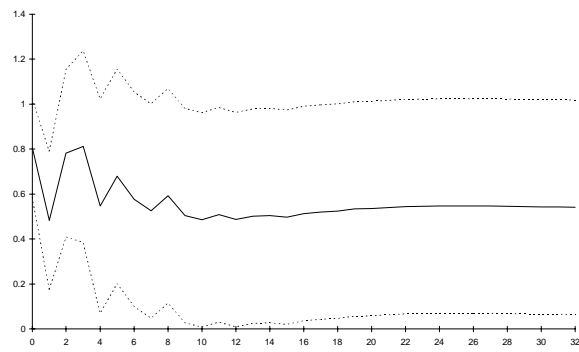
A) GDP
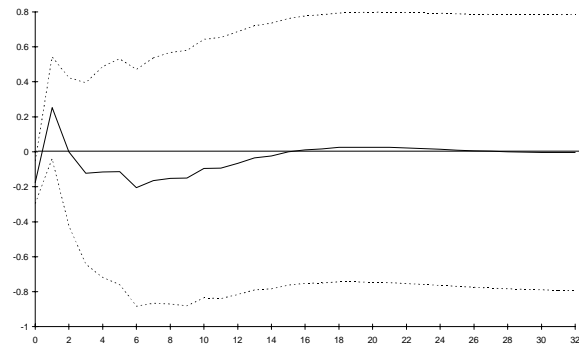
B) Unemployment

C) Real exchange rates

D) Real wages

Figure 3. Impulse responses: Productivity shocks

A) GDP
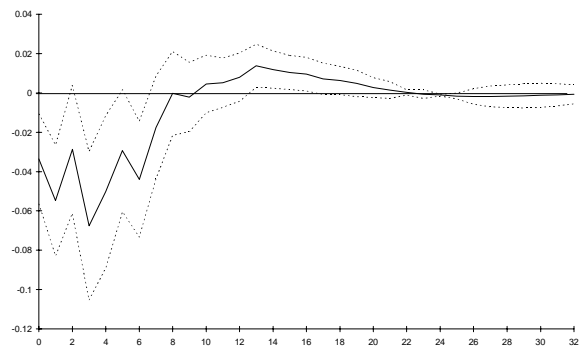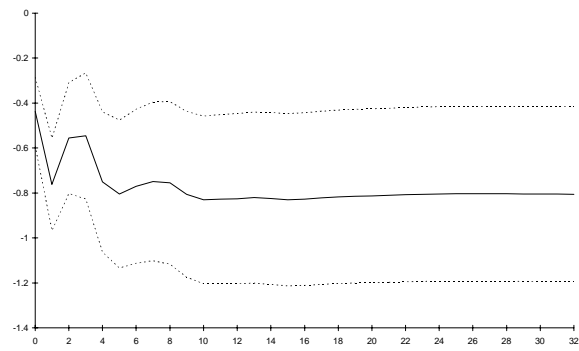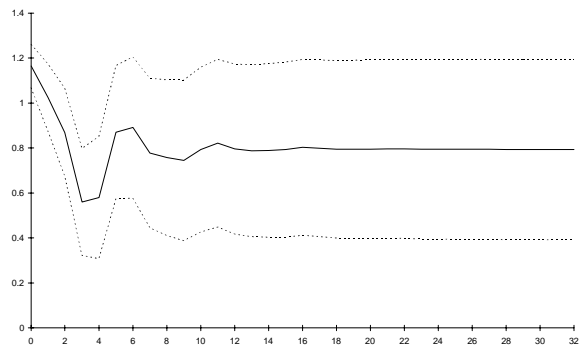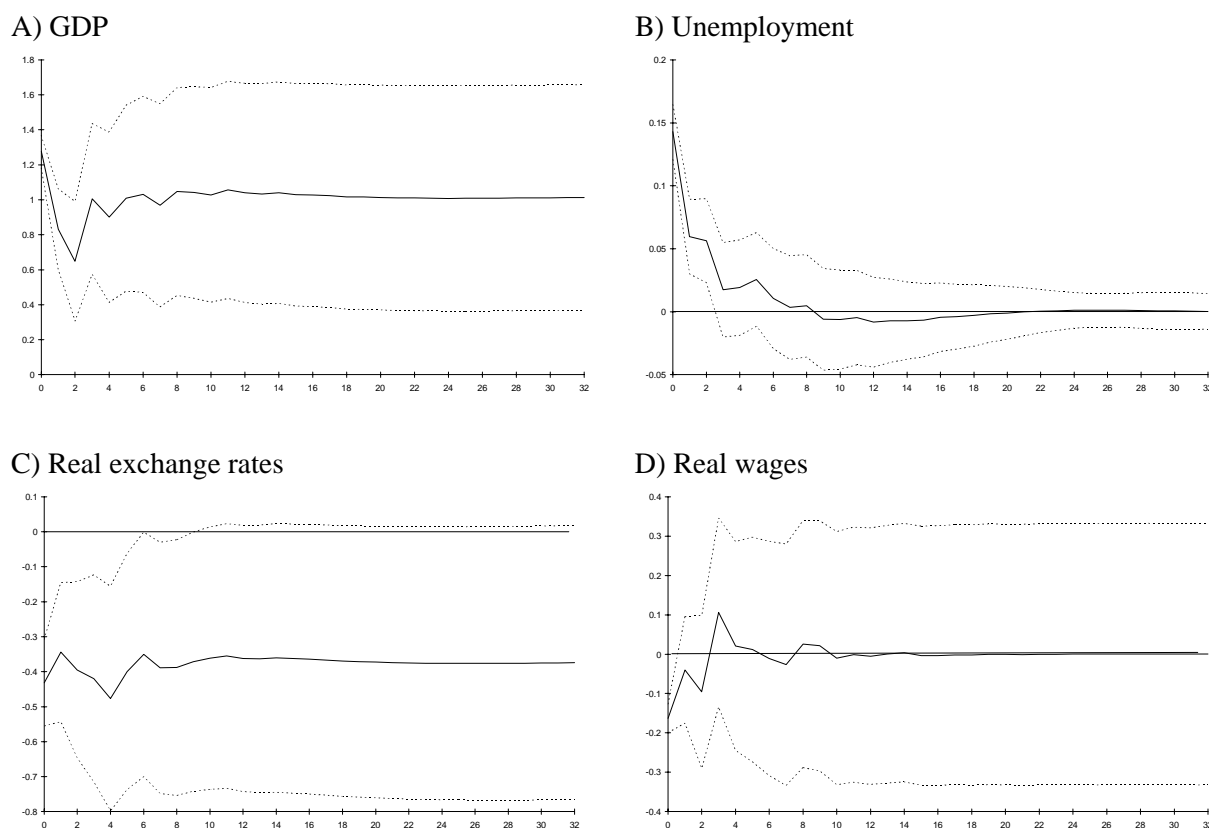

B) Unemployment

C) Real exchange rates

D) Real wages

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Figure 4. Impulse responses: Labour supply shocks

A) GDP

B) Unemployment

C) Real exchange rates

D) Real wages

The "fiscal" shock appreciates the real exchange rate, hence $\pi<0$ in (14), but has only a small positive effect on output the first half year. On the other hand, fiscal shocks have a larger effect on the rate of unemployment, which falls the first half year. The rate of unemployment thereafter increases, before it reaches long run equilibrium after three years. These findings suggest that fiscal shocks have little output effect as the exchange rate may have appreciated to such an extent that the trade balance deteriorates, leaving output unchanged in the long run. However, as will be discussed further below, the fact that fiscal shocks have a larger effect on unemployment may suggest that they capture the part of fiscal policy that has been especially aimed towards achieving full employment. Finally, following a fiscal shock the real wage behaves countercyclically the first year, again consistent with an aggregate demand driven theory of business cycles where wages are sticky.

A productivity shock has a long run positive effect on output. The unemployment rate falls temporarily, but the effect is small. A productivity shock appreciates the real exchange rate, suggesting that $\delta<0$ in (14). As discussed above, this is typical for a small open (petro-currency) economy like Norway, where the rapid growth of the energy sector had labour demand effects that increased output and appreciated the real exchange rate. As in Gamber and Joutz (1993), a productivity shock increases the real wage permanently and the effect is stabilised after two years.

A labour supply shock increases GDP. However, the rate of unemployment also increases the first year, as demand for employment fails to increase by enough to match the higher supply potential. As was also found in Gamber and Joutz (1993), a labour supply shock reduces the real wage temporarily. The real exchange rate appreciates temporarily, but thereafter depreciates back to equilibrium, when the effect is not significant different from zero after a year. In terms of the static model in section two, σ is more likely to be zero than positive in the long run.

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The variance decompositions for real output and unemployment are seen in table 1, whereas the variance decomposition for the real exchange rate and the real wage are given in table 2. The variance decompositions give the percentage of the variance of the forecast error that is attributed to each of the shocks at different horizons. The first year, 30-35 pct. of the variation in GDP is explained by velocity shocks, whereas labour supply and productivity shocks explain about 40 pct. and 30 pct. of output variation respectively. Hence, both the "nominal" and the "real" shocks are important sources of the fluctuations in GDP in the short run. The relative contribution of velocity disturbances thereafter declines gradually as expected, and after four years, labour supply and productivity shocks explain about 60 and 30 pct of the variation in output respectively.

Table 1. Variance Decompositions of GDP and unemployment[1]

Quarters	GDP				Unemployment			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	18.1	45.5	35.5	1.0	2.1	37.8	48.4	11.7
2	19.0	49.9	29.1	2.0	4.9	28.5	49.5	17.1
4	26.0	45.3	27.3	1.3	6.5	18.8	60.5	14.2
8	25.0	53.9	19.6	1.5	6.8	12.9	68.4	11.9
12	23.6	60.9	14.2	1.4	6.5	12.3	67.6	13.6
32	22.3	70.9	6.2	0.6	6.6	12.1	67.4	13.8

[1] (PR); Productivity shock, (LS); Labour supply shock, (VEL); Velocity shock and (FI); Fiscal shock.

Table 2. Variance Decompositions of real exchange rates and real wages[1]

Quarters	Real exchange rates				Real wages			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	9.8	9.6	5.0	75.6	88.7	1.7	0.1	9.4
2	15.5	6.1	4.0	74.5	89.9	1.1	0.1	8.0
4	13.9	6.4	4.2	75.4	92.7	1.3	0.2	5.8
8	17.7	6.2	2.9	73.2	95.2	0.8	0.4	3.6
12	19.3	5.6	2.0	73.2	96.5	0.6	0.3	2.6
32	22.3	5.2	0.7	71.7	98.6	0.2	0.1	1.1

[1] See footnote 1, table 1.

Velocity shocks are the most important factors behind unemployment variation, and almost 50 pct. of the variance is explained initially by velocity shocks, increasing to 70 pct. after two years. Labour supply and fiscal shocks explain respectively 40 pct. and 10-15 pct. of unemployment variation initially, but after two years, 10-15 pct. of the variance of unemployment is explained by each of the two shocks. Approximately 7 pct. of the variance in unemployment is explained by productivity shocks after a year.

For a resource rich country, stochastic shocks to the goods marked (IS shocks) may induce excessive exchange rate volatility. This view is supported in table 2, as fiscal shocks explain almost 70 pct. of the variation in real exchange rates the first year. The effect of fiscal shocks thereafter declines somewhat, explaining approximately 60 pct. of the exchange rate variation after two years. Clarida and Gali (1994), also found fiscal (as opposed to monetary) shocks to dominate in all the four countries they examined, especially in UK and Canada, which are also resource rich countries.

Productivity shocks explain about 25 pct of real exchange rate variation the first year, increasing to more than 30 pct. after two years, emphasising the importance of "real" shocks in the long run. Velocity shocks explain less than 5 pct. of the variance of real exchange rates, and the effect dies out after approximately two years.

Finally, productivity shocks are by far the most important shocks explaining variation in the real wage, and more than 80 pct. of the real wage variation in explained the first year by productivity shocks. Fiscal shocks explain about 10-15 pct. of the variation the first year. As imposed by the long run restriction, productivity shocks explain eventually all of the variation in the real wage.

5. Sources of business cycles

Until now, I have discussed the responses of the variables to the different shocks on average over the whole period. In the remaining part, I investigate instead the fluctuations in each historical period for GDP and unemployment, before in the end I focus on the real exchange rate.

Figure 5A and 5B plot the time paths of GDP that is due to velocity and fiscal shocks respectively (setting all other shocks to zero). In figure 5C, the time path of GDP that is due to the joint (permanent) effect of the productivity and labour supply shocks, adding the drift term (also referred to as the "supply potential"), is plotted together with the log of actual GDP. To also emphasise the short term effects of the "permanent" shocks, in figure 5D and 5E I graph the forecast error in GDP that is due to a productivity and labour supply shock respectively (together with the total forecast error in GDP), using an eight quarters weighted average of the estimated shocks. Figure 6A and 6B show the rate of unemployment together with the time paths of productivity and labour supply shocks respectively over the whole period, whereas figure 6C and 6D show the rate of unemployment together with the velocity and fiscal component, concentrating on the periods 1973-1987. Finally, in figure 6E, the velocity and fiscal components are graphed together with the unemployment rate over the period 1989-1994.

During the 1970s, Norway experienced higher growth rates than most OECD countries. This favourable economic performance has usually been attributed to the discovery and use of energy resources, which increased productivity and stimulated the economy so it grew at a much faster rate than otherwise would have been possible. This is supported in figure 5D, where the main factors behind the high growth rates are positive productivity shocks. These results are also consistent with the results in Bjørnland (1996), where I found that aggregate supply (the joint effect of labour supply and productivity), accounted for the high growth rates in the 1970s. Real wages were increasing rapidly in this period (hence the positive effect of productivity on real wages in figure 3). The rate of unemployment is generally very low in the 1970s, allowing for real wages to increase to the extent they did. By 1978, the adjustment period is over. However, aggregate demand is still high, and positive velocity and fiscal shocks contribute so that output lies about the supply potential and unemployment falls until the early 1980s.

Norway experienced two severe recessions during the 1980s. In Bjørnland (1996), I found that whereas the first recession was mainly "demand" driven, the second (and most severe) recession was clearly "supply" driven. Having diversified the shocks here, the main conclusions still prevail. The first recession from 1982 to 1985, is primarily explained by negative velocity shocks, pushing output below the supply potential. Fiscal shocks have also small negative effects on the real economy, and together with the negative velocity shocks, they are the main factors behind the increase in the unemployment rate in this period (see figure 6C and 6D). On the other hand, labour supply shocks contribute positively to output growth throughout all of this period due to among other thing the increases in the female participation rate.
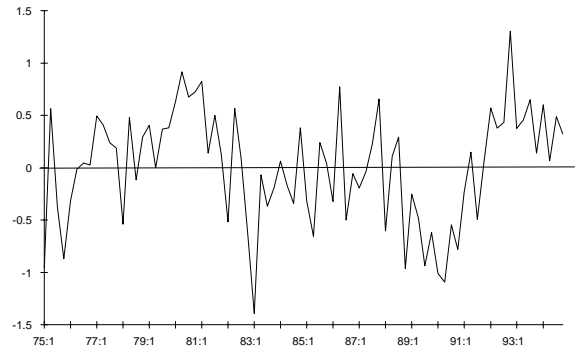
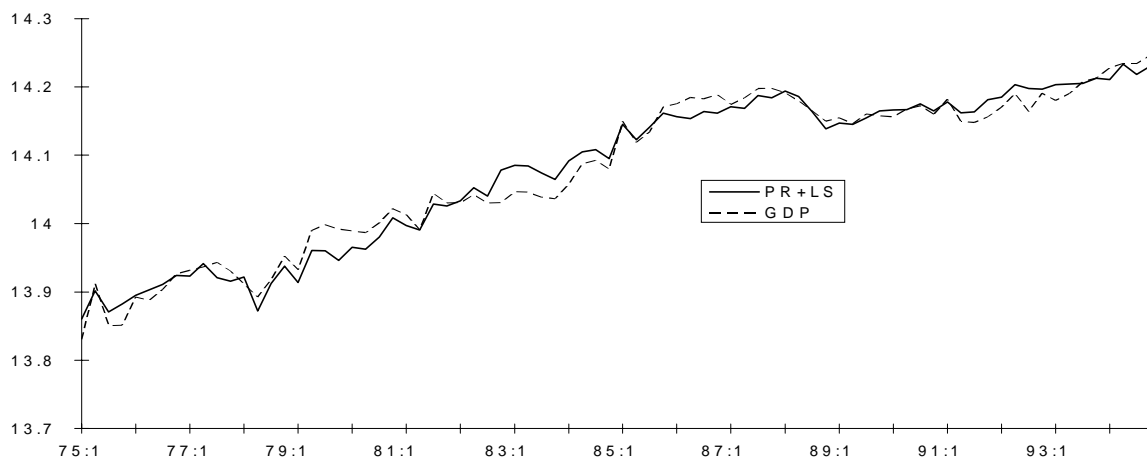**Figure 5. Components of GDP, (1975-1994)**

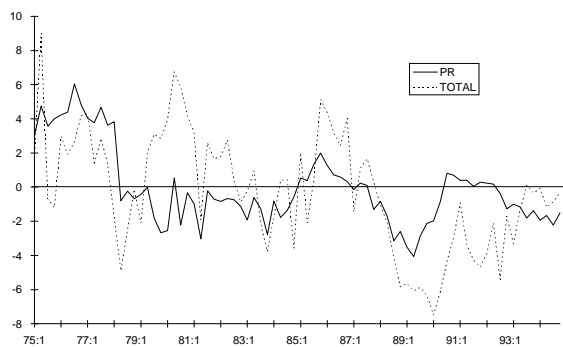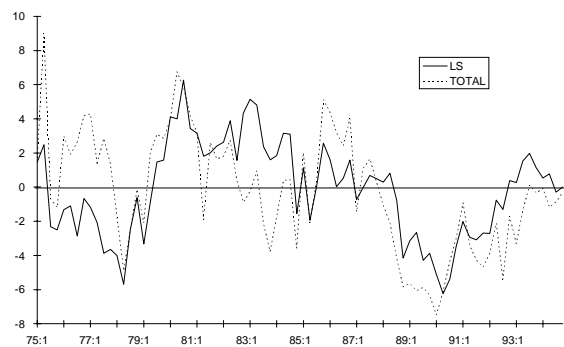A) Velocity, pct. change
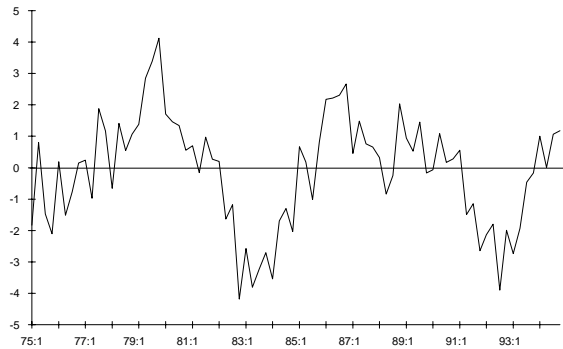
B) Fiscal, pct. change

C) Productivity and labour supply, (drift term added)

D) Productivity, pct. change
(forecast error decomposition)

E) Labour supply, pct. change
(forecast error decomposition)

The economy thereafter experiences a demand driven boom, set off primarily from the financial deregulation in 1984/1985. All shocks contribute positively towards output in this period (especially velocity), increasing both GDP and the supply potential. However, from 1988 the spending boom in Norway accumulates in a severe financial crisis. GDP is falling and now the rate of unemployment is rising drastically. This recession is at first driven by negative productivity shocks (cf. figure 5D), and eventually negative labour supply shocks (cf. figure 5E), so that the supply potential shifts down with GDP in 1988 (cf. figure 5C). The time of the fall in the supply potential in GDP, corresponds well with the upward shift in the rate of unemployment in 1988. The economy recovers somewhat by 1990, but by

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that time the international economy is slowing down, and velocity shocks contribute negatively to output growth until 1993. The rise in unemployment in this period is also mainly due to the negative velocity shocks.

Is it plausible to interpret the different shocks as I have done here? From the analysis above, productivity and labour supply shocks seem to fit well with the actual events that occurred in the Norwegian economy. Interpreting the velocity shocks as some form of monetary stance suggests in particular that monetary policy was loose in 1986-1987, tight from 1990-1992 and loose thereafter (c.f. figure 5A).

Figure 6. Components of Unemployment:

A) Productivity, (1975-1994)
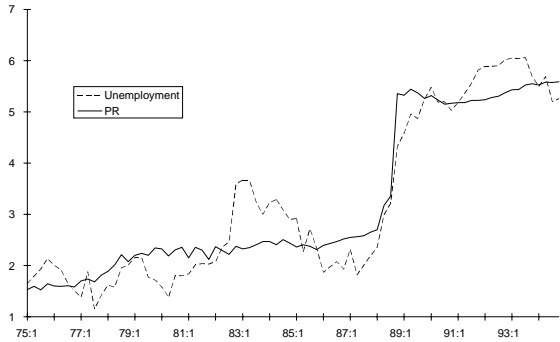
B) Labour supply, (1975-1994)
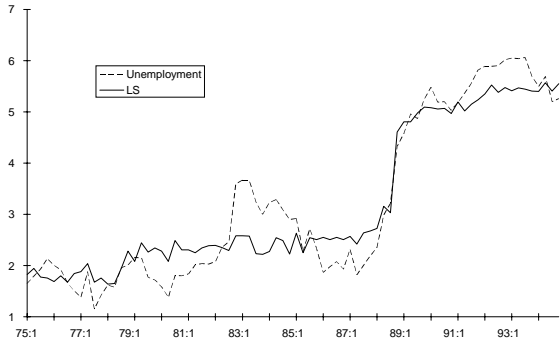
C) Velocity, (1975-1987)

D) Fiscal, (1975-1987)

E) Velocity and Fiscal, (1989-1994)

A similar stance of monetary policy is suggested using a simple monetary conditions index (MCI), that relates changes in interest rates and the real exchange rate to aggregate demand (even when we allow for uncertainty with regard to for instance dynamics, cointegration and parameter constancy), (see Eika et al. 1996).

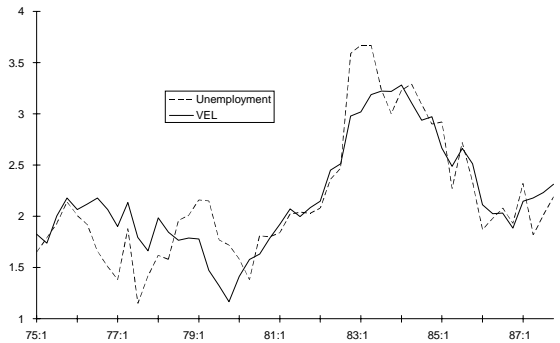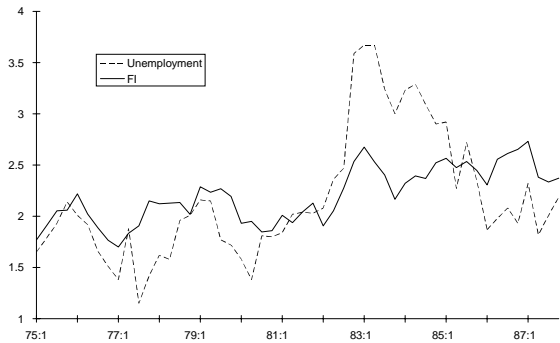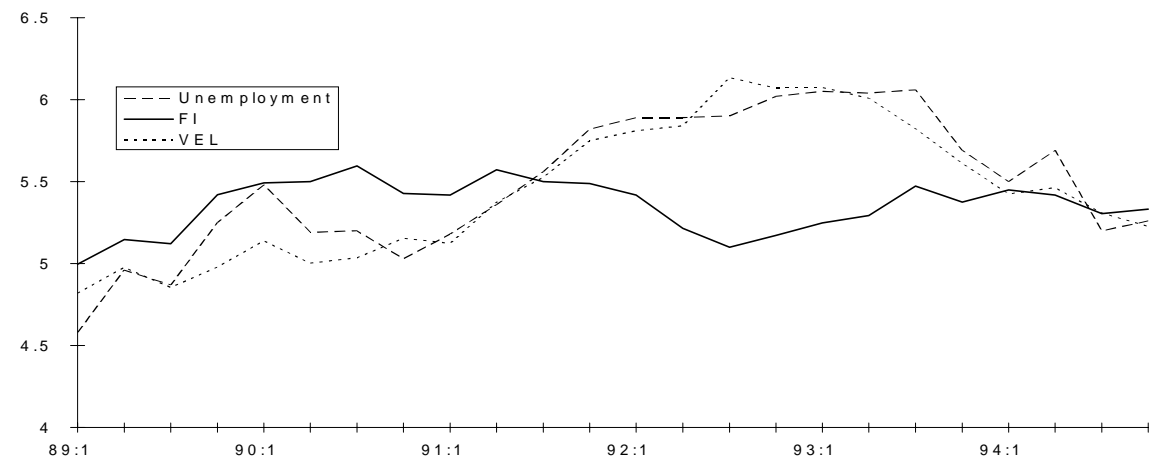The effects of the "fiscal" shocks are more difficult to interpret as the impact on GDP is small. However the fiscal shocks can be better understood by analysing the unemployment rate, and as suggested above, fiscal shocks may have captured a part of fiscal policies aimed at achieving full employment. In Norway, a period of expansionary fiscal polices ended in 1982. Except for a brief period in 1985-1986, fiscal polices remained tight throughout the 1980s, especially in 1988-1989, but was again expansionary from 1990 to 1993. During the periods of tight fiscal polices, output falls somewhat, but unemployment is clearly worsened (c.f. figure 5B and 6D). The expansionary fiscal policies in the mid-1980s and from 1990, increase output and work to reduce the unemployment rate, especially from 1990s (see figure 6E). These results emphasise that to the extent that fiscal shocks have captured the effects of fiscal polices, fiscal polices have been used countercyclically from the late 1980s, (see also Holden 1997, for similar conclusions).

Finally, what are the responses of the real exchange rate to the different shocks? Since the collapse of the Bretton Woods system of fixed exchange rates in 1971, the Norwegian currency has participated in several exchange rate systems, some more flexible than others (see Norges Bank 1995). Figure 7A-C give the time path of the real exchange rate to the three most important shocks; Productivity, velocity and fiscal shocks respectively (drift term added for productivity and fiscal shocks). To also emphasise the short term effects of the fiscal shock, figure 7D shows the forecast error in real exchange rate that is due to the fiscal shocks, together with the total forecast error.

The positive productivity shocks in the 1970s clearly worked to appreciate the real exchange rate, whereas the negative productivity shocks from 1987 and onwards, work to depreciate the real exchange rate. Negative velocity shocks in the recession in the early 1980s appreciate the real exchange rate, whereas in the boom from 1984, the real exchange rate depreciates. From 1990, the negative velocity shocks (that reduces output) also appreciates the real exchange rate.

Expansionary fiscal polices in the late 1970s, some periods in the 1980s and in the early 1990s appreciate the real exchange rate, whereas tight fiscal policies from 1982 and in particular from 1988-1989 depreciate the real exchange rate (cf. figure 7D). However, the large importance of fiscal shocks in explaining real exchange rate movements, suggests that the "fiscal shocks" identified here have also captured the exchange rate instruments used in this period. This can be explained as follows. During the 1970s and the 1980s, expansionary fiscal policies brought with them higher inflation, thereby an appreciated real exchange rate, reduced competitiveness, a current account deficit and eventually, increasing unemployment. An important part of economic policy in this period was then to devaluate the exchange rate each time competitiveness was low (see Norges Bank 1995, and Bowitz and Hove 1996).

The implied responses of the real exchange rate and the unemployment rate to a fiscal shock reported in figure 2 are consistent with this scenario. Expansionary fiscal polices reduce the unemployment rate at first, but eventually, unemployment starts to increase. The major currency devaluations in 1977Q3, 1978Q1, 1982Q3, 1982Q4 and 1984Q3 all followed after periods of increasing unemployment rates. However, the unemployment rate reacts with a lag to the exchange rate changes so that a depreciation at first increases the rate of unemployment, before after three quarters, unemployment starts to fall (cf. figure 2). The currency devaluations can be seen as positive fiscal shocks in figure 7D, and within three quarters of each of the fiscal shocks, the rate of unemployment starts to drop (see figure 6D).

Figure 7. Components of the real exchange rate, (1975-1994)

A) Productivity, (drift term added)
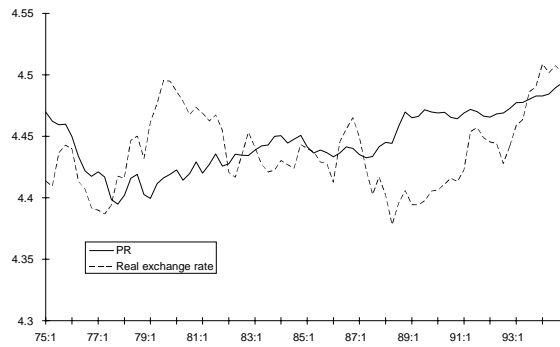
B) Velocity, pct. change
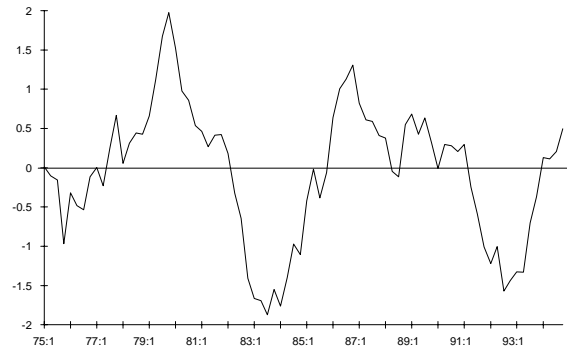
C) Fiscal, (drift term added)
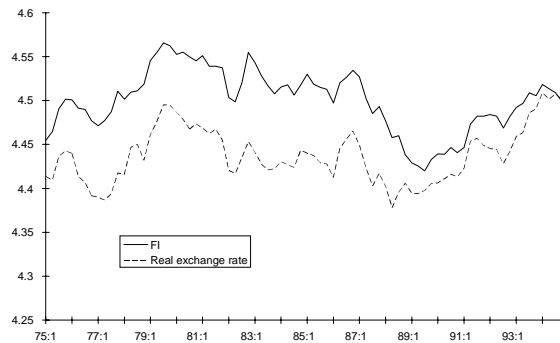
D) Fiscal, pct. change
(forecast error decomposition)
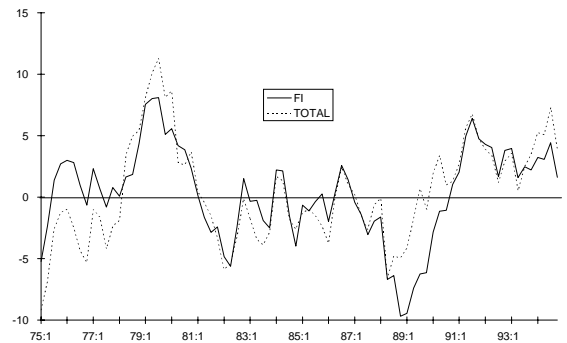
6. Extension of the benchmark model

To analyse the robustness of the results reported so far, I alter the benchmark model in several ways. First, Faust and Leeper (1997) have criticised the use of long run restrictions to identify structural shocks, and show that unless the economy satisfies some types of strong restrictions, the long run restrictions will be unreliable. In particular they argue that for the long run restrictions to give reliable results, the aggregation of shocks in small models should be checked for consistency using alternative models.[12] For instance, as the model presented in section two could have been solved for the growth rate of prices rather than for the unemployment rate, I replace the unemployment rate with inflation and re-estimate the model (denoted *inflation* model). This allows us to check whether the impulse responses remain invariant to this new model specifications. In addition, I can test for overidentifying restrictions by investigating whether the implied price response is consistent with the theoretical model presented in section two. Both the benchmark and the inflation model are thereafter re-estimated over different periods, to see if they are stable over the sample. Finally, I introduce the real price of oil into the VAR model, to investigate whether oil price shocks are important sources behind the economic fluctuations in Norway. In particular, I want to check whether the rise in the oil price throughout the 1970s can account

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[12] Strictly speaking, Faust and Leeper's (1997) critique of the use of long run restrictions in VAR models refers to a bivariate model using only *one* long run restriction like that of Blanchard and Quah (1989), where the problem stems from the fact that the underlying model has more sources of shocks (with sufficiently different dynamic effects on the variables considered) than does the estimated model. In that case, the bivariate model can be misspecified and the associated decomposition and impulse responses of little use. The fact that we here allow for more variables and use several long run restrictions together, may by itself be sufficient to side step this criticism.

for the real exchange rate appreciation already captured by the productivity shocks. The answer to this question is no.

6.1. A model containing prices

By solving the model described in section two for the growth rate in prices, I can find the implied effect of each of the four shocks on the price level:

$$(12') \qquad \Delta p_t = \varepsilon_{t-1}^{VEL} + (1 + \beta\pi)\varepsilon_{t-1}^{FI} - \varepsilon_t^{PR} + (\alpha - \gamma + \beta\delta)\varepsilon_{t-1}^{PR} - (1 - \beta\sigma)\varepsilon_{t-1}^{LS}$$

Equation (12') suggests a set of overidentifying restrictions. First, all shocks can have a permanent effect on the price, (although none of the shocks will have a long run effect on inflation if it is stationary). A velocity shock will increase the price level after a period, whereas the effect of the fiscal shock is positive if ($\beta\pi > -1$). Following a productivity shock, the price level will fall immediately, although the long run effect may be both positive or negative (recall that we expect $\delta < 0$). A labour supply shock reduces the price level directly (although the effect may be somewhat offset if the exchange rate depreciates).

To measure prices, I use the CPI as it is calculated independently of output volume. The CPI seems to be in the borderline between being an I(1) or an I(2) variable. Although I can reject the hypothesis that inflation is I(1) against the trend stationary alternative at the 5 pct. level (ADF = -3.64), all evidence of I(1) in inflation disappeared once a structural break in 1988Q2 was removed from the inflation rate (cf. Bjørnland 1995). In fact, this is the same period I found a structural break in the unemployment rate. In the remaining analysis I therefore include a dummy that is one from 1988Q2 an onwards in the inflation rate.[13] An intervention dummy that is 1 in 1979Q1 but zero otherwise, is also included in the inflation equation to reflect the price stop in that period. To be consistent with the benchmark model, the VAR contains four lags and an intervention dummy for 1973 in the equation for the real exchange rate. With four lags, the model satisfies tests of autocorrelation, heteroscedasticity and non-normality (see table A.5). Finally, the variables will be estimated in difference form, as there is no evidence of cointegration between the level of the variables (see table A.8).

Figures 8A-8D report the cumulative response in the price to a one unit velocity shock, fiscal shock, productivity shock and labour supply shock respectively, with a one standard error band around the point estimates. Clearly, the response in the price is consistent with the model predictions above and satisfy the overidentifying restrictions. The price increases gradually with both velocity and fiscal shocks, and the effect is not stabilised before after three years, where the (unit) velocity shock has increased the price level by 0.8-1 percentage. Note that the response to the velocity shock is consistent with the conventional idea of how a monetary shock works. In particular, contrary to many VAR studies incorporating monetary policy explicitly, I avoid the so-called price puzzle, where the price increases following a contractionary monetary policy (see Sims 1992, and Leeper et. al. 1996). The effect of a productivity shock is small and approaching zero the first year, but then increases somewhat and is significantly different from zero in the long run. Labour supply shocks reduce the price level monotonically as expected.

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[13] An alternative would be to use a trend in the inflation rate. However, once the dummy is included, the trend is no longer is significant. Further, prior and post 1988, we can reject the unit root in inflation in favour of the stationary alternative.

Figure 8. Impulse responses: Price

A) Productivity shock
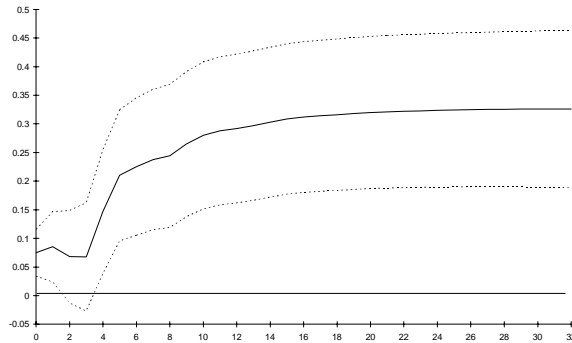
B) Labour supply shock

C) Velocity shock

D) Fiscal shock
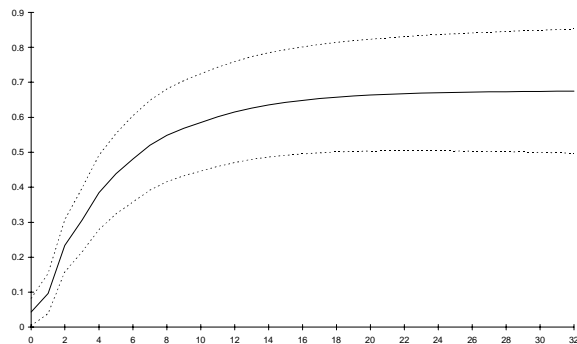
So far, I have left out the issue as to whether the response of the three other variables (GDP, real wage and real exchange rate) to the identified shocks have remained invariant to the new model specifications. Appendix B gives the impulse responses of GDP, the real wage and the real exchange rate to the most important shocks and the variance decomposition, using the inflation model.
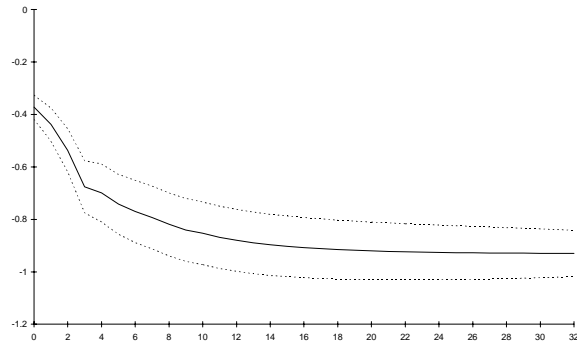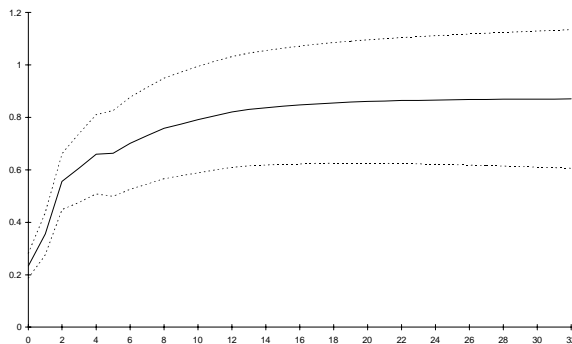
The results clearly indicate that using inflation instead of unemployment in the VAR model, does not alter the major thrusts of our conclusions above. In particular, the impulse responses are very similar to the ones obtained using the unemployment model, and the importance of the different shocks in explaining output, real wage and real exchange rate variation are roughly the same as in the benchmark model. One minor exception is the response of the real exchange rate to a labour supply shock, which now depreciate in the long run, whereas in the benchmark model the effect was not significantly different from zero. However, these results are more consistent with the model predictions above, as a labour supply shock that reduces the price level monotonically, will depreciate the real exchange rate, hence $\sigma>0$. Nevertheless, in both models the effect of a labour supply shock on the real exchange rate is small (explaining less than 10 pct.). Note also that although the two models have aggregated the shocks similarly, the inflation model attributes initially somewhat less of the output variation to velocity shocks than the benchmark model. However, below we will see that when the models are specified using a shorter sample, the identified shocks using the two different models become (even) more similar.

Thus, the results presented so far point in the direction that by incorporating a set of key macroeconomic variables and thereby using more than one long run restriction to identify the different shocks, I have imposed enough information to side step some of the criticism of Faust and Leeper (1997). For instance, in this specific analysis, I have controlled for the fact that although both labour supply and productivity shocks increase output, they have very different effects on the other variables.

6.2. Sample stability

Both the benchmark and the inflation model are re-estimated using the sample 1973-1987. 1987 is chosen as the end date, as both unemployment and inflation experienced a structural break in 1988.[14] Overall, the results reported above are strengthened by focusing on the period 1973-1987. In particular, the impulse responses and the variance decompositions indicate that using the smaller sample generates very much the same results as when the full sample was used (see appendix C). One exception is the response of output and the real exchange rate to a productivity shock, where the variance decomposition using *both* models attribute less off the output fluctuations and more of the real exchange rate fluctuations to a productivity shock than when the full sample was used. However, as the benchmark and the inflation model are consistent with each other, the results indicate that I have underestimated the importance of the productivity shocks by focusing only on the period until 1987, as was seen above, productivity shocks play an important role in the recession from 1988 and onwards. Note that now both models attribute approximately the same share of output variation to velocity shocks.

6.3. The role of oil price

The two oil price shocks of the 1970s are thought to have had important roles in explaining periods of global recession and inflation, and are therefore the typical textbook examples of adverse supply shocks. Norway is in a special position as it discovered oil in the North sea in the early 1970s, and was an exporter of oil before the oil price shock in the late 1970s. Previous studies of the effects of a real oil price shock on the mainland economy has emphasised that Norway has actually gained from a higher real oil price (by increasing net wealth and demand), and consequently, suffered when the real oil price was low (see e.g. Bjørnland 1996).

In this section I include the real oil price into the model to specifically investigate the effects of oil price shocks on the mainland economy. The model allows for a more complex set of possible channels of influence than in Bjørnland (1996). In particular, I can now control for the possibility that the exchange rate may be a "petrocurrency", that appreciates when the oil price is high and depreciates when the oil price is low. For instance, Haldane (1997) has argued that the rise in oil prices can explain a large part of the appreciated Norwegian currency. Incorporating oil prices into both models also serves as a check on whether the established effects of the other shocks remain the same.

In appendix D, the model reported in section two is augmented to allow for the influence of the real oil price. Solving the model, the oil price shock is identified as the only shock that can have a long run effect on the real oil price. However, no restrictions are placed on the response of the other variables to the oil price shocks. The impulse responses of an oil price shock using the benchmark model is presented in figure 9, while the variance decompositions for all shocks are presented in appendix E. The impulse responses of an oil price shocks using the inflation model are also presented in appendix E for comparisons.[15]

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[14] Using the period 1973-1987, we can reject the hypothesis of an unit root in favour of the stationary alternative for inflation but not for unemployment. However, there is evidence that we can reject the unit root hypothesis in unemployment, using a trend instead. Hence, we include a trend in the unemployment rate (it comes out significant). Both models satisfy tests of autocorrelation, heteroscedasticity and non-normality at the 5 percentage level, and none of the variables are cointegrated (see the results using the benchmark model in table A.6 and A.9).

[15] I can not reject the hypothesis of a unit root in the real oil price, but its first differences are stationary. There is no evidence that the oil price is cointegrating with the other variables. Four lags are used in the VAR model to be consistent with the benchmark model. An additional three intervention dummies are included into the equation for oil prices to take care of the extreme outliers (see figure A.1). The first dummy is 1 in 1974Q1 but zero otherwise, the second dummy is 1 in 1986Q1 but zero otherwise, while the third dummy is 1 in 1990Q3, -1 but 1991Q1 and zero otherwise.

The results support the findings reported in Bjørnland (1996). In particular, the benchmark and the inflation models are consistent with each other, and suggest that an oil price shock increases GDP permanently. However, the standard deviation bands are wide indicating that the long run effect is not significant. Unemployment increases temporarily, indicating that although a real oil price shock stimulates the economy (so employment increases in some sectors) some workers are laid off in other sectors so total unemployment rises.

Figure 9.   Impulse response to an oil price shock using the benchmark model

A) Real GDP

B) Unemployment

C) Real exchange rate

D) Real wage
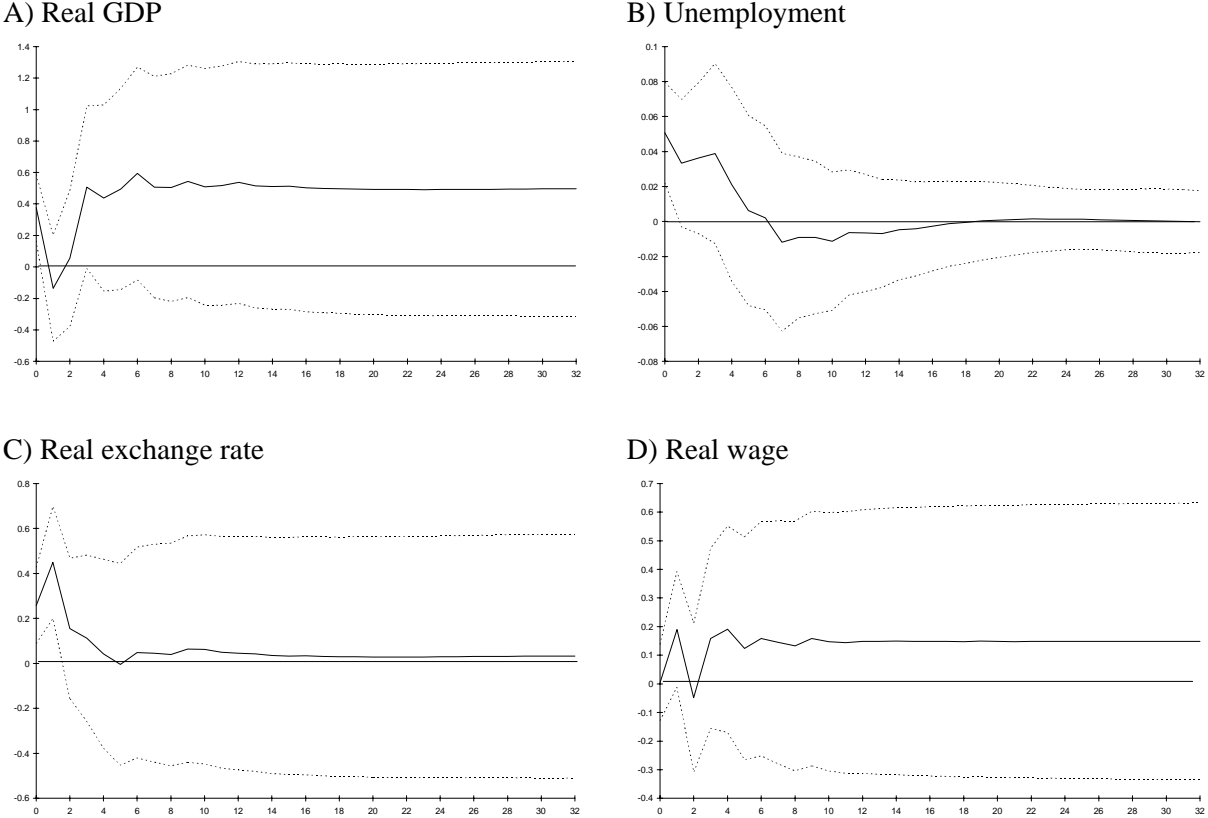
Using the inflation model, we find that the an oil price shock has initially no effect on the price level, but after a year, the price has increased and is significant different from zero (see appendix E). That an oil price shock affects the Norwegian inflation rates with a lag was also found in Bjørnland (1997). The real exchange rate depreciates the first two quarters following an oil price shock, but thereafter appreciates back towards equilibrium (or just below equilibrium), where the effect is no longer significant. The initial deprecation of the real exchange rate to an oil price shock is consistent with the fact that the domestic price level reacts slowly to an oil price increase, while foreign prices rise immediately to the same shock. The domestic price eventually starts to increase, and consistent with this scenario, the real exchange rate appreciates back to equilibrium.[16] Finally, the effect of an oil price shock on the real wage is not significant different from zero.

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[16] These results are independent of whether we use a nominal or real oil price, or whether the nominal oil price is denoted in US dollar or in Norwegian kroner.

The variance decompositions emphasise that a real oil price shock explains about 10-15 pct of the output variation, 3-5 pct. of the unemployment variation, the price variation and the real exchange rate variation, and 0-3 pct. of the real wage variation. The responses in the different variables to the other shocks (productivity, labour supply, fiscal and velocity shocks) remain invariant to the inclusion of oil prices into the models, except that the labour supply and the productivity shock now explains somewhat less of the variation in GDP than previously.

To conclude, I have found no evidence to support Haldane's (1997) claim that the oil price increases explain a large part of the Norwegian real exchange rate appreciation. Similar conclusions have also been made in Aliber, (1990) and the references cited there. On the other hand, the oil price shocks explain more of the variation in GDP, and analysis in sub samples suggest that the effect is most important during the periods 1973/1974, 1979/1980 and 1986, (corresponding approximately to the three largest oil price shocks).

7. Conclusions and summary

In this paper, I have focused on the relative ability of real and nominal shocks to explain business cycles in a small open, energy rich country like Norway. To do so I have specified a structural VAR model in GDP, the real wage, the real exchange rate and the rate of unemployment (or price), that is identified through long run restrictions on the dynamic multipliers in the model. The way the model is specified, I identify four structural shocks; Velocity, fiscal, productivity and labour supply shocks. The model is also augmented to allow for oil price shocks.

The results indicate that I have found a plausible sequence of shocks (productivity shocks in the 1970s, velocity shocks in the middle 1980s, productivity and labour supply shocks in the late 1980s, and velocity and fiscal shocks in the early 1990s) which help to explain the evolution of real GDP, unemployment, CPI, the real wage and the real exchange rate the last two decades.

The identified shocks are consistent with standard Keynesian theory on economic fluctuations. In particular, following a velocity and a fiscal shock, GDP increases and unemployment falls temporarily, while prices increase gradually and permanently. However, whereas a velocity shock depreciates the real exchange rate before it overshoots back to equilibrium, the fiscal shock has a long run appreciation effect on the real exchange rate. Both productivity and labour supply shocks have a long run positive effect on GDP, but the effects on the other variables differs. In particular, whereas a favourable productivity shock reduces unemployment (and increases the price), a favourable labour supply shock increases unemployment (and reduces the price). A productivity shock increases the real wage permanently and has a long run appreciation effect on the real exchange rate.

The results highlight the exchange rate as a transmission mechanism in a small open and energy based economy. In particular, the response in the real exchange rate to a productivity shock is consistent with the fact that Norway is a resource rich country, where the energy discoveries have given rise to productivity and wealth effects that have appreciated the exchange rate. Augmenting the model to allow for oil prices do not change this conclusion, and oil price shocks have had little explanatory power for the real exchange rate developments. These findings are robust to alternative specifications of the model and are stable over the sample.

Although most of the shocks are well interpreted in terms of the actual episodes that have occurred in the periods examined, further work may be needed in particular to validate the interpretations of the "fiscal

shocks" as those that represent fiscal and exchange rate polices. In particular, as one important motivation for the government to use exchange rate polices throughout the 1970s and 1980s was to stabilise the current account, this suggest that one possible extension of the model could be to investigate the implied effects of the fiscal shocks on the current account. Preliminary results suggest that fiscal shocks do improve the current account, but as was also found in Bowitz and Hove (1996), the effect is small and the main improvement of the current account comes through other channels.
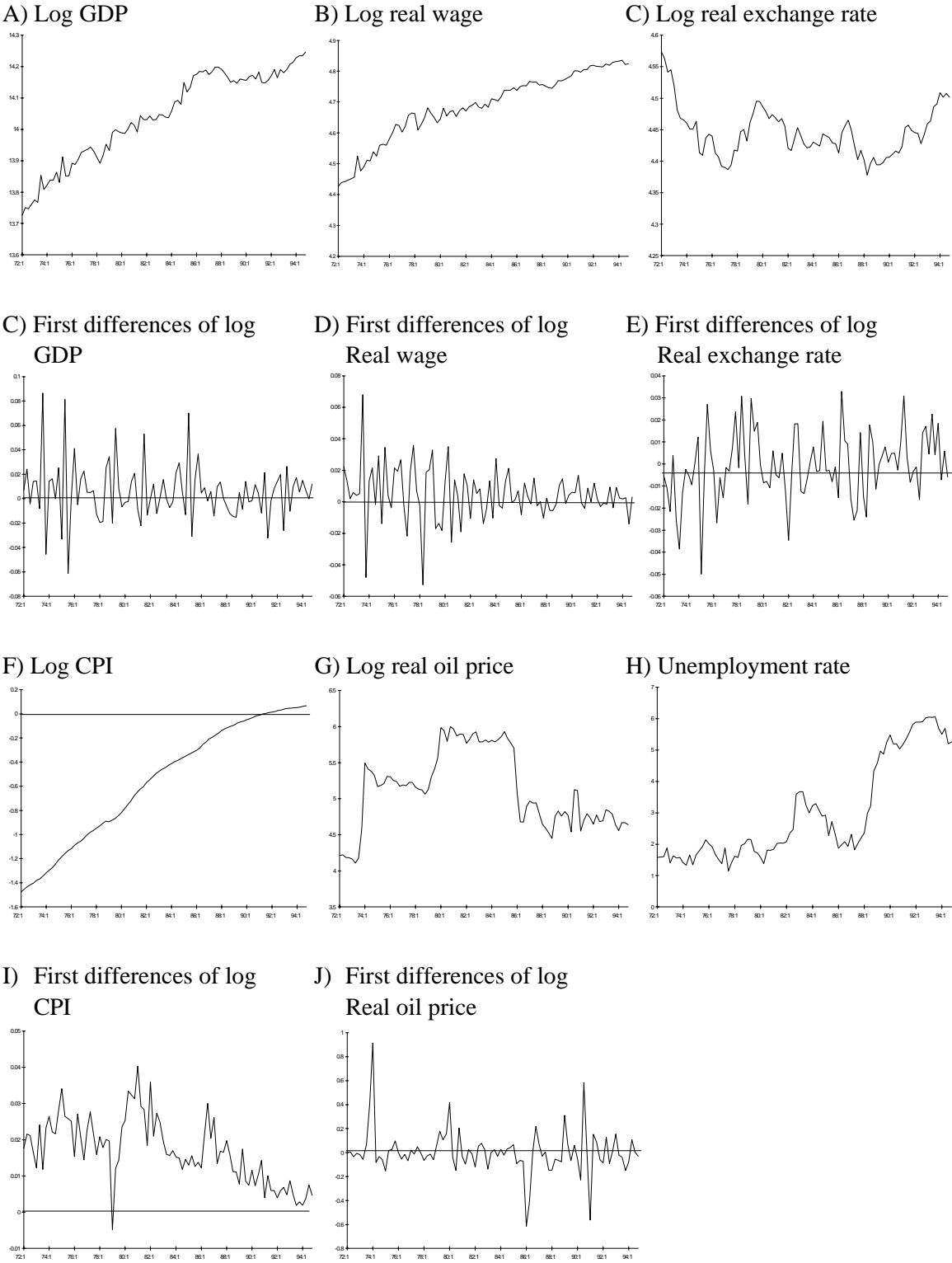
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Appendix A. Data and model specifications

Figure A.1. Plots of the data series

A) Log GDP

B) Log real wage

C) Log real exchange rate

C) First differences of log GDP

D) First differences of log Real wage

E) First differences of log Real exchange rate

F) Log CPI

G) Log real oil price

H) Unemployment rate

I) First differences of log CPI

J) First differences of log Real oil price

Data sources

The sample runs from 1972Q1-1994Q4. Using first differences and four lags in the VAR, the estimation sample is 1973Q2-1994Q4. All variables except the real exchange rate and the real oil price are seasonally adjusted quarterly variables, taken from Kvarts Database, Statistics Norway. *(y)*; Gross Domestic Product, *mainland Norway* (GDP less petroleum activities and ocean transport) constant 1991 prices. *(rw)*; Real wages in mainland Norway, deflated by the implicit price deflator of GDP mainland Norway. *(u)*; Unemployment rate. *(p)*; Consumer price index.

The real exchange rate *(s)* is taken from Troll8, Norges Bank, and is the Central Bank exchange rate index, deflated by a set of relative consumer prices. The real oil price *(op)* is calculated from the nominal oil price (Saudi Arabian Light-34, USD per barrel, fob- (n.s.a.). Prior to 1980, posted prices, thereafter spot prices) and deflated by the implicit GDP deflator, mainland Norway. Source: OPEC BULLETIN and Statistics Norway. All variables except the unemployment rate are in logarithms.

Table A.1. Augmented Dickey-Fuller unit-root tests, 1974Q2-1994Q4

Series[1]	ADF(lags)	t_{ADF}	Series[2]	ADF(lags)	t_{ADF}
y	ADF(1)	-2.01	Δy	ADF(5)	-4.51***
s	ADF(4)	-1.88	Δs	ADF(4)	-4.27***
rw	ADF(5)	-3.27	Δrw	ADF(4)	-3.88***
u	ADF(2)	-2.25	Δu	ADF(1)	-5.03***

[1] A constant and a time trend are included in the regression
[2] A constant is included in the regression.
** Rejection of the unit root hypothesis at the 5 percentage level
*** Rejection of the unit root hypothesis at the 2.5 percentage level

Table A.2. Sequential unit-roots test 1974Q2-1994Q4[1]

	Model	Period	Minimum t-statistics
Unemployment	A	1988Q2	-4.68*
Real wages	B	1976Q4	-4.01
Real exchange rate	C	1989Q4	-3.34
GDP	A	1988Q2	-4.08

[1] Critical values were taken from Zivot and Andrews (1992, p. 256-257). Three alternative hypothesis are considered: (A) change in the level of the trend, (B) change in the growth rate of the trend, (C) change in both the level and the growth rate of the trend.
* Rejection of the unit root hypothesis at the 10 percentage level

Table A.3. F-tests for model reductions[1]

Lags	Sequential F-tests	p-value	Direct F-tests	p-value
8				
7	F(16, 144) = 0.81	0.671	F(16, 114) = 0.81	0.671
6	F(16, 156) = 0.99	0.461	F(32, 174) = 0.90	0.629
5	F(16, 168) = 2.17	0.008	F(48, 183) = 1.30	0.111
4	F(16, 180) = 1.27	0.220	F(64, 186) = 1.31	0.083
3	F(16, 193) = 2.15	0.008	F(80, 187) = 1.51	0.012
2	F(16, 205) = 1.11	0.347	F(96, 188) = 1.47	0.013
1	F(16, 217) = 1.21	0.265	F(112, 189) = 1.46	0.011

[1] Sequential F-test with corresponding p-value reports the sequential model reductions (8→7,...,2→1 lags), direct F-test with corresponding p-value reports the direct model reductions (8→7, ..., 8→1 lags). All test-statistics are calculated using PcFiml 8.0 (see Doornik and Hendry 1994).

Misspecification tests

Table A.4. Misspecification tests, benchmark model, 1973Q2-1994Q4[1]

Test	Statistic	Δy	Δs	Δrw	u
Q Test[a]	*Q(21)*	10.88	16.60	21.70	26.58
		(0.96)	(0.74)	(0.42)	(0.18)
AR 1-2[b]	X^2 *(2)*	3.48	3.98	0.81	4.05
		(0.18)	(0.14)	(0.66)	(0.13)
ARCH[c]	X^2 *(4)*	5.91	5.69	9.44	0.52
		(0.21)	(0.22)	(0.06)	(0.97)
Normality[d]	X^2 *(2)*	6.96	2.91	4.70	42.57
		(0.04)	(0.23)	(0.10)	(0.00)

[1] The number in brackets are the p-values of the test statistics. All statistics have been calculated using RATS, except the normality test in (d), that has been calculated using PcFiml 8.0 (see Doornik and Hendry 1994).
[a] The Ljung-Box Q test against high-order serial correlation.
[b] General LM test for serial correlation of order 2.
[c] LM test for 4th order ARCH in the residuals, proposed by Engle (1982).
[D] Test of normality, see Doornik and Hendry (1994) for references and descriptions.

Table A.5. Misspecification tests, inflation model, 1973Q2-1994Q4[1]

Test	Statistic	Δy	Δs	Δrw	Δp
Q Test[a]	*Q(21)*	9.96	12.83	25.05	18.97
		(0.97)	(0.91)	(0.24)	(0.59)
AR 1-2[b]	X^2 *(2)*	2.56	3.99	2.83	1.97
		(0.28)	(0.14)	(0.24)	(0.37)
ARCH[c]	X^2 *(4)*	3.74	5.29	6.71	5.62
		(0.44)	(0.26)	(0.15)	(0.23)
Normality[d]	X^2 *(2)*	7.87	3.49	5.27	5.19
		(0.02)	(0.17)	(0.07)	(0.07)

[1] See footnote 1, table A.4
[a] See footnote a, table A.4, (b) See footnote b, table A.4, (c) See footnote c, table A.4, (d) See footnote d, table A.4.

Table A.6. Misspecification tests, benchmark model, 1973Q2-1987Q4[1]

Test	Statistic	Δy	Δs	Δrw	u
Q Test[a]	*Q(14)*	9.22	8.18	17.44	10.05
		(0.82)	(0.88)	(0.23)	(0.76)
AR 1-2[b]	X^2 *(2)*	2.35	3.13	0.55	2.81
		(0.31)	(0.21)	(0.76)	(0.24)
ARCH[c]	X^2 *(4)*	2.57	5.01	4.69	1.50
		(0.63)	(0.29)	(0.32)	(0.83)
Normality[d]	X^2 *(2)*	3.20	4.36	2.63	4.89
		(0.20)	(0.11)	(0.27)	(0.09)

[1] See footnote 1, table A.4
[a] See footnote a, table A.4, (b) See footnote b, table A.4, (c) See footnote c, table A.4, (d) See footnote d, table A.4

Cointegration tests

Table A.7. Johansen cointegration tests; Cointegrating vector (y_t, rw_t, s_t, u_t), 1973Q2-1994Q4[1,2]

H_0	H_1	Critical value 5 % λ_{max}	Critical value 5 % λ_{trace}	*df-adj*[3] λ_{max}	λ_{max}	λ_{trace}	*df-adj*[3] λ_{trace}
r=0	r≥1	31.46	62.99	30.62	24.99	71.09	58.01
r≤1	r≥2	25.54	42.44	21.13	17.24	40.46	33.02
r≤2	r≥3	18.96	25.32	13.25	10.81	19.33	15.78
r≤3	r≥4	12.25	12.25	6.09	4.97	6.09	4.97

[1] All test-statistics are calculated using PcFiml 8.0 (see Doornik and Hendry 1994). Critical values are taken from Table 2* in Osterwald-Lenum (1992), corresponding to the case where the constant is unrestricted but the trend restricted.
[2] u refers to unemployment rate adjusted for the structural break in 1988.
[3] df-adj refers to the eigenvalue adjusted for degrees of freedom (see Reimers 1992).

Table A.8. Johansen cointegration tests; Cointegrating vector (y_t, rw_t, s_t, p_t), 1973Q2-1994Q4[1,2]

H_0	H_1	Critical value 5 % λ_{max}	Critical value 5 % λ_{trace}	*df-adj*[3] λ_{max}	λ_{max}	λ_{trace}	*df-adj*[3] λ_{trace}
r=0	r≥1	31.46	62.99	34.79	28.39	76.34	62.30
r≤1	r≥2	25.54	42.44	23.65	19.30	41.55	33.91
r≤2	r≥3	18.96	25.32	14.09	11.50	17.90	14.61
r≤3	r≥4	12.25	12.25	3.81	3.11	3.81	3.11

[1] See footnote 1, table A.7.
[2] A dummy that is one from 1988Q2 is added to reflect the structural break in inflation. Alternatively, one could remove the structural break in inflation prior to the cointegration analysis and use the "detrended" price variable in the model instead. The results using the "detrended" price suggest even lower test statistics, e.g. for H_0=0 and H_1≥1, λ_{max} = 31.44 and λ_{trace} = 74.66.
[3] See footnote 3, table A.7.

**Table A.9. Johansen cointegration tests; Cointegrating vector (y_t, rw_t, s_t, u_t), 1973Q2-1987Q4[1]**

H_0	H_1	Critical value 5 % λ_{max}	Critical value 5 % λ_{trace}	*df-adj*[2] λ_{max}	λ_{max}	λ_{trace}	*df-adj*[2] λ_{trace}
r=0	r≥1	27.07	47.21	22.29	16.24	46.68	34.02
r≤1	r≥2	20.97	29.68	15.37	11.20	24.39	17.78
r≤2	r≥3	14.07	15.41	7.68	5.60	9.03	6.58
r≤3	r≥4	3.76	3.76	1.34	0.98	1.34	0.98

[1] All test-statistics are calculated using PcFiml 8.0 (see Doornik and Hendry 1994). Critical values are taken from Table 1 in Osterwald-Lenum (1992), corresponding to the case where the constant is unrestricted.
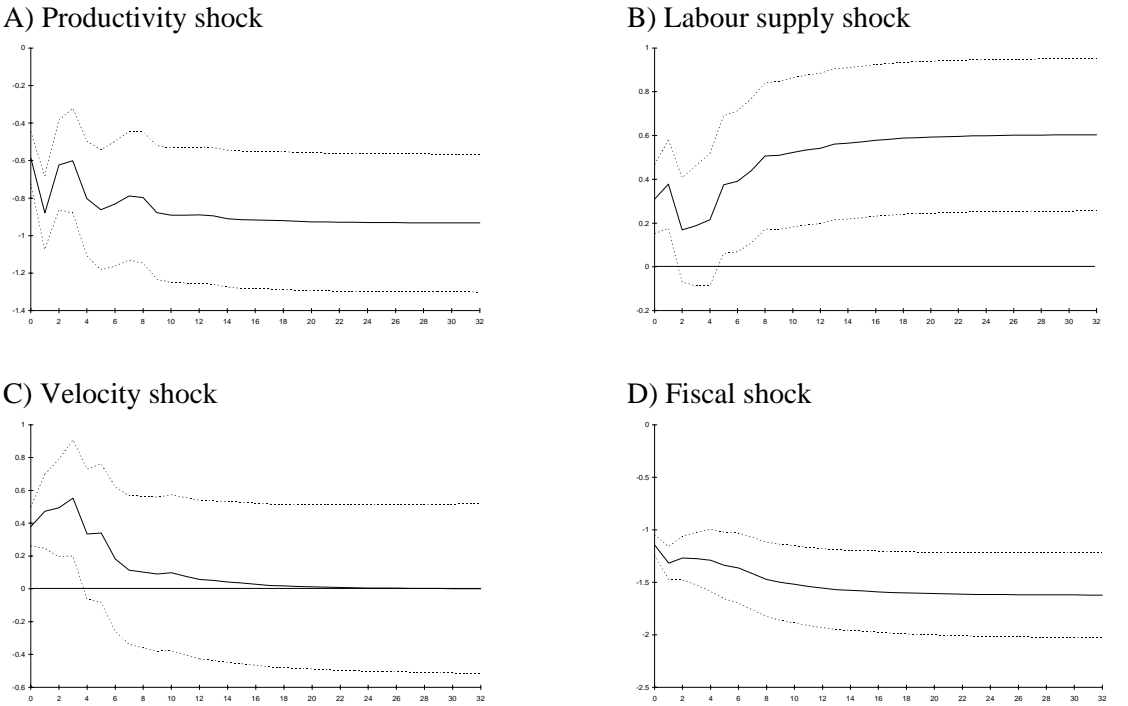[2] See footnote 3, table A.7.

Appendix B. Impulse responses and variance decomposition using the inflation model

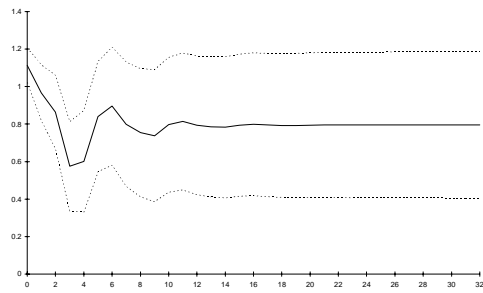**Figure B.1. Impulse responses: Real GDP**

A) Productivity shock

B) Labour supply shock

C) Velocity shock
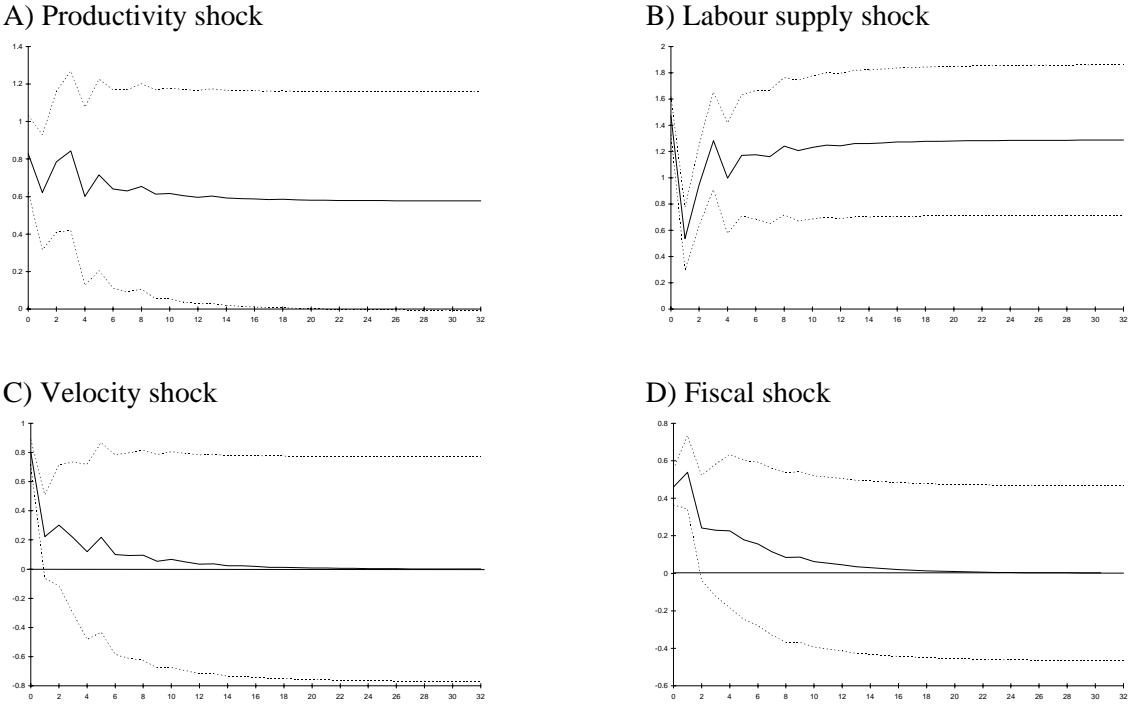
D) Fiscal shock

Figure B.2. Impulse responses: Real exchange rate

A) Productivity shock

B) Labour supply shock

C) Velocity shock

D) Fiscal shock
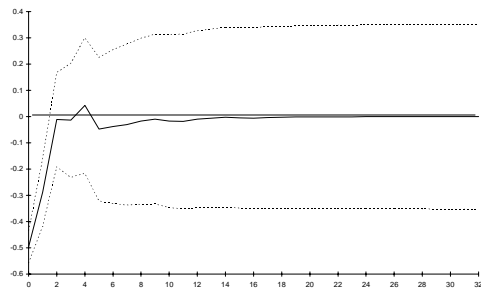
Figure B.3. Impulse responses: Real wage
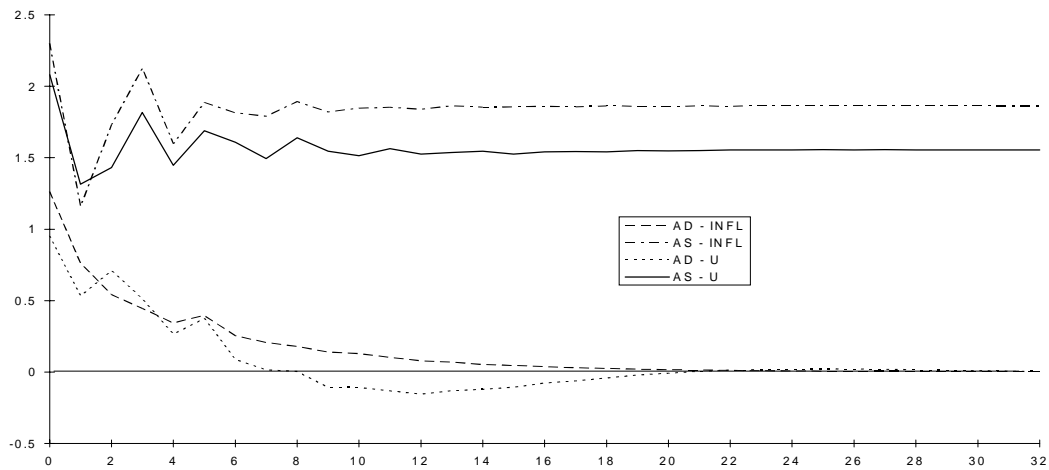
A) Productivity shock

B) Fiscal shock

Benchmark and inflation model compared

Figure B.4. Impulse responses: Real GDP[1]

A) Real GDP

[1] (AD); Aggregate demand (velocity plus fiscal), (AS); Aggregate supply (productivity plus labour supply). INFL refers to the inflation model whereas U refers to the unemployment (benchmark) model.

Table B.1. Variance Decompositions of GDP and price[1]

Quarters	GDP				Price			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	18.4	58.5	17.4	5.7	2.8	69.2	27.1	0.9
4	27.2	56.5	9.4	6.9	1.1	50.9	40.5	7.5
12	24.0	68.9	4.0	3.2	3.4	43.6	36.6	16.4
32	19.8	77.6	1.5	1.2	4.4	40.8	35.2	19.5

[1] (PR); Productivity shock, (LS); Labour supply shock, (VEL); Velocity shock and (FI); Fiscal shock.

Table B.2. Variance Decompositions of real exchange rate and real wage[1]

Quarters	Real exchange rate				Real wage			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	18.1	5.1	7.6	69.2	82.1	1.3	0.3	16.4
4	19.9	3.2	9.8	67.0	88.1	1.5	1.6	8.9
12	22.6	5.7	3.7	68.0	94.4	0.8	0.9	3.9
32	22.6	8.1	1.1	68.1	97.7	0.3	0.4	1.6

[1] See footnote 1 table B.1 for definitions.

Appendix C. Sample estimation

The benchmark model

Figure C.1. Impulse responses, full sample (1973-1994) and short sample (1973-1987) compared: [1]

A) GDP

B) GDP

C) Real exchange rate

D) Real exchange rate

E) Unemployment

F) Real wage
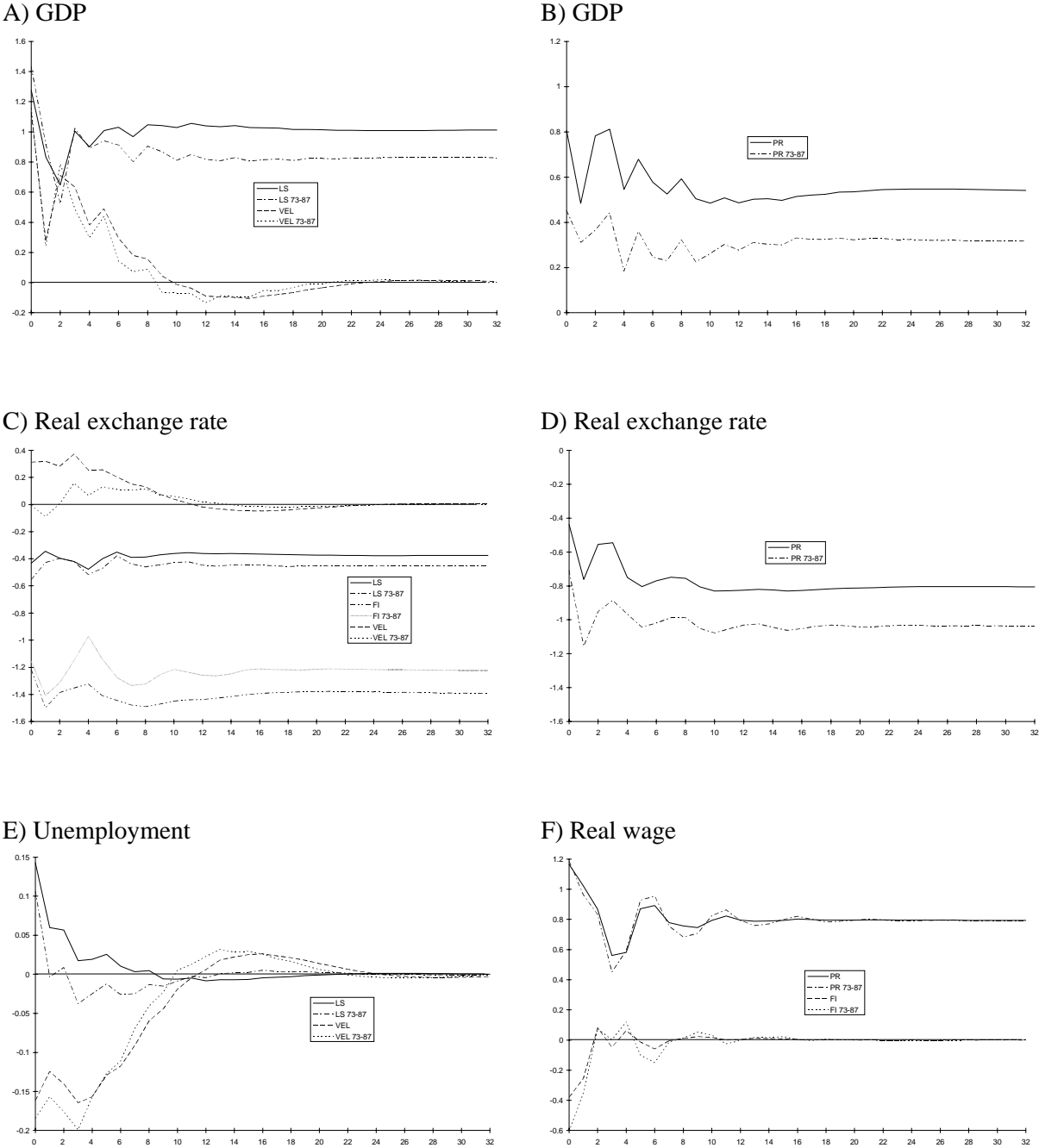
[1](PR); Productivity shock, (LS); Labour supply shock, (VEL); Velocity shock and (FI); Fiscal shock. 73-87 refers to the impulse responses using the short sample (1973-1987).

Table C.1. Variance decompositions of *GDP*, (1973-1987)[1]

Quarters	Benchmark model				Inflation model			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	5.1	50.4	32.8	11.8	9.6	51.9	32.0	6.6
4	8.1	54.5	29.2	8.2	15.9	53.9	20.4	9.8
12	8.2	68.9	17.3	5.7	14.6	71.8	9.0	4.8
32	10.6	78.0	8.6	2.8	12.3	82.5	3.4	1.9

1) (PR); Productivity shock, (LS); Labour supply shock, (VEL); Velocity shock and (FI); Fiscal shock.

Table C.2. Variance decompositions of *real exchange rate*, (1973-1987)[1]

Quarters	Benchmark model				Inflation model			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	23.5	14.3	0.1	62.2	27.0	0.5	9.9	62.6
4	32.8	7.7	1.0	59.2	34.9	0.5	11.2	53.6
12	36.3	7.4	1.0	56.0	33.6	2.7	3.7	60.0
32	37.9	7.3	0.1	54.7	31.0	4.7	1.2	63.2

1) See footnote 1, table C.1 for definitions

Table C.3. Variance decompositions of *real wage*, (1973-1987)[1]

Quarters	Benchmark model				Inflation model			
	PR	LS	VEL	FI	PR	LS	VEL	FI
1	75.3	4.1	1.1	19.6	77.8	0.4	2.7	19.1
4	83.2	2.7	1.4	12.8	84.6	1.6	2.0	11.9
12	92.0	1.3	0.7	6.1	92.5	0.9	1.2	5.3
32	96.6	0.5	0.3	2.5	96.8	0.4	0.5	2.2

1) See footnote 1, table C.1 for definitions

Table C.4. Variance decompositions of *unemployment*, (1973-1987)[1]

Quarters	Benchmark model			
	PR	LS	VEL	FI
1	0.1	24.2	72.4	3.3
4	5.4	8.2	82.5	3.9
12	4.0	6.1	74.6	15.3
32	4.1	6.0	74.7	15.3

1) See footnote table C.1 for definitions

Table C.5. Variance decompositions of *price*, (1973-1987)[1]

Quarters	Inflation model			
	PR	LS	VEL	FI
1	2.1	73.3	14.8	9.8
4	0.2	51.4	27.3	21.1
12	1.4	43.6	26.2	28.9
32	1.8	41.2	25.7	31.3

[1] See footnote table C.1 for definitions

Appendix D. An open economy with oil price shocks

The open economy model presented in section two is here augmented to allow for oil price shocks.

(D.1) $y_t = m_t - p_t + d_t + \alpha\theta_t + \beta(e + p* - p)_t + \phi o_t$

(D.2) $y_t = n_t + \theta_t + \rho o_t$

(D.3) $p_t = w_t - \theta_t + \psi o_t$

(D.4) $w_t = w \big| \left[E_{t-1} n_t = \bar{n}_{t-1} \right]$

(D.5) $\bar{n}_t = \gamma(w_t - p_t) + \lambda_t$

(D.6) $(e + p* - p)_t = \Delta m_t + \pi d_t + \delta\theta_t + \sigma\lambda_t + \kappa o_t$

where o is the log of the real oil price. Equation (D.1) states that aggregate demand will now also be a function of the real oil price. $\phi>0$ is plausible in an economy with a large energy producing sector, as higher real oil prices may increase demand from energy producers (like the government). The production function in (D.2) relates output to the real oil price as a third factor of production. The real oil price is used instead of an energy quantity, as competitive producers treat the real oil price as parametric (see also Bjørnland, 1996). Hence, we would expect ($\rho<0$). The price setting behaviour in (D.3) gives the CPI as a mark up on the real oil price, ($\psi>0$). Finally, the real exchange rate also varies with the oil price. Especially, if the Norwegian currency is a petrocurrency it appreciates when the oil price is high and depreciates when the oil price is low ($\kappa<0$).

Assume that the oil price evolves as a random walk, driven by orthogonal oil price shocks (ε^{OP}):

(D.7) $o_t = o_{t-1} + \varepsilon_t^{OP}$

Solving for Δy, u, $\Delta(w-p)$ and $\Delta(e+p*-p)$ then yields:

(D.8)
$$\Delta y_t = (1+\beta)\Delta\varepsilon_t^{VEL} + (1+\beta\pi)\Delta\varepsilon_t^{FI} + (1+\gamma)\varepsilon_t^{PR} + (\alpha - \gamma + \beta\delta)\Delta\varepsilon_t^{PR} + \varepsilon_{t-1}^{LS} + \beta\sigma\Delta\varepsilon_t^{LS} +$$
$$\rho\varepsilon_{t-1}^{OP} + (\phi + \beta\kappa)\Delta\varepsilon_t^{OP} - \psi[(1+\beta\delta\gamma)\Delta\varepsilon_t^{OP} + \gamma\varepsilon_{t-1}^{OP}]$$

(D.9)
$$u_t = -(1+\beta)\varepsilon_t^{VEL} - (1+\beta\pi)\varepsilon_t^{FI} - (\alpha - \gamma + \beta\delta)\varepsilon_t^{PR} + (1-\beta\sigma)\varepsilon_t^{LS} + (\rho - \phi - \beta\kappa)\varepsilon_t^{OP} +$$
$$\psi(1+\beta\delta\gamma - \gamma)\varepsilon_t^{OP}$$

(D.10) $\Delta(w-p)_t = \varepsilon_t^{PR} - \psi\varepsilon_t^{OP}$

$$(D.11) \qquad \Delta(e + p* - p)_t = \Delta\varepsilon_t^{VEL} + \pi\varepsilon_t^{FI} + \delta\varepsilon_t^{PR} + \sigma\varepsilon_t^{LS} + (\kappa - \psi\delta\gamma)\varepsilon_t^{OP}$$

From the set of equations above, one can conclude that an oil price shock can have a long run effect on all the variables except the unemployment rate. The short term effects are more complicated to establish, and depend on which factors dominate. For instance, whereas an oil price shock (that increases the oil price) will have a short term positive effect on GDP through increased aggregate demand ($\phi>0$), there may be negative short term effects on GDP if the Norwegian currency is a petro currency that appreciates with a higher oil price ($\kappa<0$) and if the price level increases ($\psi>0$). however, in the long run, GDP falls with a higher real oil price as the production function shifts down ($\rho<0$).

Ordering the vector of the five stationary variables as $z_t = (\Delta o, \Delta rw_t, \Delta y_t, \Delta s_t, u_t)'$ and the five serially uncorrelated orthogonal structural shocks as: $\varepsilon_t = (\varepsilon_t^{OP}, \varepsilon_t^{PR}, \varepsilon_t^{LS}, \varepsilon_t^{FI}, \varepsilon_t^{VEL})'$, the long run expression of the moving average expression of z_t, can then be written as:

$$(D.12) \qquad \begin{bmatrix} \Delta o \\ \Delta rw \\ \Delta y \\ \Delta s \\ u \end{bmatrix}_t = \begin{bmatrix} D_{11}(1) & D_{12}(1) & D_{13}(1) & D_{14}(1) & D_{15}(1) \\ D_{21}(1) & D_{22}(1) & D_{23}(1) & D_{24}(1) & D_{25}(1) \\ D_{31}(1) & D_{32}(1) & D_{33}(1) & D_{34}(1) & D_{35}(1) \\ D_{41}(1) & D_{42}(1) & D_{43}(1) & D_{44}(1) & D_{45}(1) \\ D_{51}(1) & D_{52}(1) & D_{53}(1) & D_{54}(1) & D_{55}(1) \end{bmatrix} \begin{bmatrix} \varepsilon^{OP} \\ \varepsilon^{PR} \\ \varepsilon^{LS} \\ \varepsilon^{FI} \\ \varepsilon^{VEL} \end{bmatrix}_t$$

The model presented above implies that only oil price shock can have a long run effect on oil prices: [17]

$$(D.13) \qquad D_{12}(1)=D_{13}(1)=D_{14}(1)=D_{15}(1) = 0.$$

Productivity shocks and oil price shocks can affect real wages in the long run:

$$(D.14) \qquad D_{23}(1) = D_{24}(1) = D_{25}(1) = 0.$$

All three productivity, labour supply and oil price shocks can affect output in the long run:

$$(D.15) \qquad D_{34}(1) = D_{35}(1) = 0$$

and all shocks but velocity can affect the real exchange rate in the long run:

$$(D.16) \qquad D_{45}(1) = 0$$

With these ten long run restrictions, it is now easy to see that the matrix $D(1)$ will be lower triangular, and we can use this to recover D_0.
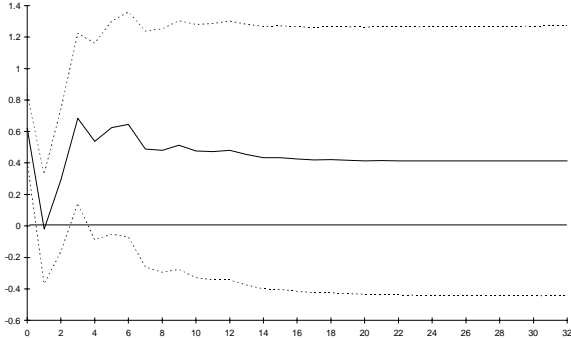
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[17] In Bjørnland (1996), I allowed demand and supply shocks to affect the real price of oil in the long run. However, by examination, none of these shocks turned out to have significant long run effects on real oil prices in Norway.
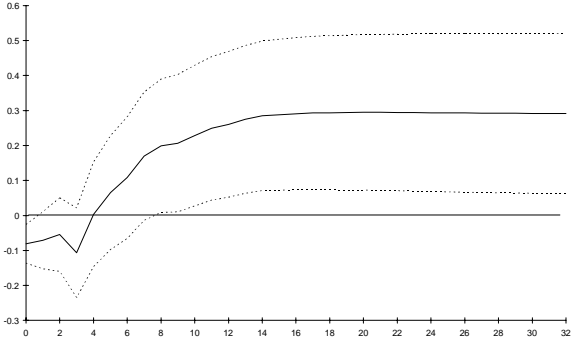
Appendix E. Effects of a real oil price shock

Figure E.1. Impulse response to an oil price shock using the inflation model
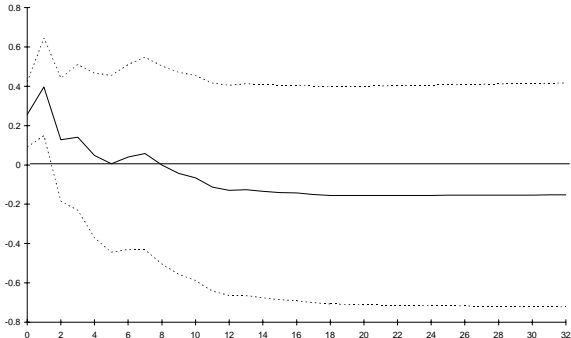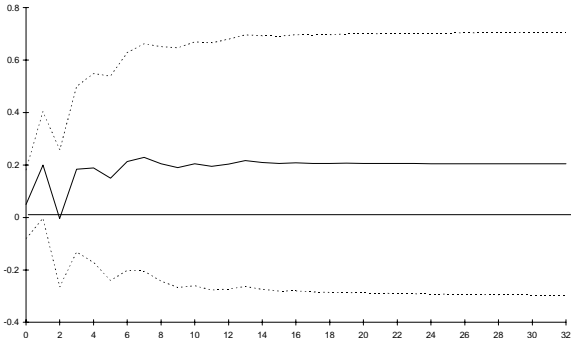
A) Real GDP

B) Price

C) Real exchange rate

D) Real wage

Table E.1. Variance decompositions of GDP and unemployment using the benchmark model

Quarters	GDP					Unemployment				
	OP	PR	LS	VEL	FI	OP	PR	LS	VEL	FI
1	4.2	17.0	39.8	38.4	1.0	4.8	1.9	33.6	48.6	11.1
4	5.4	22.1	40.8	31.2	0.5	4.5	5.9	16.3	60.2	13.2
12	12.6	18.1	53.0	15.5	0.8	3.2	5.2	11.1	68.1	12.5
20	14.3	16.3	60.0	9.9	0.5	3.2	5.3	10.9	68.1	12.7

1) OP; Oil price shock, PR; Productivity shock, LS; Labour supply shock, VEL; Velocity shock and FI; Fiscal shock.

Table E.2. Variance decompositions of real exchange rate and real wage using the benchmark model

Quarters	Real exchange rate					Real wage				
	OP	PR	LS	VEL	FI	OP	PR	LS	VEL	FI
1	3.6	12.4	11.7	5.3	67.1	0.0	88.6	1.5	0.0	9.9
4	3.2	14.3	9.1	4.2	69.2	1.7	91.2	1.5	0.2	5.4
12	1.0	18.9	8.9	1.8	69.4	2.8	93.9	0.7	0.3	2.4
20	0.7	20.6	8.9	1.1	68.8	3.0	94.9	0.4	0.2	1.5

1) See footnote 1, table E.1 for definitions.

Table E.3. Variance decompositions of price using the inflation model

Quarters	OP	PR	LS	VEL	FI
1	3.5	1.4	66.8	27.4	0.9
4	1.4	0.3	52.5	38.1	7.8
12	2.0	0.5	43.4	34.7	19.6
20	3.3	0.6	40.0	34.8	21.4

[1] See footnote 1, table E.1 for definitions.