How do Global Macro-Financial Shocks Affect Corporate Sector Expected Default Frequencies in the Euro Area?[1]

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February 2006

Abstract

Modelling the link between global macro-financial factors and firms' default probabilities constitutes an elementary part of financial sector stress-testing frameworks. Previous studies in this field have been restricted to a limited number of domestic variables. We show how to analyze the euro area corporate sector probability of default under a range of macroeconomic scenarios on a domestic and global level. We use the Global Vector Autoregressive (GVAR) model, which takes into account a large set of linkages across macroeconomic and financial variables. In addition, we construct a satellite model to the GVAR linking the Expected Default Frequency (EDF) of different euro area corporate sectors to a set of macroeconomic and financial variables. In a simulation exercise of the combined models (Satellite-GVAR model), the results show that, at the euro area aggregate level, the EDFs react most to shocks to the exchange rate, oil prices and equity prices. In general, most sectoral EDFs react rather similarly, except for the technology sector EDF, which is relatively more sensitive in our sample period. Overall, the Satellite-GVAR model appears to be a useful tool for analyzing plausible macro-financial shock scenarios designed for stress-testing purposes.

1. Introduction

This paper provides a tool for studying the global macro-financial conditions in relation to credit risk in a framework that can be applied to financial sector stress-testing. Indeed, as the world has become more financially integrated, firms are operating on multinational markets where they are investing and taking on credit available outside of their home countries. Moreover, the balance sheets of large corporations and banks typically contain assets and liabilities from several countries which increases their international exposure. Against that background, our research aims at evaluating the impact of national and international

[1] The views expressed in this paper do not necessarily reflect the views of the European Central Bank or the European System of Central Banks. We are grateful to Ivan Alves, John Fell, Ghazi Shukur, Joakim Westerlund and seminar participants at the ECB for valuable comments. We are also grateful to Vanessa Smith for her feedback on the GVAR code. None of the preceding should be viewed as responsible for any opinion and errors contained within.

macroeconomic and financial shocks such as output shocks, monetary shocks, stock market shocks or oil price shocks on euro area firms' expected probability of default. In addition, analyzing probabilities of default under a range of macroeconomic scenarios over time, our research provides a dynamic framework for stress-testing of these probabilities.

In our study, we use the Global Vector Autoregressive (GVAR) model as presented in Pesaran et al. (2004). By combining national and international variables across many countries, the GVAR model takes into account a large set of international linkages across macroeconomic and financial variables. The GVAR model therefore provides a global modelling of various transmission channels, including trade and financial linkages. The GVAR model is based on country- or region-specific vector error correction models, where domestic and foreign variables interact simultaneously. The version of the GVAR model used in this paper covers 33 countries, where 8 of the 11 countries that originally joined euro on January 1, 1999 are grouped together, and the remaining 25 countries are modeled individually.

Regarding previous work on the links between macroeconomic variables and firms' default probabilities, Alves (2005) incorporates Moody's KMV expected default frequency (EDF) data in a cointegrated VAR model to analyse the sectoral differences in reponses of EDFs to macroeconomic and systemic developments. Aspachs et al. (2006) use a VAR approach to evaluate the impact of bank equity value and bank default probabilities on output in the UK. The authors include banking sector and macroeconomic data on seven industrialised countries. They show that shocks to banks' default probabilities and equity values have an impact on GDP. Jacobson et al. (2005) study the interactions between Swedish firms' balance sheets and the evolution of the Swedish economy. They find that aggregate default frequency of banks is an important link between the financial and the real side of the economy. Moreover, they argue that macroeconomic variables are relevant for explaining the time-varying default frequency in Sweden. Pesaran et al. (2004) use the GVAR for generating conditional loss distributions of a credit portfolio of 119 firms in 10 of regions in the world. They use the GVAR as a linking model and assume that equity return of firms with debt outstanding is a function of the regional and global macroeconomic environment. The link is provided by a regression of firm stock returns on the relevant domestic and international macroeconomic variables in the GVAR model.

Due to the lack of harmonised bankruptcy data for the euro area, we use Moody's KMV expected default frequencies (EDFs) as an alternative and publicly available measure. The EDF measures the probability that a firm defaults within a given time horizon. Hence, the

EDF is a forward looking measure of default. For example, a corporation with an EDF of 1% has a 1% probability of defaulting within the next 12-months. The EDFs are derived using a structural model which relies on the contingent claim approach to assess probability of default (see for example Merton (1974)). By contrast to reduced form models (*e.g.* Jarrow and Turnbull (1995) and Jarrow et al. (1997)), the default process is endogenous and depends on the firm variables.

We link the EDFs of publicly listed euro area companies to a macro-econometric framework as modelled by the GVAR. We study the EDF at a euro area aggregate level as well as at a sector level. While our paper is closely related to the above mentioned research, it differs in some important respects. First, our aim is to quantify the impact of domestic and global macroeconomic shocks on the EDFs of the euro area as a single economic region. Second, unlike some of the previous literature, we combine a structural model (*i.e.* the Merton (1974) approach) with a macro-econometric model. Third, we only measure the effect of economic variables on the firms' default probability. For this purpose, we construct a satellite model to the GVAR linking the EDFs of different sectors to a set of macroeconomic and financial variables. As default rates vary over time and in order to capture this dynamics, we combine the multivariate distribution of risk factor changes with the GVAR model. We refer to the combined models as the Satellite-GVAR (S-GVAR) model. This model translates macroeconomic risk factor changes to default probabilities for different industry sectors as well as analyzes macroeconomic stress-scenarios related to default probabilities. Intuitively, the EDF can be interpreted as estimators that measure how close a firm's assets approach its liabilities in the particular industry sector given the macroeconomic scenario. Therefore, the EDFs measure the conditional expectation of the default intensities in the different industry sectors. The conditioning variables are the macroeconomic risk factor changes that describe a particular macro scenario created by the GVAR model.

The results show the usefulness of the S-GVAR model. We show that at the euro area aggregate level, the EDFs react most to shocks to the euro/US dollar exchange rate, to global oil price shocks and to equity price shocks. In general, most sectoral EDFs react similarly to the euro area aggregate, except for the technology sector EDF, which in our sample period is more sensitive than the other sectors. Bootstrap experiments on the S-GVAR models show that the aggregate EDF (*i.e.* the median firms) is consistent, whereas the model appears slightly weaker for certain individual sectors.

The paper proceeds as follows: Section 2 provides an overview of the GVAR model. Section 3 discusses the Satellite GVAR model. Section 4 presents the characteristics of the data.

Section 5 discusses the GVAR estimation and the impulse response analysis. Section 6 presents the results of the S-GVAR model. Section 7 contains the results of the bootstrap experiment on the S-GVAR. Section 8 concludes.

2 Global Vector Autoregressive (GVAR) Model

In an increasingly integrated global financial system, empirical modelling of the macro-financial environment has become a complex task. To this end, Vector Autoregressive (VAR) models provide a multivariate approach that allow for interdependency between selected variables. VAR modelling is one of the principal tools that have been used for forecasting and policy analysis, such as assessing consistency with impulse response functions and judging the empirical adequacy of various theories. As an extension to the traditional VAR analysis, Global VAR (GVAR) models take into account of a large set of linkages across macroeconomic and financial variables. The GVAR modelling presents a comprehensive, yet tractable approach to apply a spatio-temporal structure to the analysis of the world economy. By providing a framework capable of accounting for both trade and financial transmission channels, the GVAR model is particularly suitable to analyse the transmission of real and financial shocks across countries and regions.

The GVAR model assumes that there exist *N+1* countries, indexed i=0,1,…,N, where 0 is the numeraire (or the benchmark country).[2] Region-specific variables are functions of both their own past values and the global economy's past and current state. The GVAR model assumes that regional variables are related to a deterministic trend and/or intercept, as well as exogenous variables that are common to all countries and regions, *e.g.* oil prices.

The standard GVAR model has the following representation:

$$x_{it} = a_{i0} + a_{i1}t + \Phi_i x_{i,t-1} + \Lambda_{i0} x^*_{i,t} + \Lambda_{i1} x^*_{i,t-1} + \Psi_{i0} d_t + \Psi_{i1} d_{t-1} + \varepsilon_{it}, \qquad (1)$$

for $t=1,2,\ldots,T$ and $i=0,1,2,\ldots, N$,

where,

- x_{it} is $k_i \times T$ country-specific variables.
- a_{i1} is a $k_i \times 1$ vector of linear trend coefficients.
- Φ_i is a $k_i \times k_i$ matrix of associated lagged coefficients.

[2] In Pesaran et al. (2004), the US economy is used as a numeraire.

- x^*_{it} is a $k^*_i \times T$ matrix of foreign variables specific to country i with Λ_{i0} and Λ_{i1} denoting $k_i \times k^*_i$ matrices of fixed coefficients.
- d is an $s \times T$ matrix of common global variables, which are exogenous to the global economy with Ψ_{i0} and Ψ_{i1} as $k_i \times s$ matrices of fixed coefficients.
- ε_{it} is a $k_i \times T$ matrix of country-specific shocks which are serially uncorrelated with zero mean and a non-singular covariance matrix, $\Sigma_{ii} = \sigma_{ii,ls}$, where $\sigma_{ii,ls} = \text{cov}(\varepsilon_{ilt,}\varepsilon_{ilt})$.[3]

An important characteristic of the GVAR model is that it allows for cross regional correlation, which is given as $E(\varepsilon_{it}\varepsilon'_{jt'}) = \Sigma_{ij}$ for $t = t'$.

Note that in the special case where $\Lambda_{i0} = \Lambda_{i1} = 0$, the model reduces to a standard VAR(1) model. Otherwise, (1) is an augmented VAR model, which is called a VARX*(2,2) model.

The interaction between the various channels in the model can be described by three main points:

1. x_{it}, x^*_{it} and their lags depend directly on each other.
2. Region-specific variables depend on global exogenous variables (*e.g.* oil prices).
3. Contemporaneous shocks between region i and j are represented by the cross-country covariance (Σ_{ij}).

The GVAR treats x^*_{it} as a weighted average of x_{it}. For example, foreign and domestic log output is denoted by y^*_{it} and y_{it}, respectively. Specifically, y^*_{it} can be considered the log output of the global economy from the perspective of region i. Given a sequence of region-specific weights, w_{ij}, the region-specific weighted average is given as

$$y^*_{it} = \sum_{j=0}^{N} w_{ij} y_{it} \text{ with } \sum_{j=0}^{N} w_{ij} = 1 \text{ and } w_{ii} = 0 .$$

The weights can be constructed by using the trade structure of region i. Therefore, w_{ij} stands for the trade share of region j in the total trade volume of region i.

In the GVAR, each country has its own (error correction) VAR model allowing for unit roots and cointegration, where region-specific foreign variables are weakly exogenous except for the numeraire country. The numeraire country is treated as a closed economy. In Pesaran et al. (2004), the US, which is the numeraire country, is linked to the rest of the world through

[3] Alternatively, $\varepsilon_{it} \sim i.i.d.(0, \Sigma_{ii})$, where *i.i.d.* stands for independent identical distributed process.

exchange rate channels.[4] The general model (1) then becomes a simultaneous system which creates a global system due to the weighted-average trade links.[5]

3 Satellite GVAR (S-GVAR) model

In order to link the GVAR model with the financial sector, we build up a framework which quantifies the impact of domestic and global macroeconomic shocks on corporate sector probability of default. Such a system ignores, by construction, the feedback effects from the expected defaults rates to the macroeconomic variables. Therefore, it is modelled by constructing a satellite model to the GVAR, which links corporate variables to a set of macroeconomic variables that are included in the GVAR.

The simplest form of the Satellite model (written in levels and without lags) is given by

$$z_{jt} = b_{j0} + b_{j1}x_t + \varepsilon_t \text{, for } j=1,...k \text{ ,} \qquad (2)$$

where

- j the index for sectors
- x_t is $k \times T$ matrix of explanatory variables that are endogenous to the GVAR.
- z_{jt} is $1 \times T$ vector of the dependent variable for sector j.
- b_{j0} is the intercept for sector-j equation.
- b_{j1} is $1 \times k$ parameter vector.
- ε is $1 \times T$ vector of residuals.

The combination of (1) and (2) (*i.e.* the combination of the Satellite model with the GVAR) is referred as the Satellite-GVAR (S-GVAR). The endogenous variables of the GVAR are exogenous to the Satellite model, which in turn has no feedback on the GVAR. The S-GVAR can be used for forecasting or generalized impulse response analysis in the usual manner.

The S-GVAR model can take different representations, such as cointegration and short-term dynamics. Possible GVAR variables included in the Satellite model (x_t) could be interest rates, output, stock returns, exchange rate, inflation, and oil prices. From a risk management perspective, z can include variables such as probability of default or loan portfolios of banks and corporations.

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[4] For further details on GVAR, see Pesaran et al. (2004) and Dées et al. (2007). Related literature to the GVAR is the dynamic factor model by Stock and Watson (2002).
[5] This will be discussed in more detail in the next section.

4 The data, trade weights and unit root tests

This section discusses the characteristics of the data, the construction of the country-specific foreign variables and unit root tests.

4.1 The data and transformations

The data set for the GVAR model consists of 33 countries from different regions in the world.[6] The data include 8 of the 11 euro area countries that joined the single currency in 1999. These 8 counties are grouped together in order to represent one region. The sample period extends from 1970 to 2005 on quarterly basis. Dées et al. (2007) include a detailed description of the individual data series.

The expected default frequencies (EDF) are from the euro area corporations and originate from the Moody's KMV database. We study the median EDFs on both aggregate and sectoral levels on quarterly basis for the period 1992-2005. The median EDF at each point in time represents the median EDF among a panel of available corporations in the euro area or in a sector. The following sectors are analyzed: aggregate (AGG), basic and constructions (BAC), energy and utilities (ENU), capital goods (Cap), consumer cyclical (CCY), technology (TMT), consumer non-cyclical (CNC), and financial (FIN) sector.[7] The EDF series are logit transformed by Ln(EDF/(1-EDF)). This transformation maps the probabilities, which are bounded by 0 and 1, to the real line. The logit transformation will be important at a later stage as it prevents the S-GVAR model from generating negative probabilities.

4.2 Trade weights – Star variables

The country-specific foreign variables (*i.e.* the star variables) are constructed by using annual trade flows (1980-2005) between the countries/regions. Bilateral trade is a crucial factor for international business cycle movements (see Baxter and Kouparitsas (2004), Imbs (2004), and Forbes and Chinn (2004)). Similar to Dées et al. (2007), we use fixed trade-weights based on average trade flows over three years (1999-2001). Dées et al. (2007) take into account time-varying trade weights and show that the time-varying weights have a small impact on the results of the GVAR. In addition, we use regional responses (*e.g.* Western Europe, Asia, Latin

[6] See Appendix A for details.
[7] See Alves (2005) for a detailed discussion on the definitions of sectors used in this paper.

America, and other regions). In line with Dées et al. (2007), we use aggregate impulse response functions that are based on Purchase Power Parity GDPs.[8]

4.3 Unit root test

Following Dées et al. (2007) and Pesaran (2004) we test for unit roots in the country-specific variables. In the case where the variables are integrated of order one (*i.e.* I(1)), we can test for the identification of short- and long-run (*i.e.* cointegrating) relations.[9] In addition, we test for unit root for the euro area aggregate and sectoral EDF data. We also test for unit root of the macroeconomic risk factors for the period 1992-2005. We use the Augmented Dickey-Fuller (ADF), and KPSS tests.[10] The results are presented in Table A.1, Appendix A. We draw the conclusion that all the EDFs, the macroeconomic and financial factors (*i.e.* the fitted values of the GVAR) are integrated of order one. Only in two cases the unit root tests give different results. First, ADF test suggests a unit root at 5% level, and the KPSS test at 10% significance level, for the EnU sector EDF. Second, ADF indicates a unit root at 1% significance level, and KPSS at 5% significance level, for the short-term interest rate.

5 Estimation of the GVAR and Impulse response analysis

We re-estimate the GVAR model developed in Dees et al. (2007) by extending the dataset from 2003Q4 to 2005Q4. The estimations of the GVAR and the results are discussed briefly in this section. The GVAR allows for studying to what extent a shock in one country affects other countries. Except for the euro area, the countries in the panel are considered at an individual basis and we thus differentiate between 26 regions/countries, *i.e.* the euro area and all other individual countries. The following variables are included in the study: real Gross Domestic Product (GDP), real stock market price index, consumer price index, short-term interest rate, long-term interest rate, oil price per barrel and the exchange rate of the currency relative to the US dollar.

Impulse response analysis is conducted on the variables of the GVAR by using the Generalised Impulse Response (GIR) approach. The GIR was primarily developed by Koop, Pesaran and Potter (1996) for non-linear models, and was further extended to vector error correcting models by Pesaran and Shin (1998). This is an alternative method to the

[8] This is an alternative to the weights based on US dollar GDPs. The PPP GDPs are considered as providing more reliable comparisons.
[9] See Dées et al. (2007) for the unit root tests on the data panel used in the GVAR.
[10] The null hypothesis of the ADF test is unit root, and the alternative is no unit root; the hypotheses are reversed in the KPSS test as it puts less power on the unit root side compared to the ADF test.

Orthogonalized Impulse Responses (OIR) of Sims (1980). The GIR approach considers shocks to individual errors and integrates out the effects of the other shocks using the observed distribution of all the shocks without any orthogonalization. Thus, the GIR is invariant to the ordering of the variables and countries in the GVAR model.[11] The GIR does not explore the reasons for a shock, but it shows the dynamics of its transmission. Dées et al. (2007) provide bootstrap estimates of the GIRs as well as structural stability tests of the GVAR model.

We study one standard deviation shocks of the GVAR. The shocks originate from the euro area, US, China, Japan, UK and the global environment. We provide a brief discussion of the impulse responses in the next section.

5.1 Discussion of the impulse responses

US equity price shock

The transmission of the shock to the equity markets is quick and has significant effects. A one standard error shock to equity prices has an initial effect of 5.6% and 4% on the US and the euro area, respectively. This is comparable to Dées et al. (2007) who find that the effect is close to 4.1% for the US and the euro area. In addition, a negative US equity price shock affects the euro area real output negatively, but to a smaller extent than in the US. Inflation tends to decrease moderately. Moreover, the impact of the US stock market shock on the short-term interest rate is stronger in the US than in the euro area. The real exchange rate appreciates in the euro area throughout the horizon. Effects are similar on other countries, except that interest rates tend to vary more widely.

US short-term interest rate shock

One standard error positive shock to US short-term interest rates amounts to a 0.2% increase in short-term rate. The effects on real output and inflation are ambiguous as initially both increase, a phenomenon known as the price puzzle. However, the impact becomes insignificant after 1-2 quarters. The effects are very small and statistically insignificant in the euro area.

Regarding the effect of a US short-term interest rate shock on long-term interest rates, it is positive at all horizons for the US and in the initial periods for the euro area. A shock to the US short-term rate has no significant effects on the euro area short-term interest rates. It

[11] The reason for applying the GIR rather than the OIG is based on the fact that there is no clear theory about how to order the countries in the GVAR model.

reflects the weak interdependence of short-term interest rates between the two regions, by contrast with a strong inter-dependence in the case of long-term interest rates. Finally, a positive shock to the US short term interest rate has a negative effect on the real equity prices, the oil prices, and the real exchange rates.

Global shocks

A global shock assumes that a shock does not originate from any specific country. Global shocks can arise from oil price, stock markets, or a major slowdown in the world economic growth. Global Shocks are weighted averages of variable-specific shocks for all the countries in the GVAR model.

A one standard error positive shock to oil prices results in a 12-19% increase per quarter in the oil price. The oil price shock has a statistically insignificant negative effect on real output in the first quarters in the euro area and in the US. The effect on inflation is statistically significant and positive in the US and the euro area, which is consistent with earlier findings in the literature (see Dées et al. (2007)). Furthermore, an increase in oil prices leads to an increase in long-term interest rate in the euro area and the US. Thus, bond markets tend to react more to inflation than growth effect of oil price hikes. By contrast to other cases where the effects on the US and the euro area are similar, an increase in oil prices has a negative impact on the equity prices in the US, while the euro area stock prices does not react to such shocks.

For the global equity price shock, results are similar to those of a shock to the US equity prices. It confirms the predominant role of the US stock market in the equity prices across the countries used in the model. We can draw a similar conclusion regarding a global output shock, except that the US and the euro area are relatively less affected. The effects of global output shocks on real exchange rate are the following: the euro real exchange rate against the dollar tends to depreciate, while it appreciates in case of a US GDP shock. This is in line with the findings of Dées et al. (2007).

6 Estimation of the Satellite-GVAR (S-GVAR) model

6.1 Specification of the Satellite model for EDFs

While the GVAR has been estimated over the period 1970-2005, the Satellite model for EDFs can be estimated only over the period 1992-2005 for data availability reasons.[12] Given the relatively restricted number of observation, we specify the Satellite model for EDFs in level as cointegration relationships. Similarly, we restrict the number of macroeconomic variables to those belonging to the euro area model. Links with international variables will therefore be made using the GVAR through the impacts of foreign variables on the euro area variables.

To test cointegration relations between the EDFs and the variables included in the GVAR we apply the Engle and Granger (1987) method, which tests a unit root in the residuals of the Satellite model. Augmented Dickey-Fuller (ADF) test is applied by using Davidson and MacKinnon (1993) test statistic for cointegration. However, since the Engle and Granger method suffers from several problems, such as low power in finite samples and the absence of performing inference regarding the actual cointegrating relationship, we also invoke the Johansen (1995) trace test as well as the Saikkonen and Lütkepohl (2000) test where the small sample problem disappears asymptotically. Both tests assume that all the variables in the model are endogenous, although they might equally include exogenous variables. As a result, one may obtain more than a single cointegrating relationship. The Saikkonen and Lütkepohl test also allows for taking into account level shifts in the time series, which could be useful given the level shifts observed in the EDF series at the end of the 1990s.

Selected results of the cointegration tests are available in Table 3, Appendix A. The critical values for the ADF statistics are higher than the usual statistics since they use the residual in the ADF regression for correction (see Davidson and MacKinnon (1993)). The Engle and Granger test shows that the EDF of the financial sector (Fin) and the technology (TMT) sectors are cointegrated with the observed factors at 5% level. Furthermore, the test shows cointegration at 10% significance level for the euro area aggregate (Aggr) sector, energy and utilities (ENU) sector and consumer cyclical (CCY) sector. By contrast, the EDFs for the basic and constructions (BAC), capital goods (Cap), and consumer non-cyclical (CNC) sectors do not show any signs of cointegration. By contrast, the Johansen test and the

[12] The EDFs are available on monthly basis in the database. We did the estimations of GVAR on monthly basis in order to increase the information set in the satellite model. The relations between the variables in the GVAR get distorted by increasing the frequency domain as the volatility of the series increases. In other words, the expected sign of the parameters as well as the impulse response functions do not comply with the economic theory.

Saikkonen and Lütkepohl test both confirm a full cointegration rank (*i.e.* r=5) between all the sectoral EDFs and the macroeconomic factors at 5% significance level. The tests include constants as the only deterministic component. However, it should be recalled that the cointegration test has been applied with a deterministic trend as some of the macroeconomic variables exhibit a trending behaviour (*e.g.* GDP and CPI). Nevertheless, and although the results from the different tests differ slightly, the overall conclusion remains that full cointegration relations can be identified between the EDFs and the GVAR variables.[13] Therefore, we have decided to model the SGVAR by using the common stochastic trend between the variables.

6.2 Estimation of the Satellite model

The Satellite model has the following functional form:

$$LN\left(\frac{EDF_t}{1-EDF_t}\right) = \alpha + \beta_1 F_{GDP,t} + \beta_2 F_{CPI,t} + \beta_3 F_{EQ,t} + \beta_4 F_{EP,t} + \beta_5 F_{IR,t} + \varepsilon_t\,, \tag{3}$$

where the left-hand side denotes for the logit transformed EDF, α and β denote the parameters and $F_{GDP,t}$, $F_{CPI,t}$, $F_{EQ,t}$, $F_{EP,t}$, and $F_{IR,t}$ stands for the logarithm of euro area real GDP, CPI inflation, real equity prices, real euro/US dollar exchange rate and short-term interest rate at time t, respectively. All variables belong to the euro area model of the GVAR. The factors are given in logarithms. While the GVAR model of the euro area is represented by six macroeconomic and financial time series together with oil prices as a common variable to all economies, we prefer to restrict the number of variables to five to avoid estimating too many parameters. However, we have also estimated the Satellite model with the seven variables and compared it to a five variable model where oil prices and long-term interest rates are excluded. As the goodness-of fit of the model and the cointegration property do not change, we prefer remaining parsimonious in the selection of explanatory variables. Moreover, although some key variables are excluded from the Satellite model, the effect of such variables is still represented through the link with the GVAR (as seen below with impulse response analysis). For example, while an oil price shock does not affect directly the euro area EDFs, its impact is indirectly transmitted through the reactions of interest rates, GDP and consumer price inflation.[14]

Table 1 presents the estimated Satellite model for sector-specific EDFs. The results show that most of the parameters are significant, except in few cases. For example, the parameters for

[13] The results are available upon request.
[14] The results of the six and seven factor model are available upon request.

short-term interest rates are insignificant at 5% level (a two-sided test) for energy, financial and technology sector EDFs.

Table 1. The Satellite model estimation (1992:Q1-2005:Q4)

$$LN\left(\frac{EDF_t}{1-EDF_t}\right)=\alpha+\beta_1 F_{GDP,t}+\beta_2 F_{CPI,t}+\beta_3 F_{EQ,t}+\beta_4 F_{EP,t}+\beta_5 F_{IR,t}+\varepsilon_t$$

	A	β_1	β_2	β_3	β_4	β_5
Aggr	327.052	15.310	-63.771	-2.519	5.952	23.597
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.015)
BaC	347.438	10.636	-58.334	-2.051	5.145	31.074
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.011)
Cap	344.709	13.709	-62.970	-2.309	4.832	28.811
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.011)
CCy	316.883	13.163	-54.577	-2.130	5.284	30.201
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)
CNC	437.793	11.822	-84.324	-1.775	5.051	26.527
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.047)
EnU	213.011	12.366	-41.542	-1.897	7.237	14.641
	(0.027)	(0.000)	(0.006)	(0.000)	(0.000)	(0.275)
Fin	102.972	4.473	-21.115	-1.073	3.812	4.350
	(0.136)	(0.000)	(0.051)	(0.000)	(0.000)	(0.655)
TMT	345.925	29.299	-81.429	-4.557	9.044	19.755
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.080)

Note: EQ stands for equity, EP for euro/US dollar real exchange rate, and IR for short term interest rate. The parameters are expressed in logit terms.

The parameter signs are similar across the sectoral EDFs. Specifically, the estimation shows that a marginal increase in the equity prices has a negative effect on all the EDFs (*i.e.* reduces the probability of default). By contrast, a marginal increase in the GDP has a positive effect on the EDF, which results from the co-variation between the EDFs and the GDP. There are several explanations for this. One explanation might be that the assets or the liabilities of the median firms change in a less proportional manner during the business cycle. Thus, the more the liabilities (short- and long-term debts) of the firm increase, the higher is the EDF at that time. Given that liabilities tend to be pro-cyclical (*i.e.* higher leverage during a boom), this effect could well be driving the EDFs over the business cycle.[15]

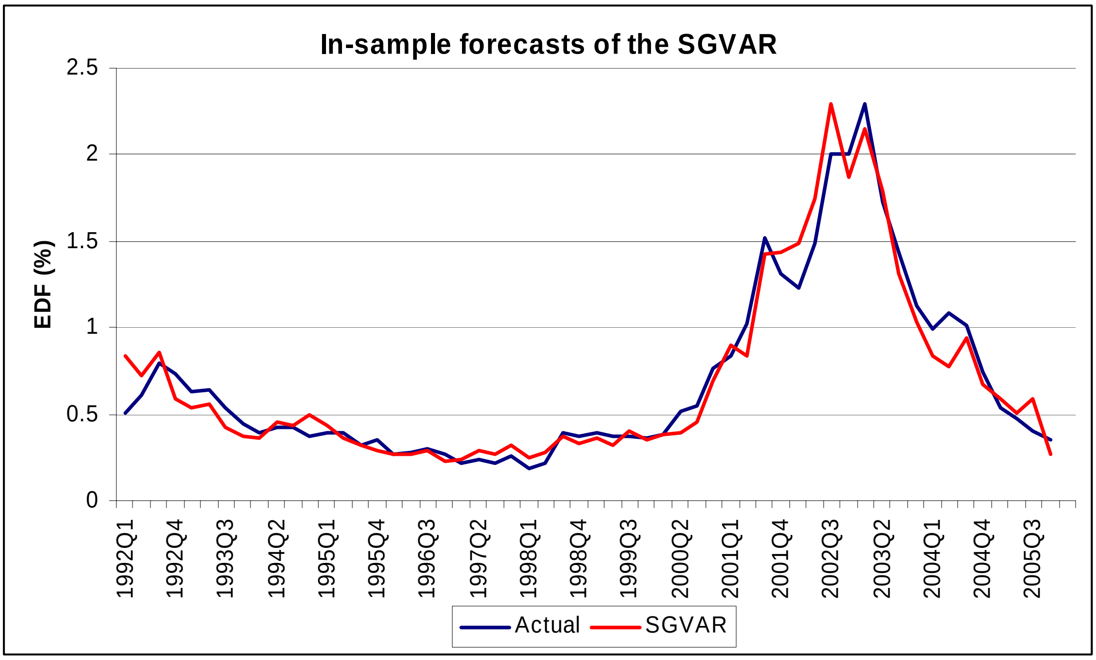
In order to verify the estimation results, we applied the CUSUM test for parameter stability, the White test for residual autocorrelation, and the Breuch-Pagan test for heteroskedasticity.

[15] It should also be recalled that our analysis does not include EDFs for the household sector that constitutes a far larger share of the euro area GDP than the corporate sector.

The CUSUM test implies parameter stability since the recursive parameters fall within the 95% confidence interval. The specification tests indicate a weak presence of autocorrelation and heteroskedasticity at lags 2-3. This later finding is not problematic, however, since the Satellite model is a contemporaneous model and includes no lags in the modelling framework. In addition, due to the cointegration relation, the parameters are consistent, supporting such a specification (See Engle and Granger (1987) and Stock (1987)).

Once estimated, the Satellite model is integrated into the GVAR model to form the S-GVAR model. Figure 1 illustrates the fitted S-GVAR model for the aggregate euro area EDF.

Figure 1. In-sample forecast of the S-GVAR for aggregate EDF



Notes: The EDFs are in levels. Actual stands for the historical EDF series, while S-GVAR is the in-sample forecast or the fitted value.

6.3 EDF reaction to shocks: Impulse response analysis using the S-GVAR

This section studies the EDF reaction over 10-years horizon to a one standard error shock of different macroeconomic and financial variables. All the impulse responses are presented in Figures B.1-B.17, Appendix B. The figures provide a measurement of the reactions compared to the baseline (*i.e.* the EDF before the shock happened). We discuss the aggregate (Aggr) case of the EDF and then the sector EDF.

Aggregate EDFs

The aggregate (Aggr) case of the EDF represents a benchmark of the median firm of all the available euro area EDFs.

A negative global shock to the GDP has a higher impact on the aggregate EDF compared to a euro area and a US GDP shock. Initially, the EDF reacts positively to a slowdown in economic growth. The EDF reactions are temporary and disappear within 3 quarters. The highest effect of a negative one standard error shock to global GDP is 4.5%. Similarly, the aggregate EDF reacts temporary to a positive shock to inflation. Indeed, the EDF is more sensitive for an increase in the euro area inflation shock relative to US and global positive shocks. The EDF changes by 7.75%, 4% and 5% in the first quarter after a euro area, US and a global inflation shock, respectively. Moreover, a negative shock to equity price has a permanent and positive effect on the median firm.

The permanent effect of a one standard error shock to the equity prices is 16% for the euro area and around 12% for most countries, including the US. A one standard error shock to short-term interest rate has an effect on the aggregate EDF in the first two quarters. In particular, the negative EDF reaction is about -5% for the euro area and -2% for the US short interest rate shock. However, in the long-run the negative interest rate shock is permanent and positive. As a result, the permanent effect is nearly 14% for a euro area shock, whereas it is 2.4% for a US shock. By comparison, the long-term interest rate has almost half of the effect relative to the short-term interest rate shock.

A negative one standard error shock to the euro/US dollar real exchange rate (*i.e.* an appreciation) has negative and permanent effect on the median firm's EDF. The highest EDF reaction is a drop of 25.50%. In similar scenarios with appreciation of other exchange rates in term of US dollars, we find a negative reaction of the EDF. It appears that a shock to the pound sterling affects the euro area EDF almost by the double amount compared to the yen. This can be explained by the fact that the UK is one of the most important trading partners of the euro area. An appreciation of the renminbi has a small and almost insignificant effect on the EDF.

Finally, a positive one standard error shock to oil prices has the most significant impact on the aggregate EDF. Consequently, The EDF reaction is permanent and positive, increasing by 24% during 37 quarters.

Sectoral EDFs

In general, most sectoral EDFs react similarly to the benchmark, except for the technology sector EDF, which is more affected than the other EDFs. Among the euro area variables, the technology sector reacts significantly to shocks to the exchange rate, stock markets and short term interest rates. This is presented in Figures B.2-B.4. Figure B.3 shows that an appreciation of the euro against the US dollar reduces the TMT and EnU EDFs about 25% to 34% during quarters 1 and 3. As a result of these shocks, the EDF reacts negatively (*i.e.* lower probability of default) with a permanent effect of approximately 30% relative to baseline. This corresponds to an increase of 0.25 in terms of probabilities.

A negative standard error shock to the euro area GDP and the US GDP have small effects on the EDFs of different sectors (see Figures B.1 and B.7). The range at which the reactions change is similar for both countries. By comparison to the global negative GDP growth shock, the initial effect on the EDF is positive (i.e. higher probability to default). Similar to the aggregate case, these results indicate that euro area firms are more sensitive to global growth compared to the euro area and the US growth. Additionally, the cyclical sector (CCy) EDF reacts initially more than the non-cyclical sector (CNC) to business cycle variables such as GDP, inflation, and short term interest rate, which is an intuitive output of the S-GVAR model.

Figures B.6, B.8 and B.14 show the EDF reactions of a positive one standard error shock to inflation originating from the euro area, the US or globally. The shock has initially a negative effect on the EDF. In addition, the EDF reactions stay negative during the 40 quarters, except for the energy sector EDF. The long-run effect of the euro area inflation shock is to lower the sectoral EDFs by 0-10%. Furthermore, the sectoral EDFs are more affected by the global inflation shock than by the US shock. Again, the technology sector is the most sensitive sector.

A negative shock to the US real equity price has a higher impact of approximately 21-25% in the first 3 quarters on the TMT sector. This is a similar effect in the case of a euro area equity shock. All the EDF reactions vanish for all the other sectors within 19-28 quarters with a US equity shock, while they remain more permanent within the euro area at a level oscillating between 5 and 35%. The consequence of a global real equity price shock is almost identical to the US shock, which is explained by the role of the US as the largest stock market in the world.

A negative monetary policy shock originating from the euro area has a significantly higher effect on the EDFs than a US monetary policy shock (see Figures B.7 and B.9). A negative one standard error shock to euro area short-term interest rates has a permanent positive effect on the EDFs within the range of 7.50-15%, while it is nearly 25% for the technology sector.

Finally, we analyzed the effect of a positive oil price shock and a negative exchange rate (i.e. appreciation) shocks of the renminbi, the yen, and the pound sterling against the US dollar. A positive standard error shock to oil prices has a significant effect on the sectoral EDFs, where the reaction is close to 50% for the technology sector and around 20% for all other sectors, except CnC and Fin sectors. The EDF reactions to a sudden appreciation in the Renminbi are insignificant (see Figure B.15). By opposition, the appreciation of the British pound against the US dollar (Figure B.17) reduces the expected probability of default across the sectors.

7 Simulation exercise – Bootstrap experiment on the S-GVAR model

In this section, we conduct a bootstrap experiment on the S-GVAR model. The purpose of the experiment is to create the maximum and the minimum bounds of the EDF reactions to the S-GVAR. Initially, the bootstrapping method assumes that the variables are independent and identically distributed (iid), and extensions to this work allow for deviations from the iid assumption. Related research is by Mantalos and Shukur (1998, 2001), Bun and Carree (2005), Everaert and Pozzi (2006) and Zaher (2006).

The bootstrap experiment shows the EDF reactions within a 90% confidence interval bound. The lower bound is the 5% and the upper bound is the 95% case. The re-sampling exercise shows to what extent the reaction changes if history is repeated a sufficient number of times. The design of the bootstrap experiment is as follows:

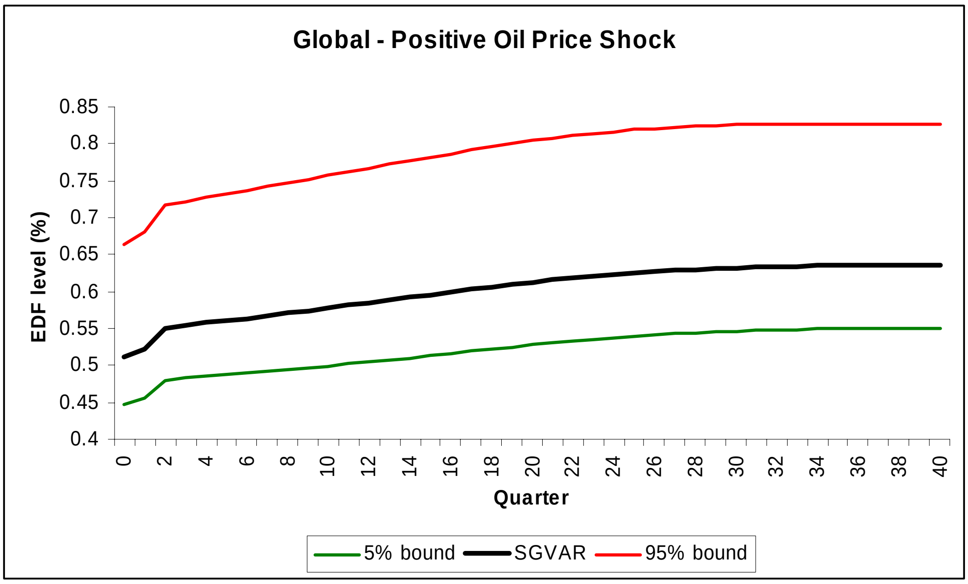
i) Draw (with replacement) a time series of length 56 from the joint 'empirical' distribution of the factors and the EDFs. For each period we draw a 6-tuple (*i.e.* from the five factors and from the one EDF time series).
ii) Re-estimate the S-GVAR model.
iii) Generate the EDF reactions given a shock to the GVAR model.
iv) Calculate the 5^{th} percentile and the 95^{th} percentile at each horizon (*i.e.* between 0-40 quarters) of the EDF reactions.

v) Repeat steps i-iv 10 000 times.

A residual based parametric bootstrap is an alternative to the current experiment.

The S-GVAR that determines the EDF reactions falls within the 90% confidence interval. Table 4 summarizes the results of the bootstrap experiment. The S-GVAR model given a shock is rejected (denoted by *Xs*) if the EDF reaction tends to be outside the 90% range, at least once the 40 quarters. Figure 2 illustrates the S-GVAR model of the aggregate euro area EDF and the simulated confidence bounds for a positive oil price shock.

Figure 2. Bootstrapped S-GVAR model for the aggregate EDF - oil price shock



The results show that the benchmark S-GVAR model representing the aggregate euro area EDF is within the 90% confidence interval for all types of shocks. By contrast, the energy and utilities, the financial and the technology sector EDFs appear insignificant for all S-GVAR models.

Table 2. Summary of the simulation exercise

Shock/Sector	Aggr	BaC	Cap	CCy	CNC	EnU	Fin	TMT
EA_Neg_GDP		X		X		X	X	X
EA_Pos_INFL		X		X		X	X	X
EA_ Neg_EP				X		X	X	X
EA_ Neg_EQ				X		X	X	X
EA_ Neg _IR				X		X	X	X
EA_Neg_LIR				X	X	X	X	X
US_Neg_GDP		X		X		X	X	X
US_Neg_INFL				X		X	X	X
US_Neg_IR		X		X		X	X	X
US_Neg_EQ				X		X	X	X
Global_Pos_Poil				X		X	X	X
Global_Pos_EQ		X		X		X	X	X
Global_Pos_INFL				X		X	X	X
Global_Neg_GDP				X	X	X	X	X
China_Neg_EP				X		X	X	X
Japan_Neg_EP		X		X		X	X	X
UK_Neg_EP				X		X	X	X

Notes: X denotes inconsistent model given a shock. The name of the shocks reads as country or region followed by the sign of the shock and the variable name. EA stands for euro area, Neg stands for negative shock and Pos is for a positive shock.

Inconsistency of some models might be due to the resampling experiment as the long-run parameters in the estimation are affected. However, this may not be the case if we would consider an alternative class of bootstrap experiment such as residual based parametric methods. In particular, such an experiment favours more the cointegration property since the cointegration parameters are fixed when the random draws of the residuals are made. On the other hand our experiment put more weights on rejecting the cointegration since the draws are based on the time series together with re-estimation of the parameters. Therefore, most of the long-run parameters of the S-GVAR models are insensitive to the resampling, which provides consistency of some models in the simulations.

8 Conclusion

The contribution of this paper is to provide a framework for corporate credit quality assessment, which allows for domestic and global analysis simultaneously. In particular, we create a link between macroeconomic variables and firms' expected default probabilities. Indeed, previous literature has found a link between probability of default and the economic activity. However, the studies are generally restricted to a limited number of domestic variables. We analyze probabilities of default under a range of macroeconomic scenarios over time. We use the Global Vector Autoregressive (GVAR) model, which takes into account a wider perspective of interdependency between large panels of variables. The GVAR model combines national and international variables by using a core set of variables for many countries. This provides a general global modelling framework for quantitative analysis of different shocks and channels of transmission mechanisms. In addition we construct a linking equation to the GVAR model. This is a convenient way of linking a structural credit risk model to time series econometric model. We refer to this link as the Satellite GVAR model. The advantages of the Satellite GVAR model are that it restricts the expected default frequency from the GVAR system, which makes the model versatile when the time dimension of the expected default frequency and the economic variables differs.

The results show that on the aggregate euro area EDF level, the EDFs react to shocks to the euro/US dollar exchange rate, oil prices and equity prices. Similar to the benchmark case, these results indicate that euro area firms are more sensitive to global growth compared to the euro zone and the US growth. In general, most sectoral EDFs react similarly to the benchmark, except for the technology sector EDF, which is more affected than the other EDFs in our sample period. Among the euro area variables, the technology sector reacts significantly to appreciation of the euro/US dollar, stock markets and short-term interest rate shocks. Additionally, the cyclical sector EDFs react initially more than non-cyclical sector to business cycle variables such as GDP, inflation, and short-term interest rate, which is an intuitive output of the Satellite GVAR model. In a simulation exercise of the S-GVAR models the aggregate EDF (*i.e.* the median firms) is found consistent, whereas the results appear somewhat weaker for some sectoral EDFs.

All in all, the S-GVAR model provides a promising framework for analysing the impact of shocks to euro area corporate credit quality. Several extensions to the work are possible. For example, the model can be conveniently linked to a credit portfolio model to provide an assessment of bank credit risk exposures under a wide range of global macro-financial scenarios.

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Appendix A

Table A.1 Unit root of the EDF and the factors

EDF	Det.	Lag	ADF	Lag	KPSS
Aggr	C	BIC=0	-0.9632*	1	1.0872*
	C	AIC=1	-1.2124*		
BaC	C	AIC=BIC=0	-0.9351*	1	0.4066**
Cap	C	AIC=BIC=0	-1.208*	1	1.1368*
CCY	C	AIC=BIC=0	-1.1131*	1	0.8165*
CNC	C	BIC=0	-1.0782*	1	1.2617*
	C	AIC=2	-1.3054*		
EnU	C	BIC=0	-0.6446*	1	0.2899*
	C	AIC=4	-1.8438*		
Fin	C	BIC=0	-1.2241*	1	0.665*
	C	AIC=4	-1.3789*		
TMT	C	AIC=BIC=1	-1.2555*	1	1.6009*
Factors		**Selection criteria**	**ADF**		
CPI	C	AIC=BIC=0	-1.4058*	1	2.1257*
EP	C	AIC=BIC=1	-0.2665*	1	2.0497*
EQ	C	AIC=BIC=1	-1.4739*	1	1.3253*
GDP	T	AIC=BIC=1	-3.2433*	1	0.2508*
IR	C	AIC=BIC=1	-2.9937***	1	2.0161*

Critical values

	1%	5%	10%
ADF, C	-3.43	-2.86	-2.57
ADF, T	-3.96	-3.41	-3.13
KPSS, C	0.739	0.463	0.347
KPSS, T	0.216	0.146	0.119

*Notes: Abbreviation of the variables. The null of in the ADF is unit root and the alternative is no unit root. The hypothesis is reversed in KPSS test. * denotes unit root at 5% significance level, ** denotes unit root at 10% significance level and *** denotes unit root at 1% significance level. C and T stands for constant and trend as a deterministic components (Det), SIC for Schwarz information criteria, AIC for Akaike Information criteria. The lag length in the KPSS test is determined by $4\times(56/100)^{1/4}$, where 56 is the sample length and 4 is frequency normalization for quarter in the KPSS test.*

Table A.2 Tests for cointegration

Panel a. Engle and Granger test – S-GVAR residual

EDF Sector	Aggr	BaC	Cap	CCy	CNC	EnU	Fin	TMT
ADF statistic	-4.06	-3.56	-3.63	-4.05	-3.20	-3.90	-4.90	-4.86
Significance level:	5%: -4.10 and 10% : -3.81							

Panel b. Johansen test and Saikkonen and Lütkepohl (S&L)

Test	Lag	Det.	r = 0	r = 1	r = 2	r = 3	r = 4	r = 5
			Aggr EDF, GDP, CPI, EQ, EP and IR					
Johansen	SIC=1	C	0.0000	0.0000	0.0002	0.0031	0.0234	0.0390
	AIC=4	C	0.0000	0.0000	0.0018	0.0071	0.0447	0.0430
S&L	SIC=1	C	0.0000	0.0000	0.0004	0.0045	0.0553	0.0145
	AIC=4	C	0.0000	0.0000	0.0063	0.0239	0.1193	0.8179
			BaC EDF, GDP, CPI, EQ, EP and IR					
Johansen	SIC=1	C	0.0000	0.0000	0.0017	0.0086	0.0401	0.0409
	AIC=2	C	0.0000	0.0000	0.0000	0.0002	0.0025	0.0469
S&L	SIC=1	C	0.0000	0.0000	0.0020	0.0037	0.0520	0.0520
	AIC=2	C	0.0000	0.0000	0.0000	0.0061	0.0488	0.0920
			Cap EDF, GDP, CPI, EQ, EP and IR					
Johansen	SIC=1	C	0.0000	0.0000	0.0043	0.0079	0.0487	0.0486
	AIC=2	C	0.0000	0.0000	0.0000	0.0001	0.0009	0.0142
S&L	SIC=1	C	0.0000	0.0000	0.0014	0.0033	0.0644	0.0586
	AIC=2	C	0.0000	0.0000	0.0000	0.0009	0.0349	0.0267
			CCy EDF, GDP, CPI, EQ, EP and IR					
Johansen	SIC=1	C	0.0000	0.0000	0.0012	0.0032	0.0227	0.0350
	AIC=2	C	0.0000	0.0000	0.0000	0.0000	0.0006	0.0153
S&L	SIC=1	C	0.0000	0.0000	0.0008	0.0027	0.0387	0.0308
	AIC=2	C	0.0000	0.0000	0.0000	0.0001	0.0407	0.1182

Table A.2 continues…

Test	Lag	Det.	r = 0	r = 1	r = 2	r = 3	r = 4	r = 5
			CNC EDF, GDP, CPI, EQ, EP and IR					
Johansen	**SIC=1**	**C**	0.0000	0.0000	0.0009	0.0174	0.1191	0.1890
	AIC=4	**C**	0.0000	0.0000	0.0008	0.0041	0.0328	0.0795
S&L	**SIC=1**	**C**	0.0000	0.0000	0.0002	0.0087	0.0801	0.6634
	AIC=4	**C**	0.0000	0.0000	0.0032	0.0582	0.2190	0.8930
			EnU EDF, GDP, CPI, EQ, EP and IR					
Johansen	**SIC=1**	**C**	0.0000	0.0000	0.0000	0.0066	0.0871	0.1907
	AIC=4	**C**	0.0000	0.0000	0.0000	0.0016	0.0084	0.0262
S&L	**SIC=1**	**C**	0.0000	0.0000	0.0001	0.0034	0.0550	0.3812
	AIC=4	**C**	0.0000	0.0000	0.0000	0.0089	0.0345	0.1980
			Fin EDF, GDP, CPI, EQ, EP and IR					
Johansen	**SIC=1**	**C**	0.0000	0.0000	0.0000	0.0173	0.1419	0.2456
	AIC=3	**C**	0.0000	0.0000	0.0000	0.0000	0.0025	0.0288
S&L	**SIC=1**	**C**	0.0000	0.0000	0.0000	0.0088	0.0845	0.4359
	AIC=3	**C**	0.0000	0.0000	0.0000	0.0080	0.0254	0.3120
			TMT EDF, GDP, CPI, EQ, EP and IR and five factors					
Johansen	**SIC=2**	**C**	0.0000	0.0000	0.0000	0.0032	0.0171	0.0594
	AIC=4	**C**	0.0000	0.0000	0.0000	0.0004	0.0031	0.0411
S&L	**SIC=2**	**C**	0.0000	0.0000	0.0002	0.0019	0.0617	0.5716
	AIC=4	**C**	0.0000	0.0000	0.0000	0.0034	0.0016	0.0733

Notes: For variable definition see Table 1. The values panel b stands for the probability values of the Johansen test and Saikkonen and Lütkepohl test ADF stands for Augmented Dickey-Fuller test, S&L for Saikkonen and Lütkepohl test, C for constant as a deterministic component (Det), SIC for Schwarz information criteria, AIC for Akaike Information criteria, r for rank.

Appendix B. EDF Reactions

Figure B.1 One negative standard deviation shock to the euro area GDP growth

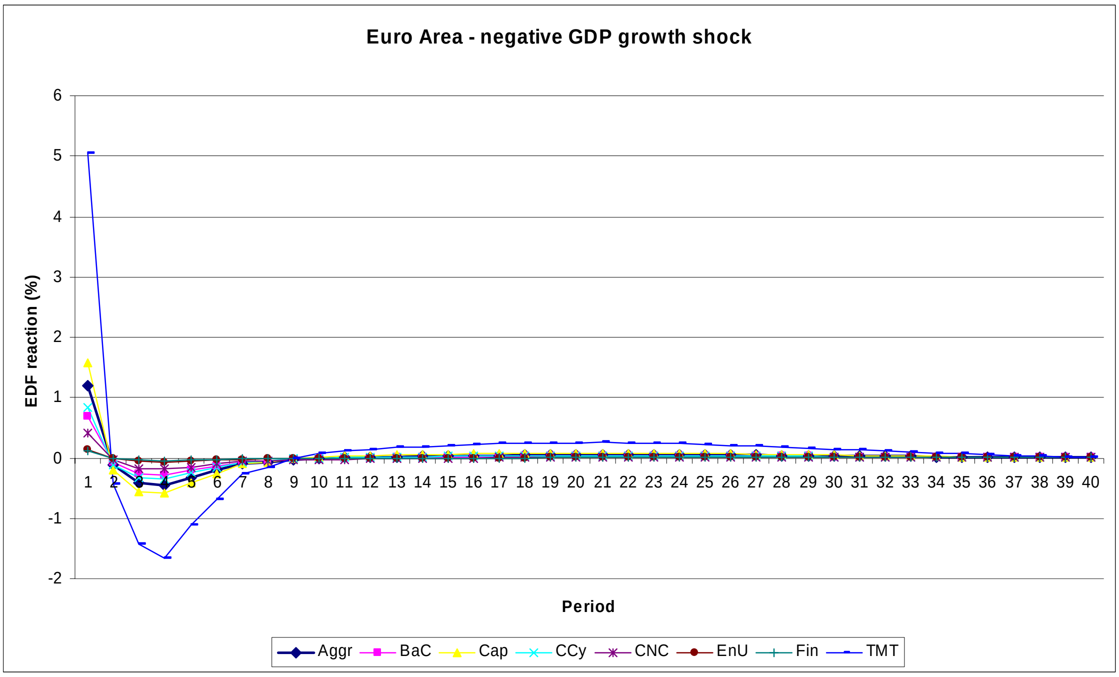

Figure B.2 One negative standard deviation shock to the euro area equity prices

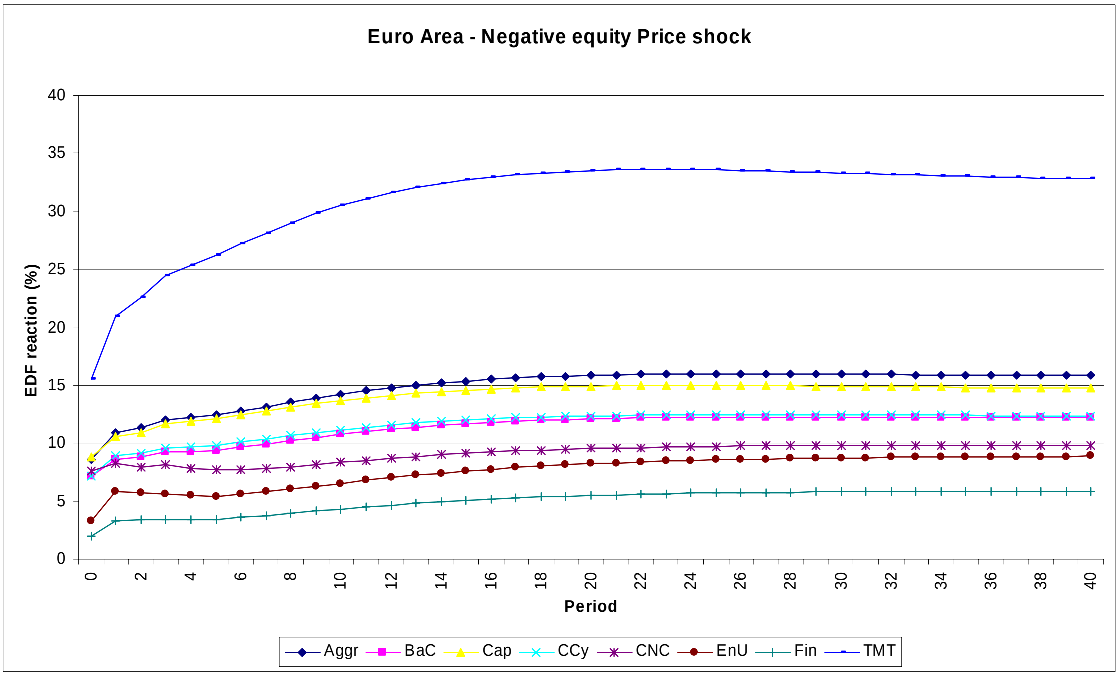

Figure B.3 One negative standard deviation shock to the euro (i.e. appreciation)

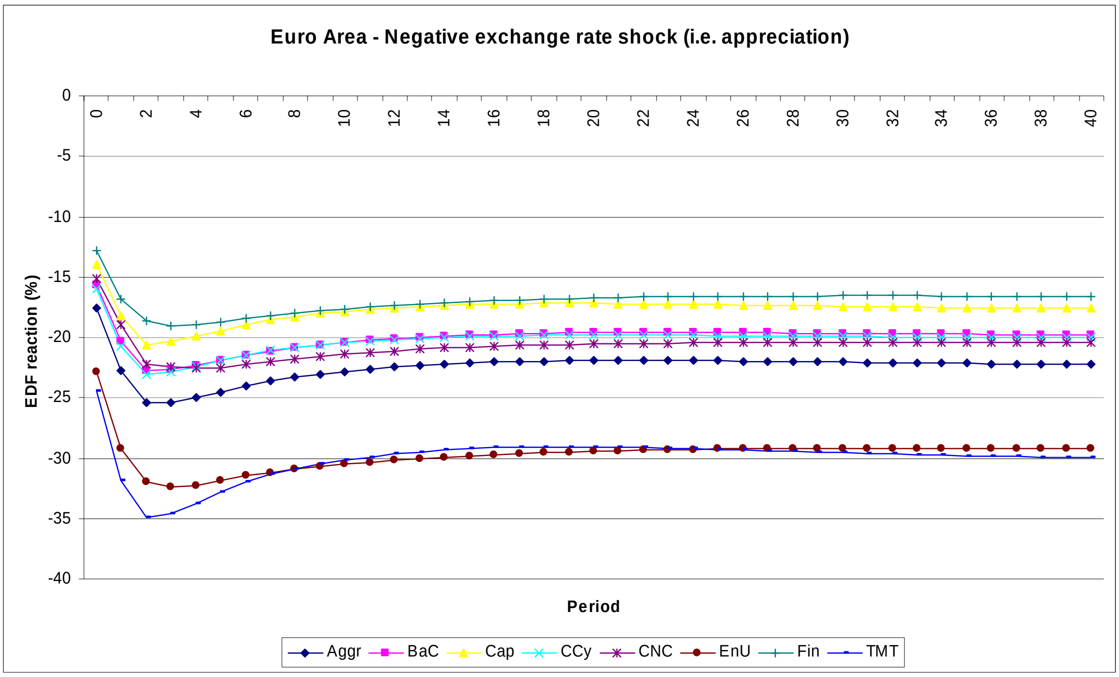

Figure B.4 One negative standard deviation shock to the euro area short-term interest rate

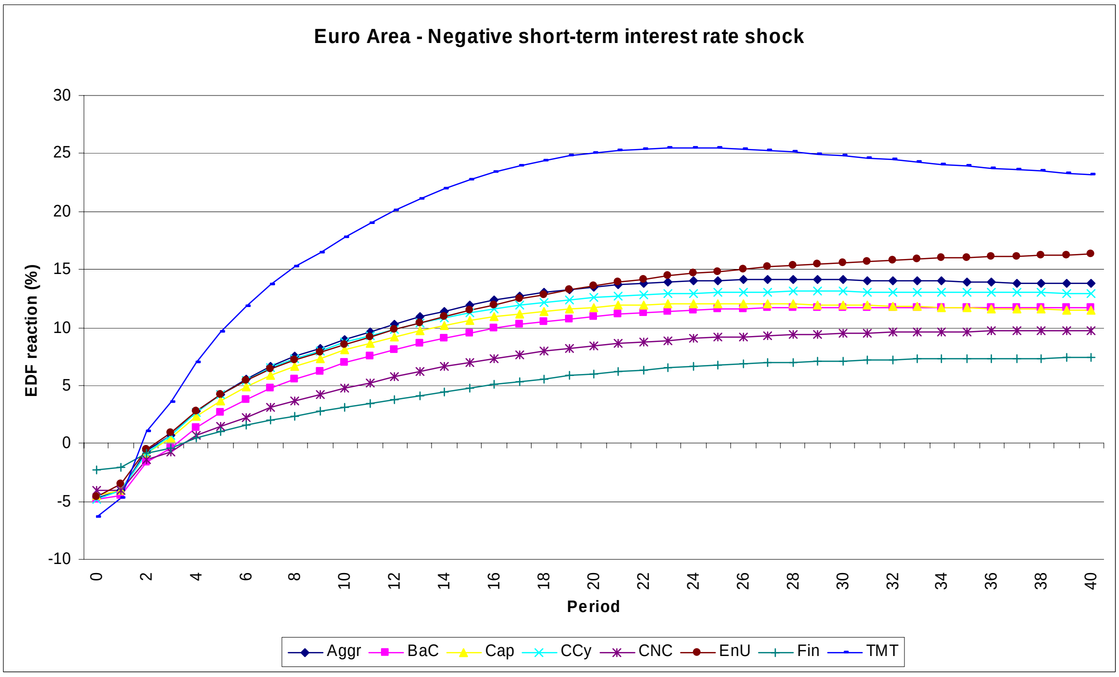

Figure B.5 One negative standard deviation shock to the euro area long-term interest rate

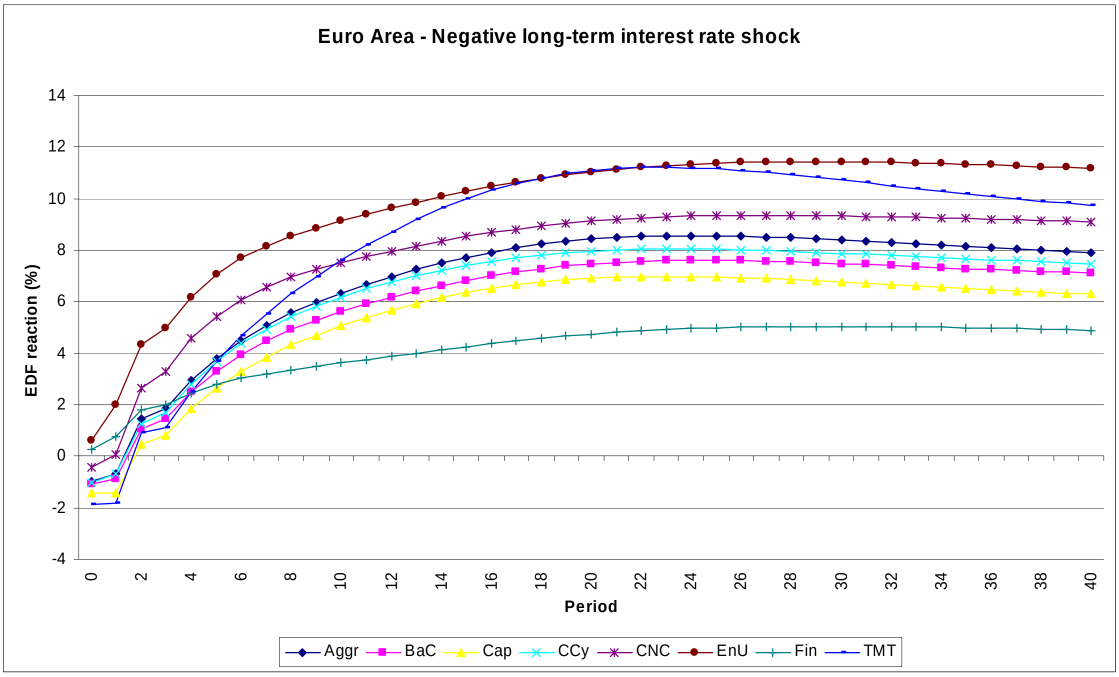

Figure B.6 One positive standard deviation shock to euro area inflation

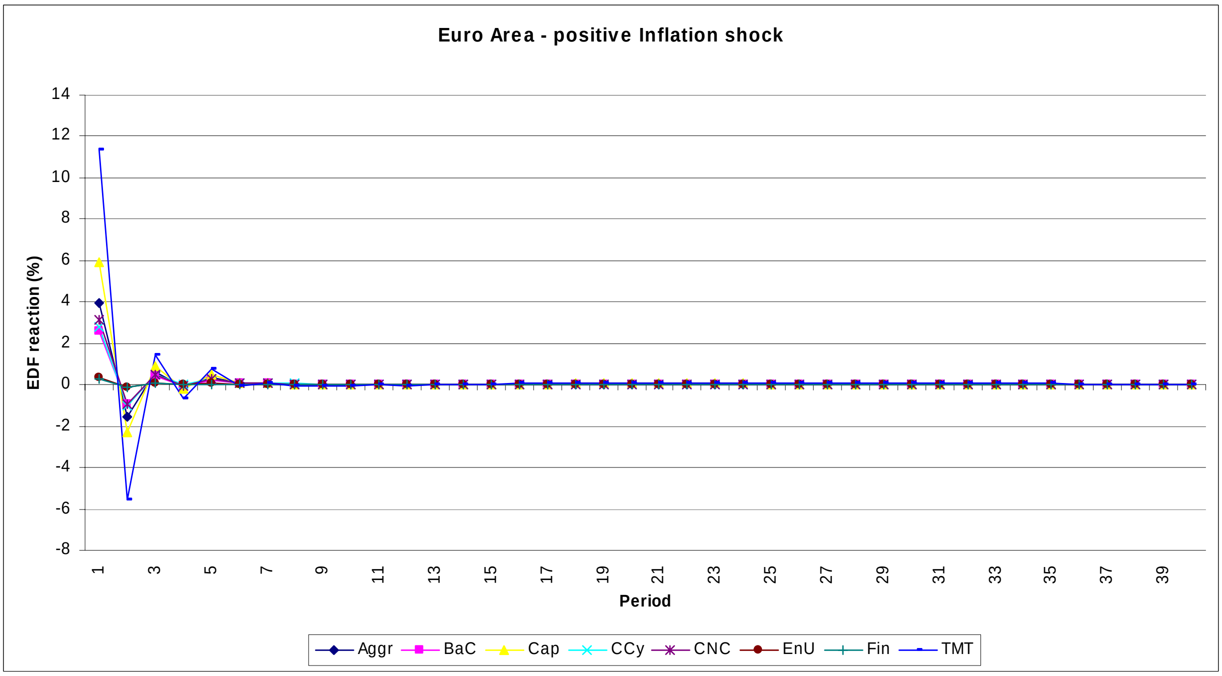

Figure B.7 One negative standard deviation shock to US GDP growth

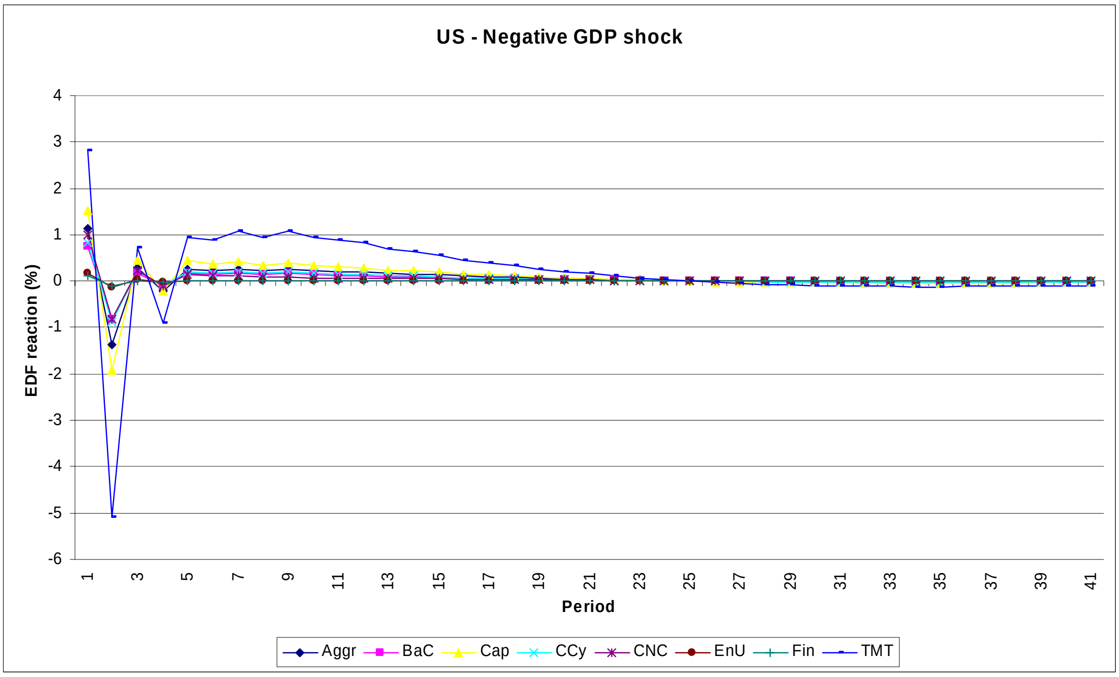

Figure B.8 One positive standard deviation shock to US Inflation

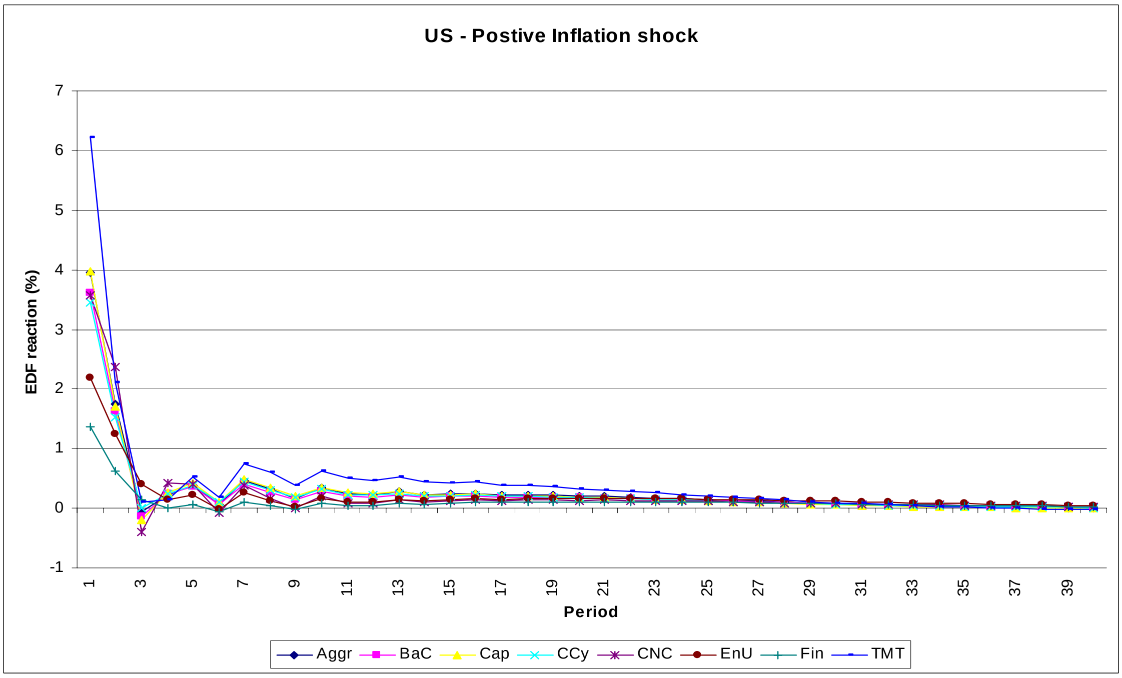

Figure B.9 One negative standard deviation shock to the US quity prices

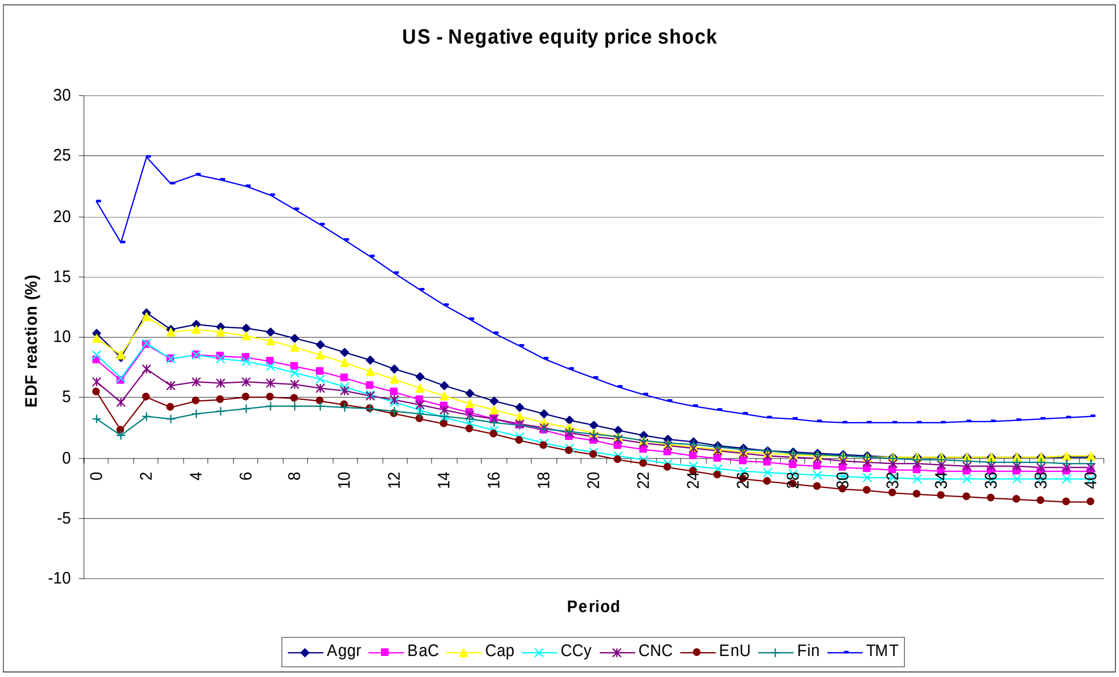

Figure B.10 One negative standard deviation shock to the US short-term interest rate

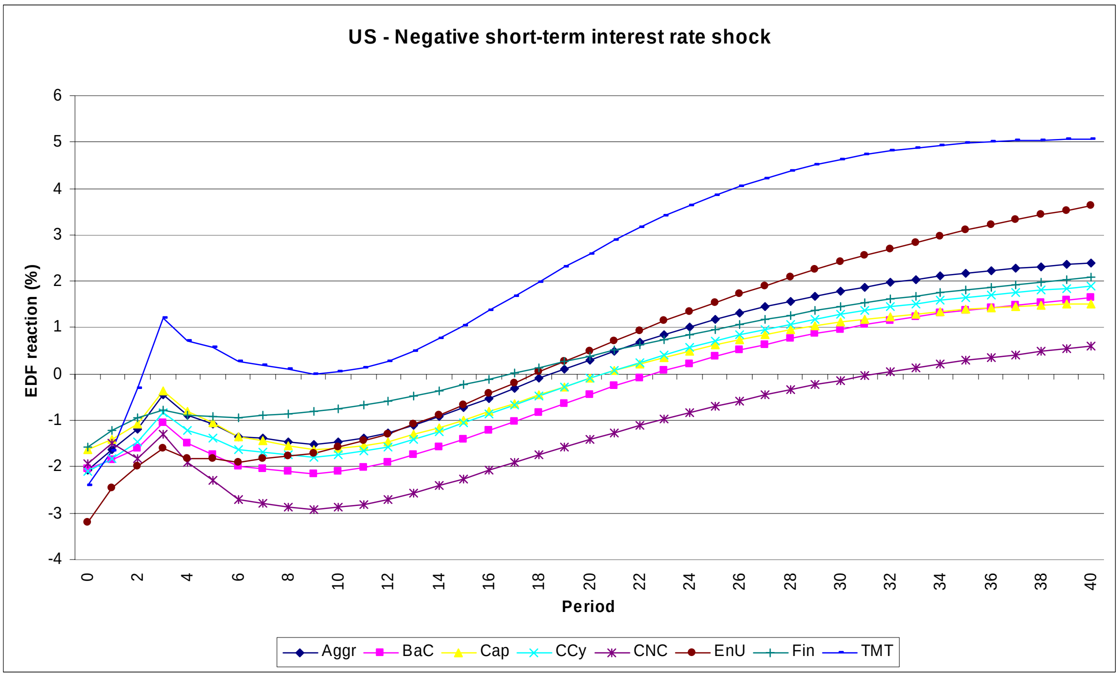

Figure B.11 One positive standard deviation shock to the global oil prices

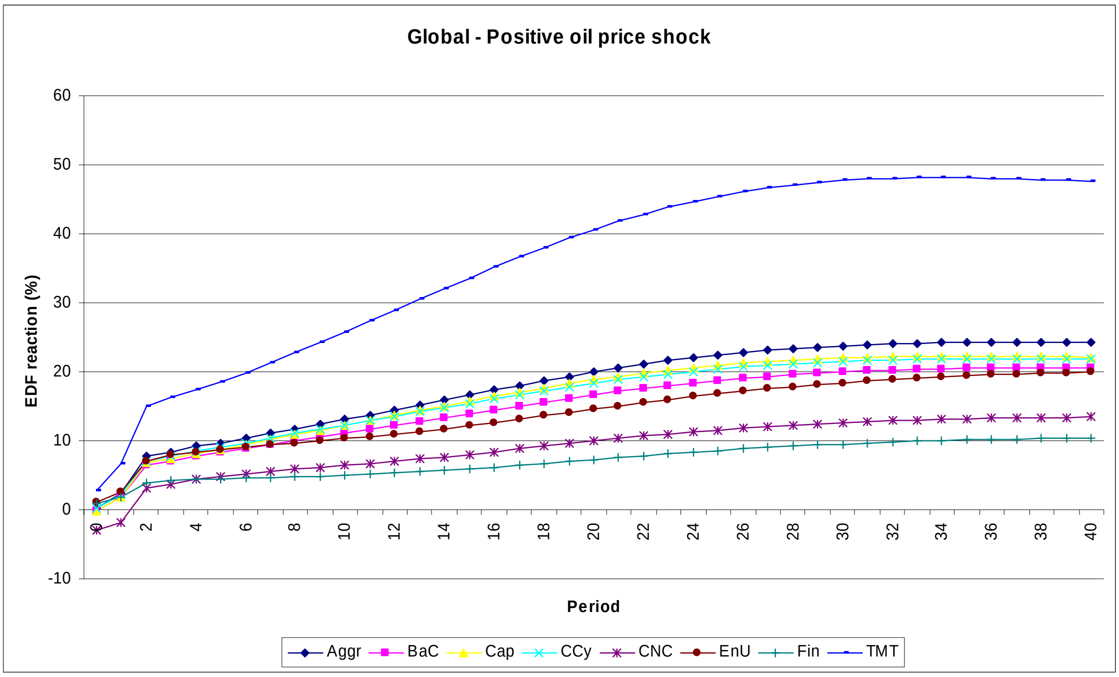

Figure B.12 One negative standard deviation shock to the global equity prices

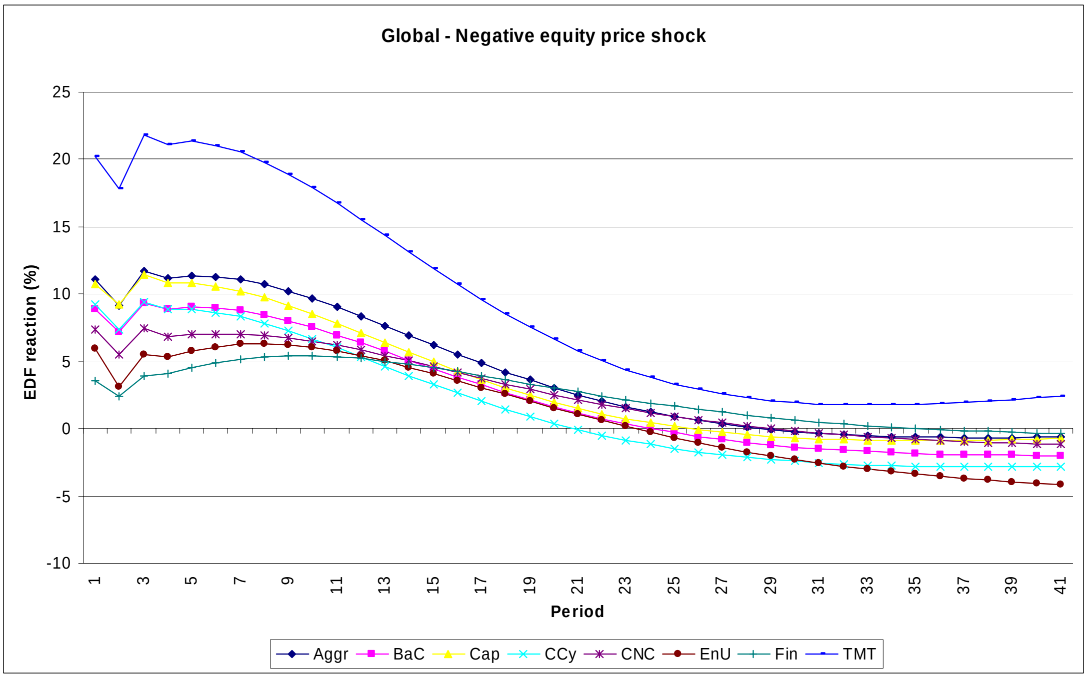

Figure B.13 One negative standard deviation shock to the global GDP growth

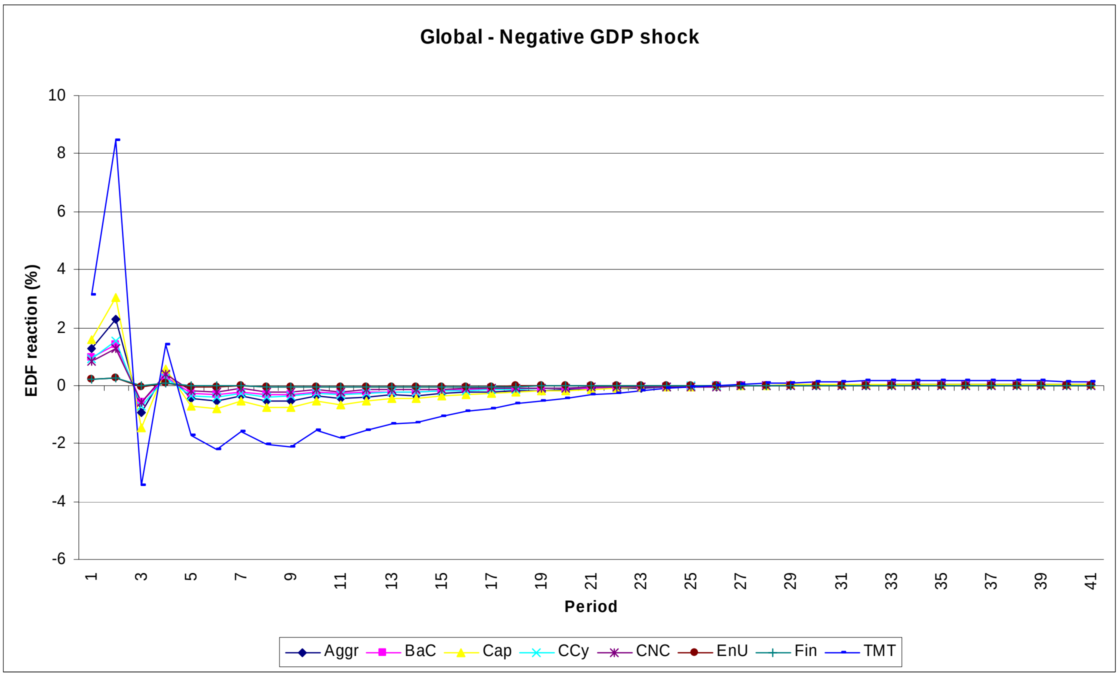

Figure B.14 One positive standard deviation shock to global inflation

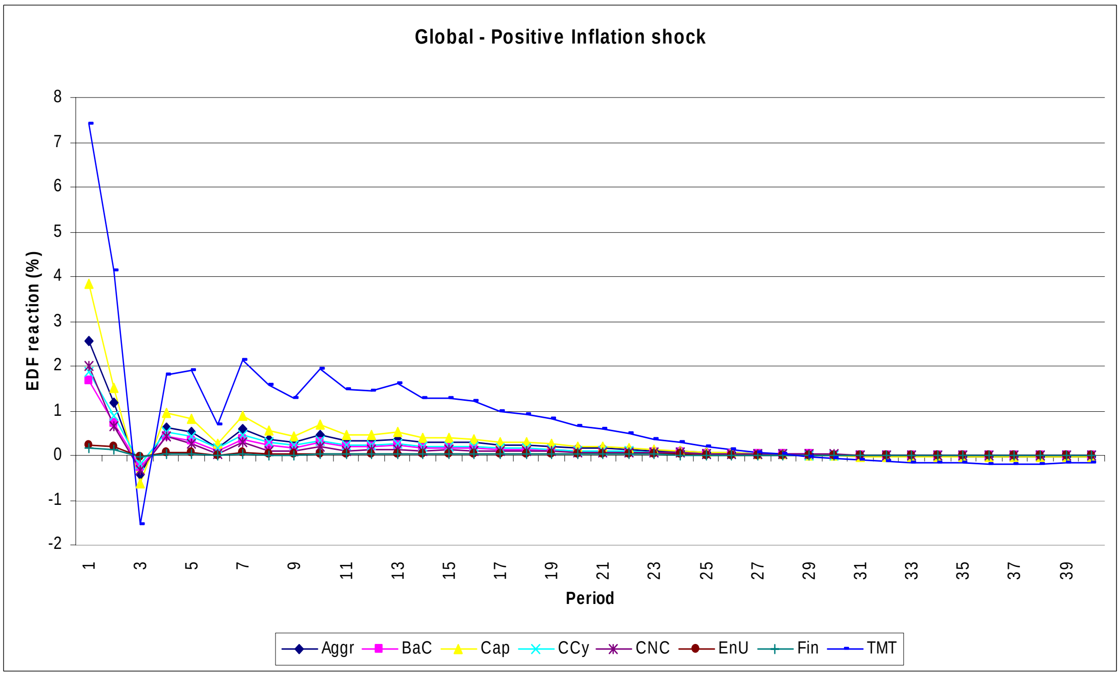

Figure B.15 One negative standard deviation shock to the Chinese renmembi

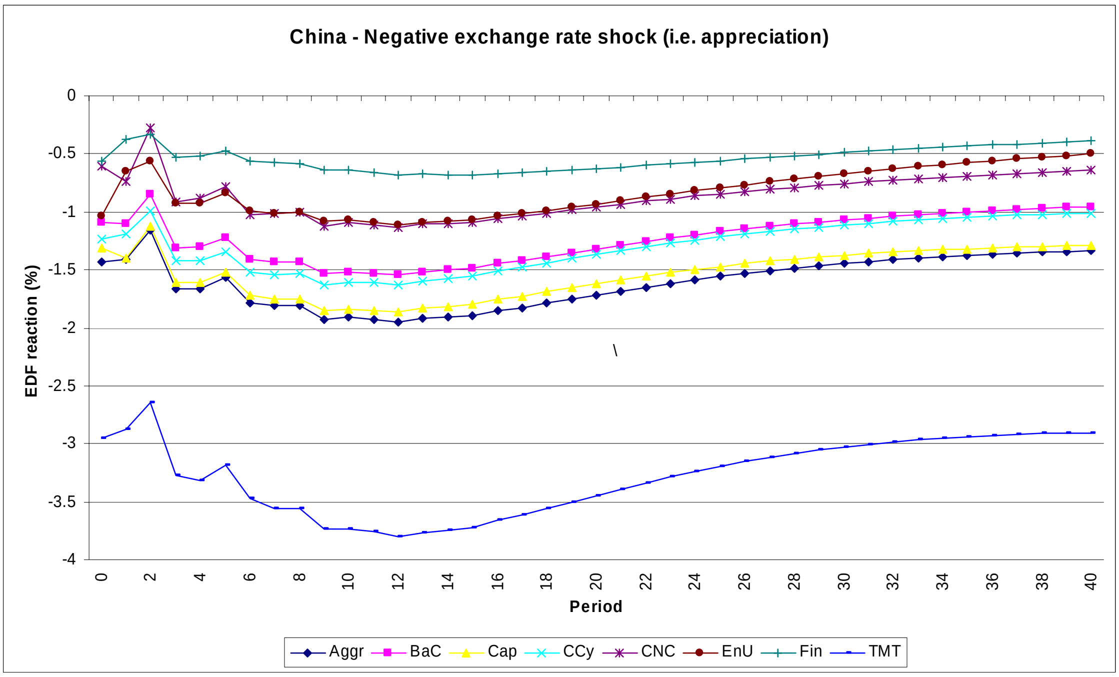

Figure B.16 One negative standard deviation shock to the Japanese yen

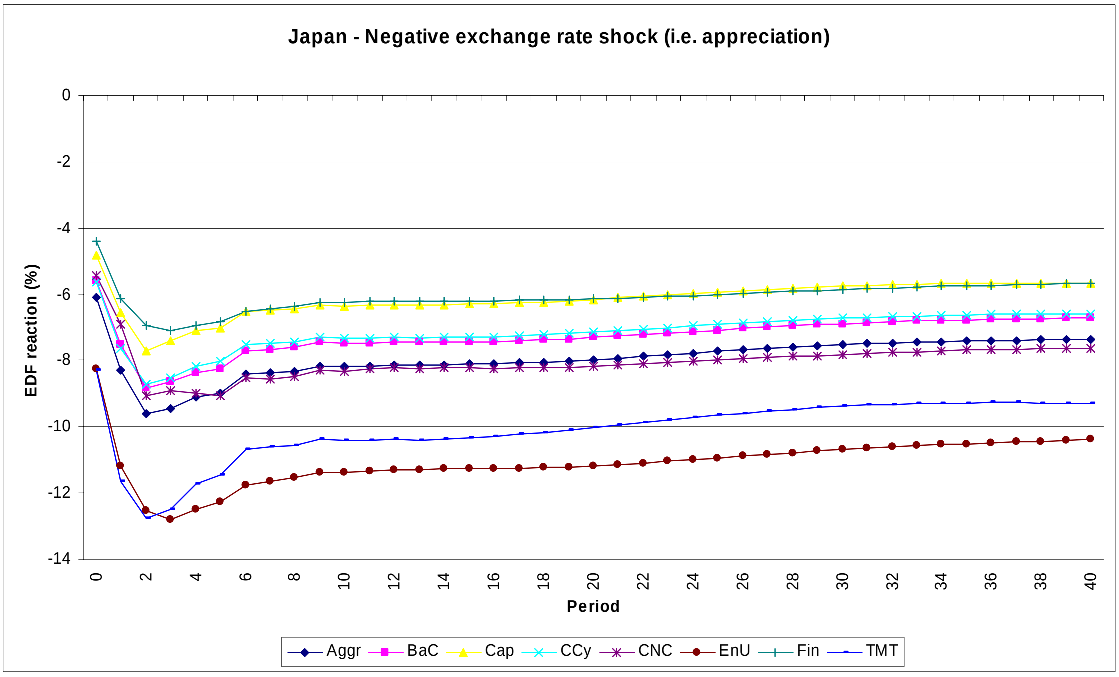

Figure B.17 One negative standard deviation shock to UK pound sterling