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The Irish Macroeconomic Response to an External Shock with an Application to Stress Testing

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Abstract

This paper carries out an empirical analysis of the sensitivity of the Irish economy to an unanticipated external demand shock using a Bayesian VAR model which includes a number of Irish macroeconomic variables such as GDP, unemployment and wages. A 1% increase in US GDP growth leads to an increase in Irish GDP growth of 1.3% in the model. We also assess the relative importance of demand shocks in Ireland's other key trading partners, the UK and the euro area. The Irish GDP response to shocks in our main trading partners is roughly proportional to our export shares to these regions. We feed the results of the VAR analysis into a mortgage delinquency model to derive the implication of changes in external demand on mortgage delinquency. The results suggest that a negative one standard deviation shock to US GDP growth leads to an increase of 1600 in the number of mortgages in arrears for at least 90 days.

Keywords: Trade Shock, Bayesian VAR, Stress Testing.

Jel Codes: F47, G21.

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Non Technical Summary

Ireland has experienced one of the most severe declines in domestic output as a result of the collapse of the property market bubble and the emergence of the financial crisis. Throughout the crisis, exports have shown remarkable resilience and this has helped to counterbalance the contraction in domestic activity. There is consensus among most policy makers and forecasters that exports will continue to lead the recovery in the Irish economy and will eventually provide the platform for a pick-up in domestic demand. In this paper, we assess how a change in world demand is likely to impact Ireland in terms of its main macroeconomic variables. The paper employs a Bayesian VAR model, which is a way of examining the interactions between a relatively large number of variables without the need for strong theoretical restrictions. We focus on the responses of Irish GDP, exports, unemployment and wages.

The results show that the Irish economy is quite responsive to changes in international demand. A 1% increase in US GDP growth leads to an increase in Irish GDP growth of 1.3%. The majority of the increase in Irish GDP comes directly from exports. The expansion of the economy puts downward pressure on the unemployment rate and causes wages to increase. The increase in the wage rate hurts Irish competitiveness and acts as a break on the economic expansion. We also compare the responses of the Irish economy to changes in the GDP growth rates of our two other main trading partners, the UK and the Euro Area. We find that the response of the Irish economy is broadly in line with the amount we export to each region.

The results of the VAR analysis are used as an input to a mortgage delinquency model in order to examine how the external demand shock might impact on the financial position of mortgage holders. This application is designed to illustrate early steps in a program of work which aims to link the macroeconomy to financial variables. We consider a slightly larger VAR model in this context, which includes financial variables such as the interest rate, credit and house prices. To begin the stress test, we take the baseline assumptions for unemployment and house prices from the Prudential Capital Assessment Review (PCAR), which was completed in March 2011. The baseline profiles for these variables are adjusted based on their response to a negative external demand shock in the VAR model. The new profiles are then used as an input to a mortgage delinquency model. This model relates mortgage delinquency to macroeconomic variables. In this way, it is possible to get an estimate of how the negative external demand shock impacts on mortgage delinquency. The model suggests that a negative shock of one standard deviation to US GDP growth would lead to an increase of 1600 in the number of mortgages in arrears for at least 90 days.

1 Introduction

Having recorded real average GDP growth of 7.1 per cent over the period 1995 to 2007, the Irish economy has experienced a dramatic reversal of fortunes in recent years. In cumulative terms, real GDP contracted by 14 per cent over the period 2008 to 2010. Using GNP in current prices as a measure of the size of the economy indicates that at the end of 2010, the economy was almost one-quarter smaller than at its peak in 2007. With domestic demand likely to remain sluggish over the short-term, as a result of ongoing household sector deleveraging, contractionary fiscal policy and a weak banking system, there is a consensus among a range of domestic and international forecasters (Central Bank, ESRI, IMF, European Commission, 2011) that the recovery in the Irish economy will be export-led. The ability to forecast future Irish economic performance is dependent on understanding the sensitivity of the Irish economy to changes in the fortune's of Ireland's main trading partners.

The contribution of this paper is threefold. It uses a Vector Autoregression model (VAR) to examine the responsiveness of the Irish economy to an external demand shock and whether this has changed over time. We also use the model to obtain estimates of the relative importance of changes in demand in Ireland's key trading partners (the US, the UK and the euro area). Finally, we feed the results of the VAR analysis into a mortgage delinquency model to derive the implication of changes in external demand on mortgage delinquency.

Obtaining an estimate of the sensitivity of the economy to an external shock is important for a number of reasons. Firstly, given the openness of the Irish economy, understanding how changes in world demand are transmitted to Ireland can provide important insights into the evolution of the economy in the coming years. Secondly, the VAR model provides a consistent framework which can be used to trace the effects on key macroeconomic aggregates of an external demand shock. By feeding the results from the VAR model into a satellite loan delinquency model, the implications of the external shock for the financial system can also be assessed. Our results show that the Irish economy is highly sensitive to changes in external demand and that the elasticity with respect to world output has increased over time. In addition, when the model is used to compare the relative importance of Ireland's main trading partners, the response of Irish GDP is closely related to our relative export shares but some results indicate that the US response is greater than our export share alone would suggest.

The basic VAR model specified in this paper is built for the specific purpose of examining the response of the Irish economy to an external demand shock. However, a well specified and rigorously tested VAR model of the Irish economy could be used to fulfil a number of functions. Given the recent financial crisis, there has been much effort aimed at incorporating financial considerations into models of the real economy. We extend the basic VAR to include financial variables which are needed for stress testing purposes. The results of the external scenario analysis from the VAR are fed into a satellite model to assess the implications of the macro scenario for mortgage delinquency. Although the exposition is for illustrative purposes, the model provides an example of how changes in the macroeconomy can be linked to financial variables.

The paper is organised as follows. Section 2 describes the open nature of the Irish economy. Section 3 discuss how VAR models of this type have also been used in the literature. Section 4 provides a detailed account of the data and the methodology. Section 5 documents the economy's sensitivity to a world demand shock in the VAR model. Section 6 compares the importance of our main trading partners. In Section 7, the results from a scenario generated using the VAR model are fed into a satellite model of mortgage delinquency to assess the implications for arrears in the Irish mortgage market. Section 8 concludes.

2 The Openness of the Irish Economy

The Irish economy is extremely open by international standards with a strong reliance on foreign trade. One measure of the openness of the economy is the combined share of exports and imports in Gross Domestic Product. As shown in Figure 1, exports and imports accounted for almost 200 per cent of Irish GDP in 2010 which was twice as large as the share recorded in other countries such as the UK and Germany and significantly above the euro area average share of 80 per cent in 2010. In a recent report, IBM (2010) ranked Ireland first in the world in terms of job creation by foreign investment relative to population size. The mobility of capital and labour contributes to the openness of the economy with large migratory flows and high levels of foreign direct investment being notable features of the Irish economy for many years.

Ireland has substantial trade and investment links with the US. According to the CSO's External Trade Bulletin, the US was the most important market for Irish manufacturers in 2009 with over a fifth of total goods exports destined for the US market. Ireland has also been the recipient of a substantial amount of foreign direct investment (FDI) from the US. Data from the Bureau of Economic Analysis (BEA) show that the stock of US investment in Ireland was valued at $122 billion in 2009. The data also indicate that around 550 affiliates of US companies operate in Ireland employing around 91,000 people or 5 per cent of total employment. Lane and Ruane (2006) estimate that based on ultimate beneficial ownership (rather than the location of the immediate owner) over half of foreign direct investment into Ireland originated in the US. The importance of the trade and investment links between the US and Ireland is reflected in the specification of VAR model in Section 5.

The contribution of different sectors of the economy to total exports has changed significantly over time. The manufacturing sector grew dramatically in size so that by 2000 it accounted for over 70 per cent of total exports and 85 per cent of GNP. In recent years, the market services sector has expanded in size and importance and in 2010 accounted for almost 48 per cent of exports, up from 22 per cent in 2000. While in the past, changes in world activity affected the Irish economy mainly through the manufacturing sector, following the growth in services exports, that sector is now an additional key channel through which changes in world demand affect the Irish economy.

The contribution of domestic demand and net exports to economic growth is illustrated in Figure 2. External demand made a positive and sizeable contribution to growth up to the middle of the last decade which, combined with strong domestic demand, drove the expansion of the Irish economy over that period. Export growth slowed over the 2005 to 2008 period due to the expansion of the construction sector and the erosion of Ireland's competitiveness. In recent years, external demand has put a floor under economic output at a time when all components of domestic demand were experiencing severe contractions. The positive contribution to economic growth provided by the external sector in 2009 was built upon in 2010 as the Irish economy benefitted from the upturn in the world economy. The data presented in Figure 1 and Figure 2 provide evidence that developments in the international economy continue to have an important influence on the Ireland.

3 VAR Models in Macroeconomic Analysis and Stress Testing

VAR models have been used to examine the impact of various types of shocks on the macroeconomy. In the context of a small open economy, Cushman and Zha (1997) used a VAR framework to identify the impact of monetary policy. Killian (2009) uses VAR analysis to assess the impact of oil price shocks on macroeconomic variables while Linde (2002) uses a vector autoregression model to examine the effect of monetary policy shocks. While these questions have also been examined using large-scale macroeconomic models, the use of VAR analysis has the advantage that it avoids the use of "incredible" identifying assumptions. The VAR model ultimately allows all variables interact if the data deem it appropriate with restrictions generally placed only on the causal ordering in the initial period.

While the VAR model developed in this paper is used for the purpose of measuring the response of the economy to an external demand shock, macroeconomic VAR models are used extensively, in particular by central banks, in the area of macro stress testing of financial sector credit risk. The first step in the stress testing process is the development of a coherent stress-test scenario. The use of large macroeconomic models to design the stress scenario has the advantage of ensuring consistency across the simulated values in the scenario. However, scenarios generated using these models are also subject to the choice of underlying assumptions and it can prove difficult to decide on the policy responses, baseline assumptions, the time horizon and the specific variables to shock. In addition, a well defined and fully developed macroeconomic model may not be available to generate internally consistent shocks. As a result, the approach adopted by many central banks, and documented in the literature, is to use vector autoregressive (VAR) or vector error correction models (VECM). In the VAR model, the macroeconomic variables are jointly affected by the initial shock and the vector process is used to trace the combined impact of this initial shock on the set of macroeconomic variables.

The VAR methodology allows for a transparent and consistent way of generating stress scenarios although it lacks the richness and detail on the economic structure which large macroeconomic models embody. A number of papers use the VAR approach to generate macroeconomic scenarios. These include Asberg and Shahnazarian (2008) for Sweden, Jimenez and Mencia (2007) for Spain, the Bank of Japan (2007) and Castren, Dees and Zaher (2008) for the euro area. Hoggarth et al (2005) describe the use of the VAR approach for stress testing UK banks. These papers all follow a sequential process. In the first stage, the macroeconomic VAR model is used to generate projections for key macroeconomic indicators under the stress conditions assumed. In the second stage, the outputs from the simulation of the macroeconomic model, including projections for macroeconomic variables such as GDP and interest rates, are fed into a satellite model which links credit risk to the macroeconomic model variables. In the case of Hoggarth et al. (2005), measures of credit risk are included directly in the macro VAR model and the interaction between credit risk and shocks to the macro variables is examined. The lack of a long time series of credit risk variables makes this latter approach more difficult in an Irish context. We use two versions of the VAR in this paper. The basic model contains key macroeconomic variables and is the version used to examine the external demand shock. For the stress testing application, we extend the model by including financial variables and use the response of these variables as inputs to the stress testing model.

4 Data and Methodology

4.1 Data and Variable Selection

In constructing the VAR it is necessary to decide on the choice of variables which can capture the key interactions in the Irish economy. Since the basic version of the model will be used to examine the impact of a world growth shock, the specification of the VAR is tailored in order to incorporate the channels through which developments in the world economy affect Ireland. In deciding on the measure of external demand to include in the VAR, we draw on the results of previous research on the Irish economy and in particular, the modelling of the tradable sectors of the Irish economy in the *HERMES* model maintained by the ESRI.

The *HERMES* macro-economic model of the Irish economy was first developed in the late 1980s (Bradley, Fitz Gerald, Hurley, O'Sullivan and Storey, 1993). *HERMES* models the supply side of a small open economy. The determination of output is modelled separately for the tradable sector and the non-tradable sector. In the current version of the *HERMES* model, output of the tradable sector (manufacturing and business and financial services) is a function of world demand, proxied by US GDP, and Irish competitiveness, broadly defined. This specification of the manufacturing sector is described in Bradley, Fitz Gerald and Kearney (1993); an overview of the determination of output in the tradable sector in the model is given in the appendix of Bergin et al. (2010).

The benchmark VAR model specification comprises a six variable system of key macroeconomic variables. The variables are growth rates of: real seasonally adjusted US GDP (US), oil prices in euros per barrel (OIL), total Irish exports of goods and services (EXP), Irish GDP, wages as measured by compensation per employee (WAGES) and the unemployment rate on an ILO basis (UR). Additional variables are needed for the stress testing application. In this case, the VAR is then extended to included the real mortgage interest rate (MIR), total private sector credit excluding financial intermediation (CRXFI) and house prices (HP). The US GDP data come from the Federal Reserve Bank of St. Louis databank, the remaining data come from the Bank's model database. The model is estimated using quarterly data from 1980Q1 to 2010Q4. To take account of seasonality, the model is expressed in terms of the logged year-over-year change in the variables. Time series plots of the data are shown in Figure 3.

In light of the importance of US trade for the Irish economy, we use US GDP in the first version of the VAR model. We substitute the GDP growth rates of the UK and euro area in later versions of the model. Oil prices are included as a second international variable. Most US recession since World War II have been preceded by an increase in oil prices and the price of oil impacts on Ireland directly. Wage rates are included in the specification to capture the impact of changes competitiveness on output and employment.

The key channel through which changes in world demand are transmitted to the Irish economy is through the effect on exports of goods and services and this variable is also included in the model. The labour market effect of changes in economic activity in Ireland arising from a change in world demand is modelled by including the unemployment rate (as well as wage rates) in the specification. This completes the list of variables included in the basic version of the VAR.

Additional financial variables are included in the extended VAR in anticipation of the stress-testing exercise. However, there is justification for the inclusion of these variables outside their role as inputs to the stress tests. A common criticism of traditional macro models is the exclusion of credit and other financial sector variables from these models. There is a large international literature documenting the interrelationship between credit and developments in the real economy. For Ireland, Kelly, McQuinn and Stuart (2011) estimate a long-run equation for the relationship between private sector credit and GDP. The authors report evidence of a statistically significant relationship between the variables over the period 1982-2010, although the estimated relationship is stronger over the period 1982-1997.

In order to incorporate a financial channel in the extended VAR model, we make use of historical quarterly time series data compiled by the Central Bank of Ireland on the sectoral allocation of credit. The credit variable included in the model is total private sector credit excluding credit extended to the financial intermediation sector (CRXFI). The latter sector accounts for around 10 per cent of the total outstanding stock of private sector credit reflecting the presence in Ireland of a large number of international financial services companies, in particular IFSC companies. In order to derive a series which best reflects the level of credit extended to the real economy, we exclude the financial intermediation sector, which would include the more internationally focussed banks in the IFSC, from our measure of total private sector credit.

The building and construction sector has played a prominent role in the Irish economy over the last decade. In the period 2003 to 2007, much of the growth in the Irish economy could be attributed to the boom in activity in this sector and the associated expansion in lending and house prices. In a similar way, the collapse of the property has been one of the main reasons for the difficulties experienced by Irish financial institutions since 2008. Consequently, house prices are also included in the extended VAR model.

We now present some brief empirical evidence in support of our choice of variables in the form of bivariate Granger causality tests. We do this for the larger version of the model. Although bivariate causality tests will not pick up on all predictability from larger multivariate models, where predictability can operate through intermediate variables, it provides a useful starting point. The tests are designed to assess the predictive ability of each of the variables in the VAR with respect to the other variables. A finding that one variable in the system has predictive content for another does not imply the existence of a causal relationship between them. The output of this test is displayed in the form of a matrix. The entries in the matrix are levels of statistical significance. Values less than 0.1, which are highlighted, denote statistical significance at the 10% level. The table is most easily read by column. The variables listed by row are the variables being predicted. The variable in the column heading is the variable under test. For example, US GDP growth is being tested in the first column. The highlighted entries show that it helps to predict Irish GDP, unemployment and credit growth.

Table 1: Significance Levels from Bivariate Causality Tests

	US	OIL	EXP	GDP	WAGES	MIR	UR	CRXFI	HP
US	1.00	0.46	0.62	0.26	0.99	0.02*	0.39	0.81	0.43
OIL	0.70	1.00	0.98	0.54	0.91	0.48	0.51	0.80	0.66
EXP	0.59	0.55	1.00	0.81	0.97	0.66	0.01*	0.84	0.92
GDP	0.06*	0.01*	0.79	1.00	0.43	0.34	0.00*	0.62	0.04*
WAGES	0.44	0.99	0.54	0.15	1.00	0.99	0.26	0.29	0.10*
MIR	0.62	0.06*	0.85	0.84	0.80	1.00	0.35	0.88	0.99
UR	0.01*	0.01*	0.12	0.17	0.12	0.03*	1.00	0.01*	0.05*
CRXFI	0.00*	0.54	0.20	0.02*	0.04*	0.14	0.01*	1.00	0.00*
HP	0.45	0.56	0.22	0.34	0.85	0.99	0.41	0.92	1.00

The aim of the analysis here is not to pin down all predictability within the system or to highlight specific results. Instead, the aim is to demonstrate that the variables interact with each other in a meaningful way. The significant entries are well distributed by row and column. This shows that there are a lot of direct relationships between the variables and, as mentioned, this is without accounting for indirect relationships. As such, there is strong empirical justification for the variable choice.

4.1.1 The Bayesian VAR

A standard VAR model with up to nine variables estimated with quarterly data over the sample available would suffer from degrees of freedom problems. In short, there would be too many parameters to estimate. This leads to the known problems of high estimation uncertainty, overfitting and poor out-of-sample forecasts. One way of dealing with these problems is to use the Bayesian approach to estimation. The Bayesian approach introduces priors to the estimation process. A prior is a value for a parameter in the model, specified by the researcher before seeing the data. A number of priors are commonly used when estimating VAR models. The prior used in this paper is frequently referred to as the Minnesota prior.[1] In a VAR model of order s

$$\begin{aligned} y_t &= C + B_1 y_{t-1} + ... + B_p y_{t-s} + \epsilon_t \\ \epsilon_t &\sim N(0, \Sigma) \end{aligned}$$

Our aim is to "shrink" the coefficients towards the following naive model

$$y_t = C + y_{t-1} + \epsilon_t \tag{1}$$

In this model, the diagonal coefficients of B_1 are equal to unity and all other lag coefficients are set equal to zero. The number of parameters has been reduced greatly as all coefficients beyond the first lag are now gone, as are all non-diagonal coefficients in the first lag. In practice, the naive model is not imposed. The final model, which combines the prior with the likelihood (the estimated part), only pushes the results in the direction of this naive model. If there are lags which the data find to be important, they will not be close to zero. Unimportant lags will be close to zero. This reduces the impact of unimportant coefficients, has the desirable effect of avoiding over-fitting and also results in smoother impulse response functions.

The naive model is a random walk model in each of the variables in the VAR. This does not mean that the variables in the VAR must be non-stationary or that we are trying to impose non-stationarity on stationary variables. It does presuppose that the variables are persistent however.

[1] A proliferation of terminology means that it is also referred to as the Litterman prior or the random walk prior.

We put the nine variables included in the extended VAR in individual AR(1) models. The lowest AR coefficient is 0.73 and the average persistence in the nine regressions is 0.87 so the assumption of high persistence is a valid one in this application.[2] The shrinkage towards the naive model is done using the following prior:

$$[B_s]_{ij}|\Sigma \sim N\left(b_{s,ij}, \left(\lambda \frac{1}{s^\alpha} \frac{\sigma_i}{\sigma_j}\right)^2\right)$$

$$b_{s,ij} = \begin{cases} 1 & \text{if } s = 1 \text{ and } i = j \\ 0 & \text{otherwise} \end{cases}$$

where $b_{s,ij}$ is the coefficient of variable i in the equation for j at lag length s. There are two elements to the prior distribution - the mean and the variance. The mean of the prior tells us what we are shrinking towards. This is expanded upon in the second part of the equation. We shrink towards one when $s = 1$ and $i = j$, which corresponds to the diagonal elements of B_1 but shrink towards zero otherwise. The variance of the prior indicates by how much we shrink. If the prior variance was set to zero, the prior would be imposed fully (i.e. there is zero deviation from the prior) and we would just have the random walk model. Instead, we use the formula to define the variance of the prior and this has three elements. The first element is λ, which is the overall tightness of the prior. The closer it gets to zero, the tighter we impose the naive model. Conventional values have long been available for this parameter and Banbura et al (2010) argue that overall shrinkage should be increased in line with the number of variables in the VAR and the degree of correlation between them. The second element is $\frac{1}{s^\alpha}$, where α is normally set equal to one. As s gets bigger, this fraction gets smaller and so the prior is imposed more tightly. This means we impose the restriction that the lag coefficient equals zero more stringently the further back we go in terms of lag length. The final element $\frac{\sigma_i}{\sigma_j}$ is just a relative variance factor that adjusts for the units that the variables are measured in. In short, the prior says that we think the series are persistent, we are more concerned with own lags rather other variable lags (diagonal B_1) and we are more concerned with recent lags than older lags. This prior has been found to work well in many empirical applications.

The ultimate aim of Bayesian analysis is to find the posterior distribution. The posterior can be thought of as our belief of the distribution of the "true" parameters having seen the data. The concept differs from classical analysis, which deals with the distribution of the estimator rather the

[2]If the variables have strong mean reversion, an alternative prior which shrinks all coefficients to zero can be used instead.

true paramater.[3] In theory, the posterior is found by multiplying the prior by the likelihood. The likelihood is the model that we choose to estimate, again based on some distribution for the data generating process. A VAR model already has a well defined conditional likelihood function, based on the assumption of normally defined residuals. We also had a normally distributed prior. This makes the theoretical multiplication of the prior and likelihood easier as it involves the multiplication of two normal distributions. In this situation, however, there is an even easier alternative estimation method known as Theil's mixed estimation strategy. The formula for the posterior distribution of the parameters is given by

$$\hat{B} = \left(x'x + \Omega^{-1}\right)^{-1} \left(x'y + \Omega^{-1}\widetilde{b}\right)$$

where Ω measures the variance of the prior and $\widetilde{b}$ is the peak of the prior. Note that if we set these terms which relate to the prior equal to zero, we just have the standard OLS formula for the coefficients. Thus, the posterior is a weighted average of the OLS estimate (equivalent to our likelihood function) and the prior, with the weight on the prior given by the prior variance. The implicit weight on the OLS part depends on how tightly the parameters are estimated, which depends in a large part on the number of data points in the sample. This representation suggests a simple way to proceed with Bayesian estimation. It is possible to pad the dataset with artificial or dummy observations at the end of the sample to represent the prior. For an artificial point in time t^*, add the artificial observations

$$y^* = y_0,\ x^* = [1, y_0] \implies y_0 = c + \rho y_0 + \epsilon_{t^*}$$

which is centred on the unit root case. We can then apply standard OLS estimation to the padded dataset. The amount of artificial data determines the tightness of the prior. If we have 200 actual data points and do not believe strongly in the prior, we might add five artificial data points. Our OLS estimates will not be heavily influenced by the prior in this case. If we believe in the prior

[3] In classical analysis, we construct a confidence interval and says that the true parameter will lie within that interval a certain percentage of the time, based on the concept of hypothetical repeated sampling. The only information used in Bayesian analysis is the prior and the data. Bayesians are not concerned with other samples that may have been observed but never were. As there is no concept of hypothetical repeated sampling, the posterior distribution is said to reflect the true parameter value. This is consistent with the prior, which is our belief of the true parameter before seeing the data.

quite dogmatically, we could add 1000 artificial data points in which case the influence of the data is quite limited.

5 Results

In this section, we present the impulse response functions for the benchmark specification of the VAR, which excludes the financial variables. The variables included are the growth rates of US GDP, oil prices, Irish GDP, Irish exports, Irish unemployment and the Irish wage rate and the sample period, prior to data transformations, is 1980Q1-2010Q4. The system has two lags. We implement a positive one standard deviation shock to US GDP growth and examine the responses of key Irish macroeconomic aggregates. The shock represents a once-off, unanticipated change in external demand. The size of the one standard deviation shock in this case amounts to around 0.85 of one per cent. We measure the cumulated responses, which sums the impulse response functions for each period. This is equivalent to measuring the area under the impulse response curve. To calculate an elasticity, we then calculate the ratio of the cumulated response of the Irish target variable over the cumulated US GDP response, which is the ratio of the area under the Irish curve to the US curve. This elasticity is then rescaled so that it is expressed in terms of a 1% shock to US GDP growth. The US shock is not a one-period shock. There is a shock in the initial period and its effect slowly diminishes over time in accordance with the autoregressive dynamics of US GDP growth in the system. The properties of the US shock are discussed in Appendix A.5 and the impulse response can be seen in Figure 4. The results are presented in Table 2.

Table 2: VAR Model Elasticities

	Elasticity With Respect to US GDP
Irish GDP	1.29
Exports	1.62
Unemployment Rate	-5.32
WAGES	1.39

In the VAR model, the main channel through which the positive shock to US GDP impacts on the Irish economy is through exports. Given the openness of the Irish economy, with the bulk of Irish manufacturing output and a growing share of services output being destined for the export market, the positive shock to US GDP leads to a significant increase in Irish exports in the VAR model. The elasticity of total Irish exports with respect to the change in US GDP, derived by summing the impulse responses, is calculated as 1.6. The overall effect of the shock is to increase GDP by almost 1.3 per cent with over two-thirds of this increase due to the increase in exports (Figure 5). The increase in output and activity as a result of the increase in exports has a large effect on the labour market (Figure 6) with the reduction in the unemployment rate amounting to over 5 per cent. To clarify, this means that the unemployment rate will be 95% of it previous value so that if unemployment was 12.0% before the shock, it would be 11.4% after the shock. This represents a 5% reduction in the *level* of unemployment. Overall, the impulse responses shown in Figures 5 and 6 for output, exports, employment are similar to the effect of a shock to external demand generated using the *HERMES* model.

The impulse responses for Irish output, employment and wages display a hump shaped pattern with the peak effects occurring 1-2 years after the initial shock. The peak output effect does not take place for around 6 quarters after the shock as it takes time for firms to adjust their output in response to higher world demand. Activity in the economy begins to moderate then in response to higher wage rates. In the *HERMES* model, an increase in employment and a reduction in the unemployment rate consequent on higher economic activity put upward pressure on real after tax wage rates. This loss of competitiveness over time gradually dampens the initial positive impact of the demand shock. The impulse responses illustrate that a similar effect is also at work in the VAR model with upward pressure being placed on Irish wage rates following the positive shock to world output.

A number of robustness checks are carried out in Appendix A. The VAR is estimated over two subsamples and there is evidence that the sensitivity of the Irish economy to external shocks has increased over time but the key transmission mechanisms remain unchanged. The results are not sensitive to small changes in the number of lags or the order of differencing. The ordering of the domestic variables in the VAR is changed but this also has little impact on the results. We make the US growth shock fully exogenous so that Irish macro variables cannot impact on US GDP growth but the results are not sensitive to this restriction. Finally, we estimate the VAR with the standard OLS approach rather than the Bayesian approach. Although the results differ somewhat, we argue that the results from the Bayesian approach are more plausible. More details on all these sensitivity checks are provided in the Appendix.

6 Comparison to Other Trading Partners

The analysis undertaken thus far has concerned the response of the Irish economy to a US shock. In this section, we compare the results obtained by measuring the reaction to the same shock to the UK economy and to the euro area. This will allow a comparison of the responses to the other main Irish trading partners. The VAR model used is exactly the same as that used for the US growth application, both in terms of the variables included and the specification of the model. The only difference is the inclusion of UK GDP or euro area GDP (which is fixed as the sum of the 17 countries currently in the euro) in place of US GDP in the original model.

Table 3: VAR Model Elasticities

Elasticity	US Shock	UK Shock	Euro Area Shock
Irish GDP	1.29	0.81	2.51
Exports	1.62	1.07	2.29
Unemployment Rate	-5.32	-3.58	-8.67
WAGES	1.39	0.93	0.97

The UK elasticities all have the expected sign, as was the case with the US. In terms of the magnitude of the responses, they are generally about two thirds the strength of the response to the US GDP shock. For example, the GDP elasticity is 0.81 for the UK whereas the corresponding figure for the US was 1.29. The impulse response functions are not graphed but are very similar for the most part, indicating that the transmission mechanisms are the same. The third column examines the response to euro area GDP based on the fixed 17 country composition of the euro area. The GDP series is available from 1995-2010, which is considerably shorter than the 1980-2010 span used for the US and UK exercises. The results of the euro area model again mirror those of the other exercises in many respects. The elasticity of Irish GDP response to the euro are GDP shock is 2.51. This is quite an elastic response. As with the other shocks, exports are a key driver.

The size of the GDP responses to the foreign shock in each of the different scenarios tallies quite closely with the amount Ireland exports to each of these areas. The GDP elasticity for the US shock is 59% greater than the UK elasticity and CSO trade figures show that Irish exports to the US are about 50% larger than exports to the UK, according to trade statistics for 2010. Similarly, the GDP response for the euro area is 94% greater than the US response but Ireland exports 85% more to the euro area. The VAR results mimic our current trade patterns very closely. This gives us confidence that the VAR is capturing the external trade shock adequately. In addition, the elasticities give us an idea of the relative importance of our main trading partners in terms of leading an export driven recovery.

The size of the unemployment response in each region is broadly related to the size of the GDP response for that region although there is some difference in the sensitivities. For example, if we divide the unemployment figure of -5.32 for the US shock by the corresponding GDP number of 1.29, the resulting figure of 4.12 implies that every percentage point increase in GDP growth from the US shock should reduce unemployment rate growth by 4.12%. The corresponding elasticity for the euro zero is 3.45, suggesting the employment response is a bit less elastic for the same size GDP response, which might be explained by our strong ties with the US. The UK elasticity is 4.9, meaning that employment is more elastic for a given GDP response if the shocks is UK based. This finding is consistent with the nature of Irish exports to the UK which come from sectors which tend to be quite labour intensive.

7 Macro Stress Testing Using the VAR Model: An Application to Loan Delinquency

As discussed in Section 3, VAR models have been widely used by central banks as part of a multistage stress testing process. The first stage requires an adverse macroeconomic shock. In the second stage, the macroeconomic variables are mapped to key financial sector variables using satellite models of asset quality, credit losses or other measures of financial sector credit risk. We illustrate this approach to stress testing by applying the results of a negative external demand shock from the VAR model to a satellite model of loan delinquency. The model is a simplified variant of the delinquency model in a forthcoming paper by Lydon and McCarthy (2011). This application is intended to illustrate the way in which macro shocks can be linked to financial variables. However, this work is preliminary so the methodology and results should be viewed in that light.

7.1 Stage 1: Generating Stress Scenario

We generate the macro scenario in the first stage using the extended version of the VAR model described in Section 4 which includes financial sector variables. For the stress testing application, we examine the response of the economy to a negative one standard deviation shock to US GDP. Since the model is symmetric, the response of the key macroeconomic aggregates to this negative shock mirrors the results presented above but with the opposite signs. The inclusion of interest rates, credit and house prices in the extended model does not have a major impact on the response of the key macroeconomic aggregates compared to the results from the benchmark model, as shown in Table 4.[4]

Table 4: VAR Model Elasticities

	Elasticity With Respect to US GDP, Extended Model
Irish GDP	1.13
Exports	1.54
Unemployment Rate	-4.70
WAGES	1.30

In March 2011, the Central Bank of Ireland published the results of the Prudential Capital Assessment Review (PCAR) 2011. The purpose of the PCAR was to stress test the domestic banks in order to determine the cost of recapitalisation required to meet standards imposed by the CBI. [5] As part of the PCAR process, the Central Bank outlined a baseline scenario and a stress scenario for a range of macroeconomic variables. We take the baseline profiles for house prices and the unemployment rate from the PCAR process and adjust them according to the results of negative external demand shock.

House prices in the PCAR baseline are expected to decrease by 14.4 per cent in 2012. The results from the VAR model indicate that house prices would be reduced by 0.5 per cent following the external demand shock. Applying this reduction to the PCAR forecast for house price growth in 2012 produces a new projected fall of 15 per cent. The PCAR baseline assumes an average unemployment rate in 2012 of 12.7 per cent. Applying the change in the unemployment rate arising from the negative US GDP shock in the VAR model to the PCAR baseline produces a new estimate of the 2012 unemployment rate of 12.9 per cent. Figure 7 shows the projections for house prices and the unemployment rate which were used for the PCAR process together with the new adjusted profiles.

[4] Table 4 shows the response to a positive shock for comparative purposes.

[5] Further details on PCAR 2011 can be found in Central Bank of Ireland (2011).

7.2 Stage 2: Mapping the External Shock onto Loan Delinquency

We take the projections for house prices and the unemployment rate from the first stage and feed them into a satellite model of loan delinquency in the Irish market in the second stage. The delinquency model is estimated using monthly loan level data for eight regions of Ireland for the period June 2008 to December 2010. These data became available arising out of the stress-testing exercise carried out by BlackRock Solutions and the Central Bank of Ireland on financial institutions in early 2011. The loan book data contains information on the original amount of the loan advanced, the term of the loan, the interest rate tpye (fixed, variable or tracker), income of the borrower at the time of origination and the location of the property for which the loan was granted. We construct a panel for estimation purposes by pooling together the loan book data for each of the regions. With eight regions and thirty one months of data for each region, the total sample size is 248.

A simple long-run OLS model of the form represented by the equation below is estimated where the dependent variable, $A90$, is the percentage of total loans more than ninety days in arrears. The key independent variables are housing equity, e, defined as the outstanding loan balance minus the curent value of the property, the unemployment rate, ur, and its one-year lag and the ratio of the loan repayment to borrower income lti. All variables are expressed in log terms. In addition to these key variables, seven regional dummy variables, D_r, are included to account for differences in delinquency rates across regions while time dummies, D_t, are included to account for seasonality. The inclusion of these variables mirrors the approach taken by BlackRock Solutions whose framework included variables such as the loan-to-value ratio, loan age, affordability and the unemployment rate which are predictive in forecasting loan delinquency.

$$A90 = \alpha + \beta_1 e + \beta_2 ur + \beta_3 ur_{t-1} + \beta_4 lti + \beta_5 D_t + \beta_6 D_r + \epsilon_t \tag{2}$$

The estimated regression coefficients from the delinquency model show the expected signs with the percentage of loans more than ninety days in arrears found to be positively related to the unemployment rate, the repayment to income ratio and the equity variable (higher negative equity increases the percentage of delinquent loans). The estimation results indicate that the unemployment rate is a key driver of loan delinquency in this model with a one per cent increase in the unemployment rate leading to a 1.02 per cent increase in the percentage of total loans more than ninety days in arrears. The full estimation results are reported in Appendix B.

We feed the projected values for house prices and the unemployment rate under the stress scenario into the delinquency model to assess the impact of the external demand shock on arrears in the mortgage market. The negative external shock reduces house prices, which in turn affects the equity variable in the satellite delinquency model. The shock also increases the unemployment rate, which is a key driver of arrears in the satellite delinquency model. Figure 8 shows the implications of this scenario for mortgage delinquency in the Irish market. As a result of the negative external shock affecting house prices and the unemployment rate, the percentage of total loans greater than 90 days in arrears would be close to 0.2 of a percentage point higher than projected by the model when the PCAR baseline macroeconomic projections are used (Figure 8). With current estimates indicating that the total number of mortgages in Ireland is around 800,000, this would equate to around 1600 additional mortgages in delinquency.

This application illustrates how the macro VAR model developed in this paper for the purpose of generating an external demand shock can be used in conjunction with a satellite model of loan delinquency as part of a coherent stress testing process. For the purpose of the application described here, two of the variables from the macro stress scenario (house prices and the unemployment rate) were used in the satellite delinquency model in the second stage of the stress testing process. Further refinements to the satellite model would allow the impact of other variables from the macro model, such as interest rates, to be transmitted to mortgage delinquency.

8 Conclusions

This paper examines the response of the Irish economy to a shock to external demand using a VAR model. In keeping with the results of previous research on the Irish economy, our results show that the domestic economy is highly sensitive to changes in external demand. The responses of key macroeconomic aggregates to a foreign demand shock are broadly as expected with the initial positive response of output and exports being moderated in later periods by higher wage rates and interest rates. The use of the VAR methodology allows for the propagation of the foreign demand shock to be traced clearly using the impulse responses.

The model generates consistent dynamic responses to the effect of the external demand shock that accord with theory and are similar to the results obtained in other studies where a large macroeconomic model has been used. The results from our VAR model indicate that the Irish economy remains highly responsive to changes in external demand, a finding which echoes the results of previous research on the behaviour of the Irish economy. The results are also similar to those obtained in other studies where VAR models have been used to examine the impact of shocks in small open economies. We assess the relative importance of Ireland's key trading partners and our findings confirm the of importance external developments for Ireland.

Finally, we provide a tentative illustration of how the VAR model developed in the paper could be used as part of a stress testing process. We incorporate the projections from the stress scenario into a satellite model of mortgage delinquency. The results from the VAR are used to adjust the baseline outlook for unemployment and house prices from the last stress testing exercise. The effects of these changes are then traced through to mortgage arrears. We find that a negative one standard deviation shock in US GDP growth leads to an extra 1600 mortgages falling into arrears greater than 90 days.

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A Appendix: Sensitivity Analysis

In this appendix, we examine the robustness of the impulse response functions obtained in the previous sections to changes in the sample period, the number of lags in the VAR, alternative ordering of the variables and changes in the degree of differencing. We also report results from standard VAR estimation. Overall, while the magnitude of the estimated impulse functions change in some cases, changes in model specification do not have a major effect on the benchmark model.

A.1 Sample Period

Table 5 shows the results when the VAR is estimated over two subsamples from 1980 to 1999 and from 2000 to 2010. The elasticity of Irish GDP in responses to changes in US output is higher in the latter period indicating that the sensitivity of the Irish economy to changes in US growth has increased over time. This may reflect the internationalisation of the Irish economy over this period and the fact that the traded services sector, in addition to traded manufacturing, is now a key channel through which developments in the world economy impact on Ireland.

The most striking figure from the subsample analysis is the change in the unemployment elasticity, which is -2.8 in the first period but -8.0 in the second. The growth in the unemployment rate is the variable used in the analysis as the unemployment rate in levels is non-stationary. Unemployment rate growth is stationary according to standard statistical tests although the series is far more volatile at the end of the sample relative to the beginning of the sample. The variance of the series during the last ten years of the sample is over three times higher than the first ten years. Furthermore, there is a doubling of the covariance between unemployment and US GDP from the first to the second subsample. Meanwhile, the variance of US GDP growth is quite stable over the entire. Given that the VAR coefficients will reflect the covariance of the two variables over the variance of US GDP, a stronger coefficient and elasticity should be expected in the second subsample.

Table 5: VAR Model Estimates over Subsamples

	Sample 1980-1999	Sample 1990-2008
Irish GDP	1.1	1.7
Exports	1.2	2.3
Unemployment Rate	-2.8	-8.0
WAGES	0.7	1.7

The statistical changes can be explained by changes in the economy. The last ten years have been very volatile for Irish macroeconomic variables given the initial boom and subsequent bust. Despite the economic problems during the eighties, most economic variables were less volatile relative to the last decade. This explains the change in the volatility of the unemployment rate. The change in the covariance between Irish unemployment and the US growth rate is due to the increasingly important role played by the US in Ireland. At the beginning of the sample, US foreign direct investment in Ireland was still relatively small. This situation changed dramatically over the following thirty years and in this way the change in the elasticity reflects changes in the structure of the economy.

A.2 Number of Lags in the VAR

We examine the impulse response functions of the key macroeconomic variables in the VAR model using different lag lengths $p; p = 1, p = 2, p = 3$. The choice of lag length does not have a major impact on the benchmark results from section 3. The impulse response functions generally have broadly the same shape and peak effects around the same dates.

A.3 Ordering of the Domestic Variables in the VAR

A standard Choleski decomposition is used in the VAR, which imposes a certain ordering on the variables. The ordering of the domestic variables in the VAR system was changed to test the sensitivity of the responses. The shape of the impulse response functions are very similar for all variables regardless of the ordering system used for the domestic variables. The ordering of US GDP before the other variables in the VAR implies that US GDP affects all of the other variables in the system but is not itself affected by innovations in the other variables in the initial period. The imposition of this strict open economy assumption that domestic shocks (in Ireland) have no effect on the world economy (here proxied by the US) is an approach which has been adopted in other studies where VAR models are estimated for SOEs, for example Linde (2003) for Sweden. We also estimate a version of the model in which we make US GDP growth exogenous so that changes in the Irish economy are not allowed to impact on US GDP. This change has no impact on the results. This is not surprising as the priors implemented in the VAR partially implement this restriction in the sense that they downplay the importance of cross lags and increase the importance of own lags.

A.4 Order of Differencing

We test the sensitivity of the model to changes in the order of differencing. The benchmark model is estimated taking fourth differences of the variables to account for seasonality effects in the underlying quarterly data. We estimate the model using first differencing and compare the results to those obtained using the benchmark specification. Overall, the impulse response functions to the shock to US GDP are robust with respect to the degree of differencing used. The Irish GDP elasticity falls slightly and there are marginal changes to the magnitude of some of the elasticities, however the overall pattern of results is similar to those produced using the benchmark model and the impulse response functions have broadly the same shape.

A.5 Standard VAR Estimation

One final sensitivity check carried out is to estimate the VAR model using standard VAR techniques in place of the Bayesian approach. As part of this exercise, we also calculate the matrix of bivariate causality statistics to ensure that the choice of variables included in the model is not unduly influenced by the estimation technique. Although the table is not reported[6], we find that there is very little difference in the results of the causality tests. The choice of variables is not influenced by the use of Bayesian methods. The impulse responses from the standard approach are qualitatively very similar to the Bayesian approach but the measured elasticities are notably stronger. For example, the Irish GDP elasticity increases to 2.3 from 1.3 and there are similar magnitude increases in the elasticities of the other responses. A more detailed inspection of the results from the standard VAR finds that the US response to its own shock is driving this increase in the elasticities.

Figure 4 plots the response of the US GDP to its own shock using both estimation techniques. The responses are very similar on a qualitative basis. The US GDP response in the BVAR model slowly falls towards zero after the initial shock but remains above zero. In the standard VAR, GDP also falls after the initial shock but the fall is a bit quicker and after 2 years the responses remains at a low and negative level. When the responses are cumulated, this persistent negative component at the end of the response significantly lowers the total positive US GDP response in the standard VAR. As this cumulated response is the denominator for all the elasticities, the corresponding elasticities are higher as a result. If we take the cumulated Irish GDP response in the standard VAR, it is only 11% different from the BVAR response. Thus, there is very little difference in the numerator of the elasticity. Similarly, with a lot of other variables, the difference in the cumulated response is not

[6] It is available upon request from the authors.

that large so the numerator is not changing significantly but the denominator effect pushes up the elasticity. We argue that the BVAR response of US GDP is the more plausible.

Following an initial positive shock, one would expect US GDP to slowly return to zero, which is what we see in the BVAR model. The BVAR coefficients on US GDP suggest that it mainly responds to its only lags but there is also some sensitivity to interest rates and oil prices. Irish variables, as expected, exert no influence on US GDP in the BVAR. In the standard VAR, there is an overshooting response so that US GDP falls below zero after eight quarters. Inspection of the standard OLS coefficient estimates finds that US GDP has a slight negative response to changes in Irish GDP. The positive Irish GDP response leads to a negative feedback in the system. We do not believe that Irish variables could exert an influence of this magnitude on US GDP. In addition, the BVAR finds that this response is insignificant and pushes the coefficients back towards zero. We consider this BVAR response and the associated elasticities to be more credible.

B Appendix: Delinquency Model

This Appendix contains the detailed estimation results from the satellite delinquency model discussed in Section 7. The model is used to illustrate the impact of the external demand shock carried out in the macro VAR model on loan delinquency in the Irish market. The estimated coefficients from the delinquency model are shown in Table 1 with the estimated standard errors in brackets.

Table 1: Delinquency Model Regression Results

Dependent Variable: A90	
	(1)
Constant	1.10
	(1.18)
e	0.21
	(0.13)
ur_t	1.02
	(0.11)
ur_{t-1}	0.73
	(0.07)
lti	0.36
	(0.18)
Sample	2008:6-2010:12
$\bar{R}^2$	0.94

Notes: Standard errors in brackets.

C Figures

Figure 1: Exports and Imports, Selected Countries, % of GDP

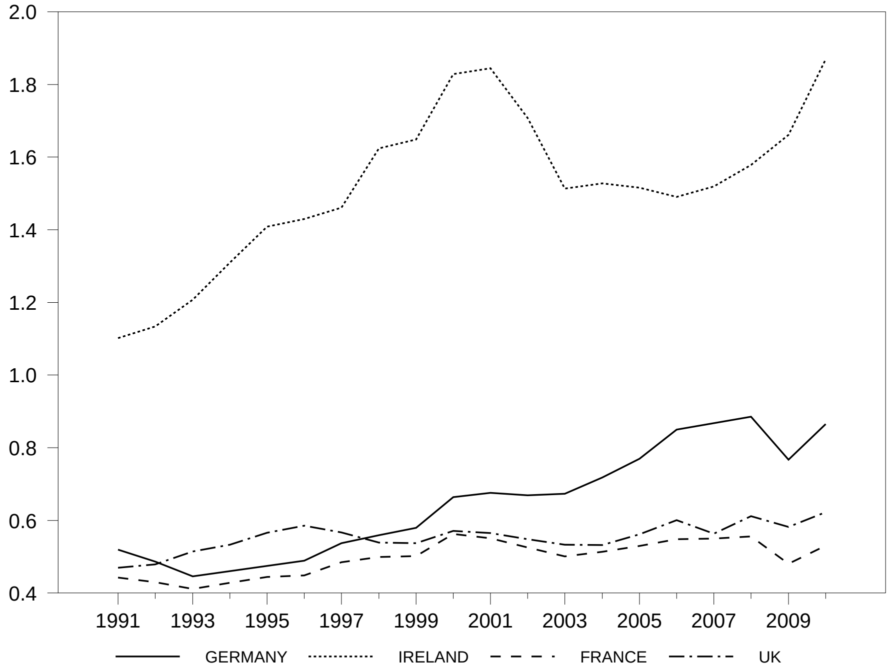


Figure 2: Contribution to Growth, Domestic and External Sector, %

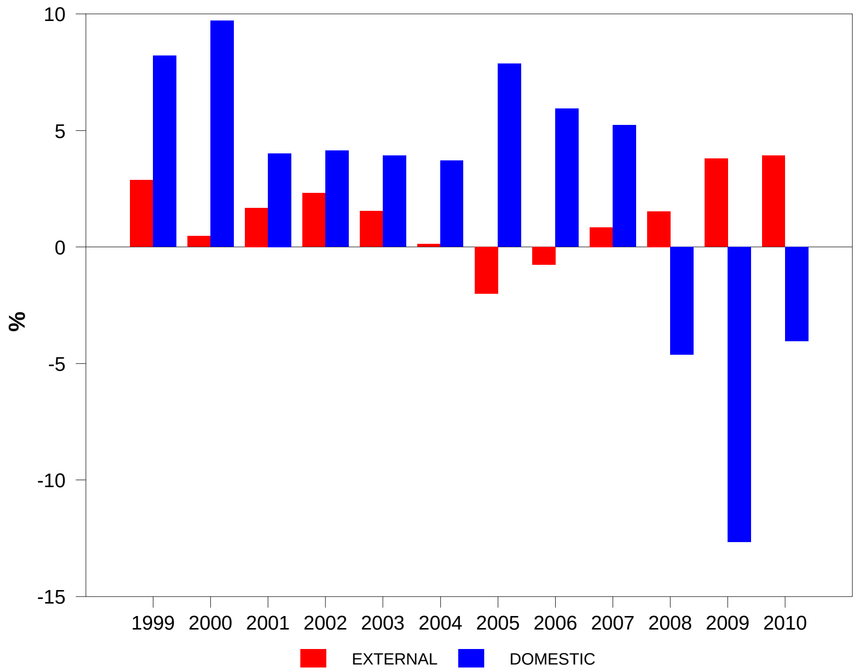


Figure 3: Variables Included in the VAR

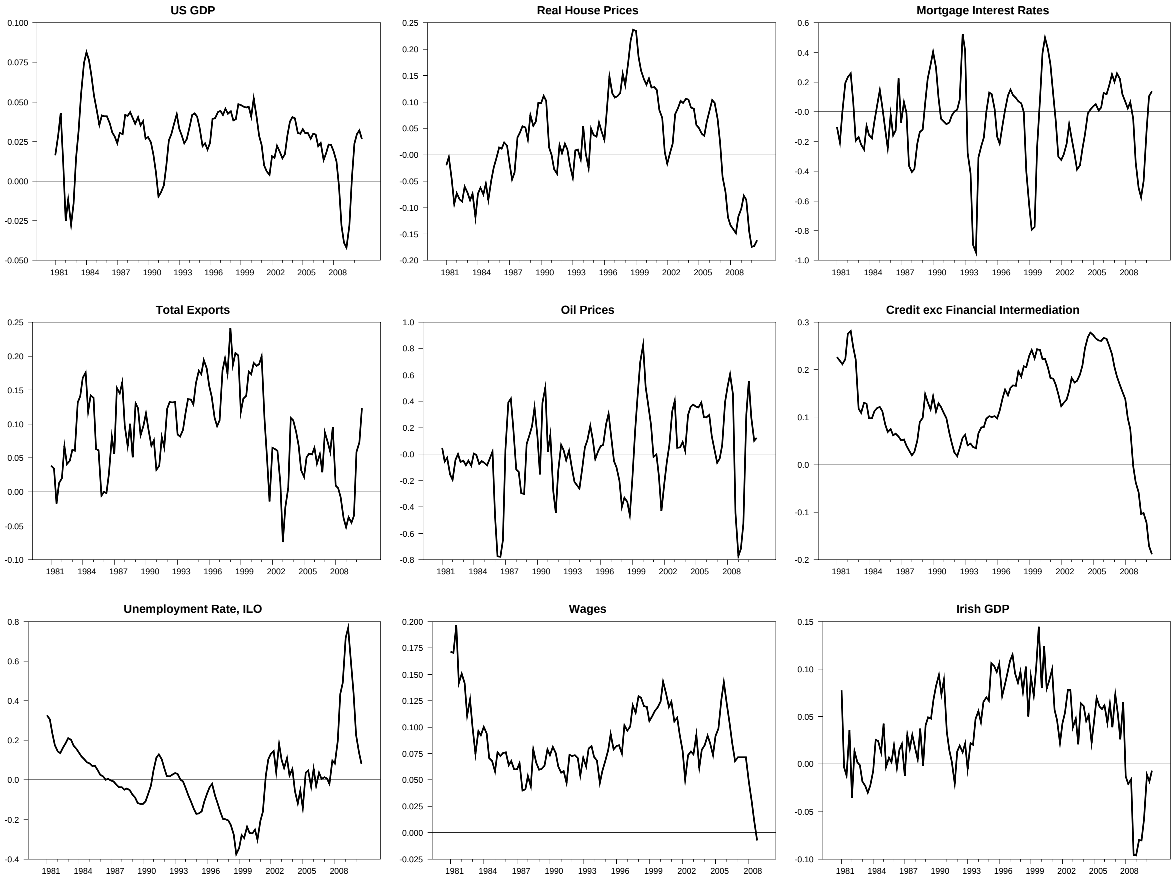


Figure 4: US GDP Responses under Different Estimation Techniques

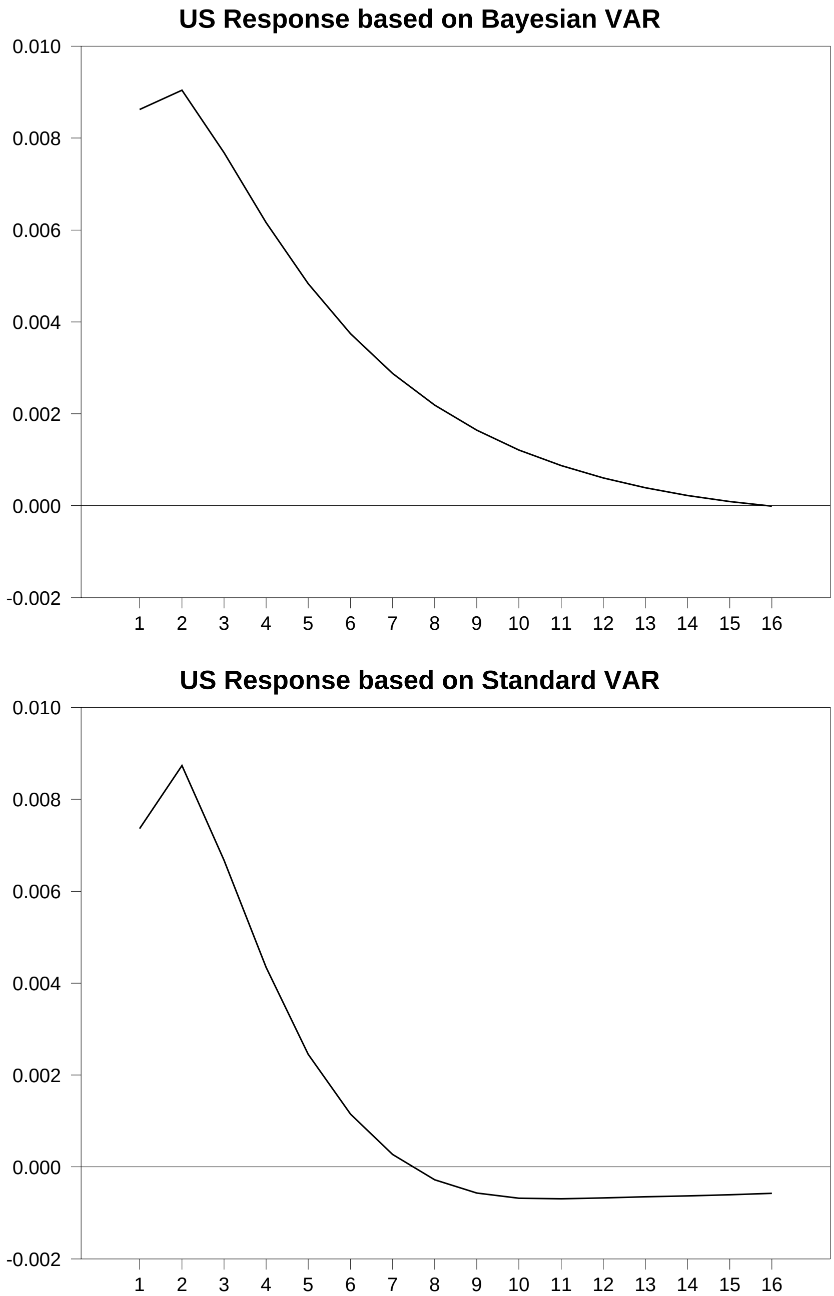
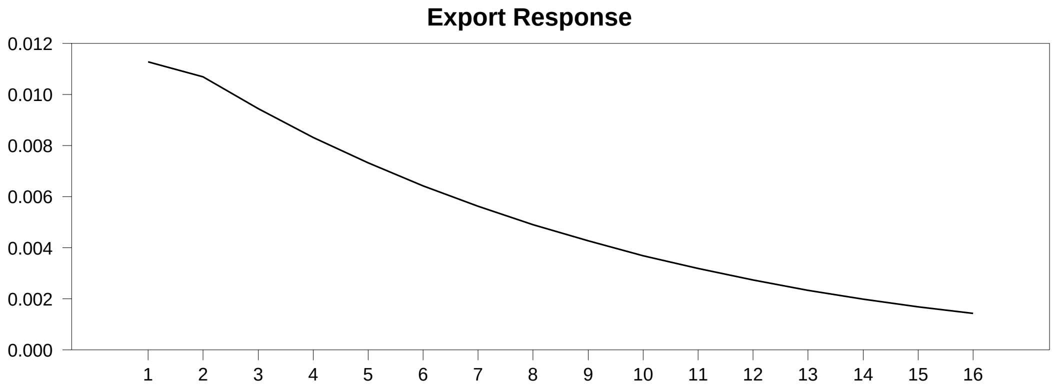


Figure 5: Responses to US Shock in Baseline Model



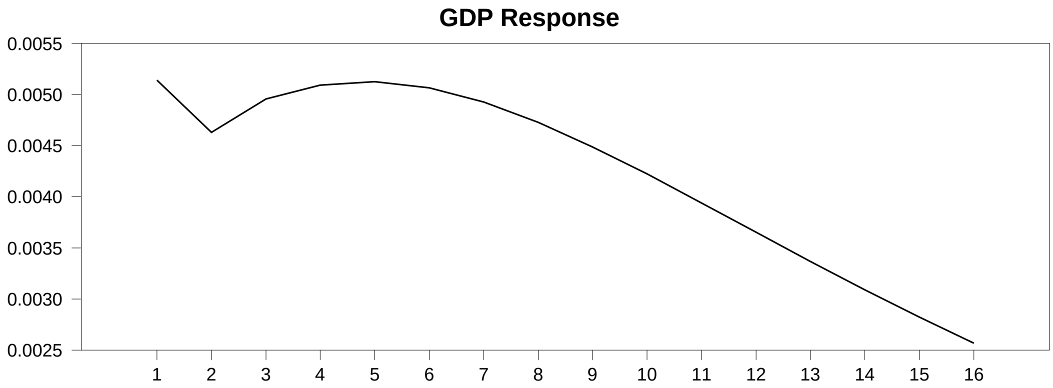
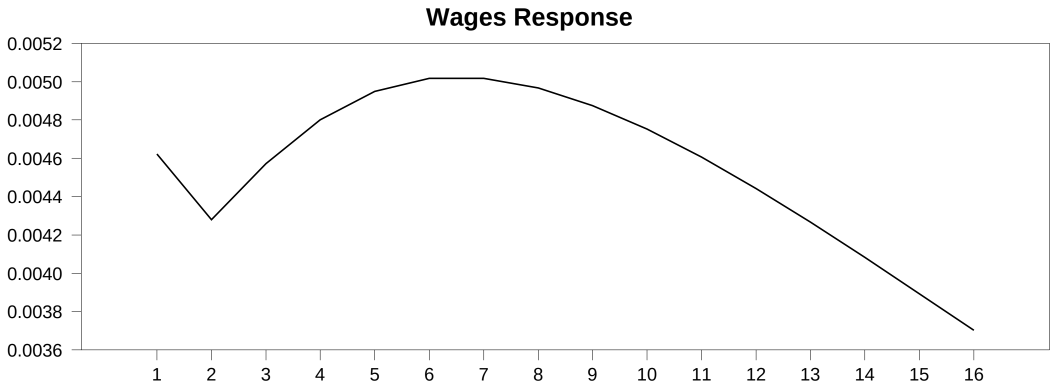


Figure 6: Responses to US Shock in Baseline Model



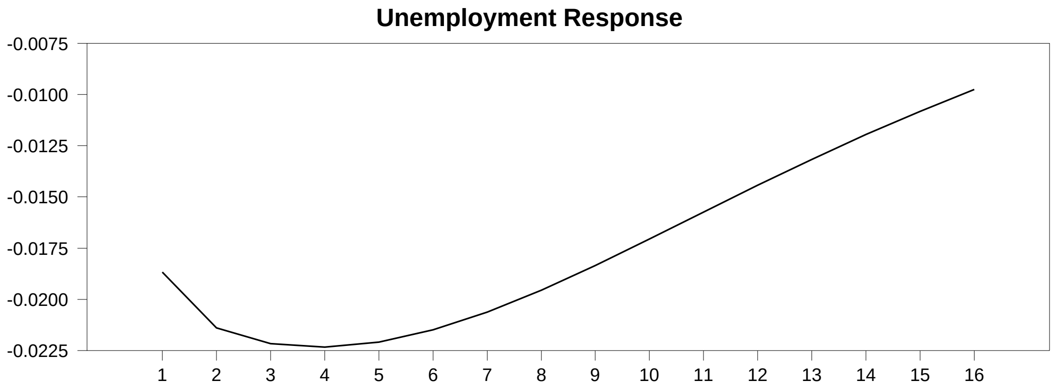


Figure 7: Effect of External Demand Shock on PCAR Assumptions, %

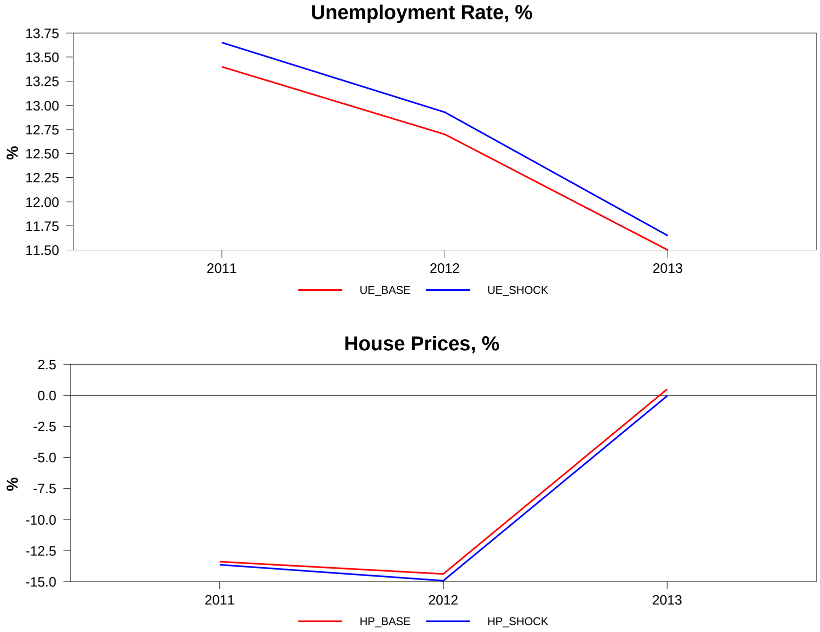


Figure 8: Mortgage Delinquency, % of Total Loans