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by Olli Castrén, Stéphane Dées and Fadi Zaher

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Olli Castrén [2], Stéphane Dées [3] and Fadi Zaher [4]

In 2008 all ECB publications feature a motif taken from the €10 banknote.

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Abstract

Modelling the link between the global macro-financial factors and firms' default probabilities constitutes an elementary part of financial sector stress-testing frameworks. Using the Global Vector Autoregressive (GVAR) model and constructing a linking satellite equation for the firm-level Expected Default Frequencies (EDFs), we show how to analyse the euro area corporate sector probability of default under a wide range of domestic and foreign macroeconomic shocks. The results show that, at the euro area aggregate level, the median EDFs react most to shocks to the GDP, exchange rate, oil prices and equity prices. There are some intuitive variations to these results when sector-level EDFs are considered. Overall, the Satellite-GVAR model appears to be a useful tool for analysing plausible global macro-financial shock scenarios designed for financial sector stress-testing purposes.

Key words: Credit risk, Global VAR, corporate default probability, macro stress testing.

JEL codes: C33, F47, G32, G33.

Non-technical summary

With the global economy becoming increasingly financially integrated, large euro area firms are more and more exposed to shocks from the international environment. The analysis of risks to corporate sector credit quality – which is an important component of any financial stability monitoring exercise – should therefore account for shocks that originate from the global environment rather than from the purely domestic macro-financial sources. The present paper evaluates the impact of national and international macroeconomic and financial shocks on euro area firms' expected probability of default. In so doing, it also provides a dynamic framework for stress-testing these probabilities, with number of potential applications for financial stability work.

In this paper, we use the Global Vector Autoregressive (GVAR) model as first presented by Pesaran, Schuermann and Weiner (2006, hereafter PSW) as a macroeconometric framework to generate shocks to the financial system. The GVAR model is based on country- or region-specific vector error correction models, where domestic and foreign variables interact simultaneously. 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 novelty in our work is to construct a satellite equation which links the measures of probability of default to a set of macroeconomic and financial variables as specified in the GVAR. The aggregate Satellite-GVAR model allows for a richer representation of the international transmission of shocks to corporate sector credit quality than a framework that uses a simple euro area VAR, as it helps to understand and account for various global linkages (direct, second-round and third-market effects as well as transmission through financial variables).

When specifying the Satellite equation, we us the Moody's KMV expected default frequencies (EDFs) which are a publicly available measure of firms' probability of default. The EDF measures the probability that a firm defaults within a given time horizon and, hence, it provides a forward-looking measure of default.[2] Intuitively, the EDFs can be interpreted as estimators that measure how close a firm's assets approach its liabilities given the macroeconomic scenario. When incorporates in the Satellite-GVAR model, the shifts in EDFs provide a measure of the conditional expectation of the firms' default intensities, where the

[2] For example, a corporation with an EDF of 1% would have 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 firm variables.

conditioning variables are the macroeconomic risk factor changes that describe a particular macro scenario generated with the GVAR model.

There is a large and growing literature on the determinants of corporate sector default rates and probabilities of default (see for example McNeil, Frey and Embrechts, 2005, for a thorough review of this literature). Recently, important progress has been made in modelling the links between macroeconomic models and more micro-level developments in corporate sector credit quality as characterised by variables such as probabilities of default or banks' loan loss provisions.[3] Although several alternative model specifications have been applied, the VAR framework has proven a popular and flexible framework to this end. Among the more recent contributions which use the VAR model to analyse the links between the macroeconomy and the corporate sector credit quality are Alves (2005) and Shahnazarian and Åsberg-Sommer (2007) who incorporate the Moody's KMV expected default frequency (EDF) data in cointegrated closed-economy VAR models. They find cointegration relationships between the macro and EDF variables and identify significant relationships between EDFs on the one hand and short-term interest rates, GDP and inflation on the other hand. Aspachs, Goodhart, Tsomocos and Zicchino (2006) use a VAR model which includes the banking sector EDFs and macroeconomic data on seven industrialised countries. They show that shocks to banks' default probabilities and equity values can have an impact on GDP variables. Jacobson, Lindé and Roszbach (2005) use the VAR approach to study the interactions between Swedish firms' balance sheets and the evolution of the Swedish economy. They find that macroeconomic variables are relevant for explaining the time-varying default frequency in Sweden. Drehmann, Patton and Sorensen (2005) analyse corporate sector defaults in a non-linear VAR framework for the UK economy and find that non-linearities matter for the shape of the impulse response functions. Finally, Pesaran, Schuermann and Weiner (2006) adopt the GVAR model to generate conditional loss distributions of a credit portfolio of a large number of firms in various regions of the world.

While our paper is closely related to the above mentioned previous research, it differs from them in some important respects. First, our aim is to quantify the impact of domestic and global macroeconomic shocks on the corporate sector EDFs of the *euro area,* which is modelled as a single economic region. Second, we study the corporate EDFs both at a euro area aggregate level as well as at a sector level. Third, our proposed framework provides us with some flexibility as regards the analysis of EDFs for which available time series data are typically shorter than for the global macro-financial variables included in the GVAR; it also

[3] See Sorge (2004) for a comprehensive review of the literature in this area.

provides a convenient framework to model non-linearities and heterogeneity in default frequencies without intervening with the structure of the underlying macro model.

The results clearly demonstrate the usefulness of the Satellite-GVAR approach. We show that at the euro area aggregate level, the corporate EDFs react most to shocks to the GDP, exchange rates, equity prices and oil prices. In addition, there are some interesting variations to these results at the sector EDF levels; for example, the more "cyclical" sector EDFs, such as building and construction and consumer cyclical sectors, are typically more sensitive to shocks to the GDP and inflation variables. To better exploit the cross-sectional variation in the data, we also look at the results using median-leverage firm EDFs in each sector and find that the results are quite robust to this alternative specification of the EDF variable. Bootstrap experiments on the Satellite-GVAR model show that the aggregate sector EDF (*i.e.* the EDF of the median euro area firm) is consistent, whereas the model appears slightly weaker for some of the individual sector level EDFs.

1. Introduction

With the global economy becoming increasingly financially integrated, large euro area firms are more and more exposed to shocks from the international environment. The analysis of risks to corporate sector credit quality – which is an important component of any financial stability monitoring exercise – should therefore account for shocks that originate from the global environment rather than from the purely domestic macro-financial sources. The present paper evaluates the impact of national and international macroeconomic and financial shocks on euro area firms' expected probability of default. In so doing, it also provides a dynamic framework for stress-testing these probabilities, with number of potential applications for financial stability work.

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The results clearly demonstrate the usefulness of the Satellite-GVAR approach. We show that at the euro area aggregate level, the corporate EDFs react most to shocks to the GDP, exchange rates, equity prices and oil prices. In addition, there are some interesting variations to these results at the sector EDF levels; for example, the more "cyclical" sector EDFs, such as building and construction and consumer cyclical sectors, are typically more sensitive to shocks to the GDP and inflation variables. To better exploit the cross-sectional variation in the data, we also look at the results using median-leverage firm EDFs in each sector and find that the results are quite robust to this alternative specification of the EDF variable. Bootstrap experiments on the Satellite-GVAR model show that the aggregate sector EDF (*i.e.* the EDF of the median euro area firm) is consistent, whereas the model appears slightly weaker for some of the individual sector level EDFs.

The rest of this paper proceeds as follows: Section 2 provides an overview of the Satellite-GVAR model. Section 3 presents the data. Section 4 discusses the estimation results. Section 5 shows the results of the impulse response analysis and section 6 contains the results of the bootstrap experiment on the Satellite-GVAR model. Section 7 concludes.

2. The Model

To analyse the transmission of macro-financial shocks to corporate sector credit quality, the first step is to formulate a model that characterises the macroeconomic environment of the corporate sector. Given the increasing exposure of the euro area firms to the global marketplace, a global macroeconomic model is well placed to capture the various shocks and interlinkages that might affect large euro area firms' credit quality. By taking into account a large set of linkages across macroeconomic and financial variables, the GVAR model is particularly suitable for analysis of the transmission of real and financial shocks across countries and regions. The version of the GVAR model used in this paper originates from Dées, di Mauro, Pesaran and Smith (2007) – hereafter DdPS. Appendix B includes the details about the countries and variables included in the model.

In short, the GVAR provides a simple solution where country-specific VAR models are estimated by relating a vector of domestic variables, x_{it}, to their foreign counterparts, x_{it}^{*}.

These vectors are then combined to form a GVAR in which all the variables are endogenous. The high dimensional nature of the model is circumvented at the estimation stage by constructing the country-specific foreign variables x_{it}^* using predetermined coefficients, such as trade weights, and by noting that for relatively small open economies the x_{it}^* variables can be treated as weakly exogenous (or forcing) for the parameters of the conditional model.

More specifically, we consider identical country-level VAR (denoted as VARX*) specifications across all countries:[6]

$$x_{it} = A_{id}d_t + \Phi_{i1}x_{i,t-1} + \Phi_{i2}x_{i,t-2} + \Psi_{i0}x_{i,t}^* + \Psi_{i1}x_{i,t-1}^* + \varepsilon_{it}\,, \qquad (1)$$

where x_{it} is a $k_i \times 1$ (usually five or six) vector of domestic variables, x_{it}^* is a $k_i^* \times 1$ vector of foreign variables specific to country i, and d_t is an $s \times 1$ vector of deterministic elements as well as observed common variables such as oil prices. The unknown coefficients are the $k_i \times s$ matrix A_{id} and the $k_i \times k_i$ matrices Φ_{i1} and Φ_{i2} of the lagged coefficients of domestic variables; Ψ_{i0} and Ψ_{i1} are $k_i^* \times k_i^*$ matrices of coefficients of foreign variables specific to country i and ε_{it} is a $k_i \times 1$ vector of idiosyncratic country-specific shocks with $E(\varepsilon_{it}\varepsilon'_{jt}) = \Sigma_{ij} = \Sigma'_{ji}$ and $E(\varepsilon_{it}\varepsilon'_{jt'}) = 0$, for all i, j and $t \neq t'$. The VARX* models are estimated separately for each country conditional on x_{it}^*, taking into account the possibility of cointegration both within x_{it} and across x_{it} and x_{it}^*. Theory restrictions can be imposed on the long-run relations as well as on the short-term dynamics.[7] In the GVAR approach, the international linkages between countries are therefore ensured at three different levels: (i) x_{it}, x_{it}^* and their lags depend directly on each other; (ii) the country-specific variables depend on global exogenous variables (*e.g.* oil prices); and (iii) the contemporaneous shocks between country i and j are represented by the cross-country covariance (Σ_{ij}).

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,

[6] The model for the US economy is treated slightly differently due to the dominant role that the US plays in the world economy – see DdPS for details.

[7] For example, Dées, Holly, Pesaran and Smith (2007) – hereafter DHPS – are able to impose a number of restrictions on the long-term relations of the model that are consistent with the data (purchasing power parity, uncovered interest parity, the Fisher equation and the term structure condition between short and long term interest rates).

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 Orthogonalised Impulse Responses (OIR) of Sims (1980). While the OIR requires the impulse responses to be computed with respect to a set of orthogonalised shocks, 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 orthogonalisation. Thus, unlike the OIR, the GIR is invariant to the ordering of the variables and countries in the GVAR model which is clearly an important consideration in the absence of any clear theory as to how the countries should be ordered. For this reason, the GIR rather than the OIR is also more suitable for our purposes, as there is no clear theory about how to order the countries in the GVAR model.[8]

In order to link the GVAR model with the corporate sector credit quality variables, we set up a framework which quantifies the impact of domestic and global macroeconomic shocks on euro area firms' probabilities of default. Such a system ignores, by construction, the feedback effects from the default probabilities to the macroeconomic variables. There are several reasons why we find this approach useful. First, since the availability of the EDF data is scarce relative to the large country dimension of the GVAR and the time series of the EDFs are also shorter than the series used for the GVAR , it would not be possible to include EDFs as an additional variable in the individual VARX* models. Second, a separate equation for EDFs allows us to experiment with various specifications for the EDF model without interfering with the relationships in the GVAR model. And third, the feedback effects from credit risk models to macro models are generally complicated and controversial to interpret and possibly involve also non-linear reactions. Against this background, our preferred approach is to construct an external equation which connects the forward-looking corporate sector credit quality variables to a set of macroeconomic variable that are included in the GVAR.[9]

The simplest form of the Satellite model is given by

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

[8] Furthermore, although the GIR does not explore the reasons for a shock, it is informative about the dynamics of its transmission from the rest of the world to the euro area. DdPS provide bootstrap estimates of the GIRs as well as structural stability tests of the GVAR model.

[9] It is important to note that the lack of explicit feedback from the Satellite model to the GVAR does not imply that the macro model would be invariant to corporate sector developments as the GVAR already includes variables that capture the impacts of macroeconomic shocks on the corporate sector, such as equity prices. The feedback would be necessary in the case we would like to specifically assess how corporate defaults impact the macroeconomic variables; however, this is beyond the scope of the present paper. Rather, the Satellite model allows us to simulate the impact of macroeconomic shocks to the corporate sector credit quality and the model can be used for forecasting or for generalized impulse response analysis in the usual manner.

where

- j is the index for sectors
- x_t is $k \times T$ matrix of explanatory variables from the euro area VARX* model that are endogenous to the GVAR
- s_{jt} is $1 \times T$ vector of the dependent variables for corporate sector j
- b_{j0} is the intercept for corporate sector-j equation
- b_{j1} is $1 \times k$ parameter vector
- ε is $1 \times T$ vector of residuals

The vector $s_{j,t}$ can include variables such as probability of default or bank loan loss measures. The satellite equation can also conveniently include non-linear specifications of the RHS variables without the need to specify the GVAR in a non-liner form. The combination of (1) and (2) (*i.e.,* the combination of the GVAR with the Satellite equation) is referred to as the Satellite-GVAR model. For estimation purposes, the endogenous variables of the euro area block of the GVAR model are used as exogenous variables to the Satellite model.

3. The data

The data set for the GVAR model consists of 33 countries from different regions in the world. The data include 8 of the 11 euro area countries that joined the single currency in 1999, and these 8 counties are grouped together in order to represent one region. 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 in US dollar per barrel and the exchange rate of the currency relative to the US dollar. The sample period extends from 1979 to 2005 on a quarterly basis; we refer to DdPS who include a detailed description of the individual data series. Following DdPS 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.[10]

In the GVAR, 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 as demonstrated, among others, by Baxter and Kouparitsas (2004), Imbs (2004), and Forbes and Chinn (2004). Reflecting this fact, and similar to DdPS, we use fixed trade-weights based on average trade flows over three

[10] See DdPS for the unit root tests on the data panel used in the GVAR.

years (2000-2002). DdPS also consider time-varying trade weights and show that including time-varying elements has a small impact on the results of the GVAR. In addition, we use regional responses (*e.g.* Western Europe, Asia, Latin America, and other regions). In line with DdPS, we use aggregate impulse response functions that are based on Purchasing Power Parity GDPs.[11]

The data we use as a measure of corporate sector credit quality are the expected default frequencies (EDFs), which are provided at the firm level by Moody's KMV. The chosen sectoral aggregation relating firm-specific EDF information to industry-specific risk measures needs to weigh the positive information content of a possibly large set of indicators and their cost in terms of modelling requirements (allowing distinct characteristics across sectors). EDFs for euro area firms are available from KMV on a common methodology from January 1992 until December 2005. Using as a basis the EU classification of economic activities (NACE Rev. 1), the over 1,500 SIC codes were mapped to a simpler classification of seven broad industries characterising the largest distinct economic sectors of interest. These are: Basic goods and construction (BaC), Energy and utilities (EnU), Capital goods (Cap), Consumer cyclicals (CCy), Consumer non-cyclicals (CNC), Financial (Fin) and Technology, media and telecommunications (TMT). As a benchmark, we also consider the aggregate EDFs across the entire data set.

Once the industrial sectors have been defined, there are a number of ways of aggregating the firm-level EDF information into measures of sectoral default probability; of these, the simplest to implement is the sector's sample median where the median EDF at each point in time represents the median EDF among a panel of available corporations in a sector.[12] Alternatively, and to better exploit the cross-sectional variation in the EDF data, we also use the median-leverage firm in each sector. The following selection criteria are used to choose these firms:

(i) Calculate the leverage (Debt-to-Equity ratio) for all firms in the euro area.
(ii) Select the firms that have data from 1992Q1-2005Q4.[13]
(iii) Finally, for each industry sector, the firm with median leverage in 2005Q4 is selected from the overall euro area group.

[11] This is an alternative to the weights based on US dollar GDPs. The PPP GDPs are considered as providing more reliable comparisons.
[12] See Alves (2005) for a detailed discussion on the data and the definitions of sectors used in this paper. Recent advances in analysing Moody's KMV EDF data focus on capturing the aspects of firm heterogeneity in the data. See *e.g.* Hansen, Pesaran and Schuermann (2005) for a comprehensive exposition.
[13] Firms with missing observations at any point in time are excluded from the selection.

Appendix A plots the time series of the median and median leverage EDFs for each sector. The charts sow that there are rather substantial differences both in levels and in dynamics of the EDF developments across sectors and across the two median firms selected for each sector. In particular, the sharp increase and subsequent decline in TMT sector firms' EDFs reflects the "New Economy" boom and bust of the late 1990s and early 2000s that was particularly concentrated on the firms in this sector.

4. Estimation of the Satellite-GVAR model

For the Satellite-GVAR analysis, we first estimate the GVAR model developed in DHPS by extending the dataset from 2003Q4 to 2005Q4. The detailed estimation results are available in Appendix B. While the GVAR has been estimated over the period 1979-2005, the Satellite model for EDFs can be estimated only over the period 1992-2005 for data availability reasons.[14] When estimating the satellite equation, we specify the EDFs in levels and the right-hand side variables (the endogenous variables of the euro area VARX* model) in first differences.[15] Although the macroeconomic variables on the RHS of the satellite equation originate from the euro area block of the GVAR only, links with international variables will be transmitted by the GVAR through the impacts of foreign variables on the euro area variables.

The estimated Satellite model has the following functional form:

$$EDF_t = \alpha + \beta_1 \Delta GDP_t + \beta_2 \Delta CPI_t + \beta_3 \Delta EQ_t + \beta_4 \Delta EP_t + \beta_5 \Delta IR_t \ , \qquad (3)$$

where α and β denote the parameters and ΔGDP_t, ΔCPI_t, ΔEQ_t, ΔEP_t, and ΔIR_t denote the logarithmic difference 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. While the GVAR

[14] The EDFs are available on monthly basis in the database. We also did the estimations of GVAR on monthly basis in order to increase the information set in the satellite model. It turned out that the relations between the variables in the GVAR get distorted by increasing the data frequency 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 fully comply with economic theory.

[15] An earlier version of this paper used a specification where the variables of the satellite model were also in levels, using the common stochastic trend between the variables. To test for cointegration relations between the EDFs and the variables included in the GVAR we applied the Engle and Granger (1987) method, which tests a unit root in the residuals of the satellite model, and the augmented Dickey-Fuller (ADF) test by using Davidson and MacKinnon (1993) test statistic for cointegration. We also invoked the Johansen (1995) trace test as well as the Saikkonen and Lütkepohl (2000) test where the small sample problem disappears asymptotically. The latter 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. Although the results from the different tests differ slightly, the overall conclusion was that full cointegration relations can be identified between the EDFs and the GVAR variables. These results are available upon request.

block of the euro area is represented by six macroeconomic and financial time series together with oil prices as a global variable, we prefer to restrict the number of variables to five to avoid estimating too many parameters.[16] Note, however, that 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 directly enter the equation for the euro area EDFs, its impact is indirectly transmitted through the reactions of interest rates, GDP and consumer price inflation. As discussed above, equation 3 is estimated separately using the sector-median and sector median-leverage firms' EDFs as LHS variables, in order to capture some of the cross-sectional variance in the EDF data.

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

	Const	GDP	INFL	EQUITY	EP	IR	Adjusted R-squared
Aggr	0.853	-0.350	-0.054	-0.018	-0.028	-0.010	0.377
P-value	0.000	0.040	0.823	0.020	0.077	0.228	
BaC	0.663	-0.285	0.161	-0.014	-0.012	-0.007	0.470
P-value	0.000	0.006	0.268	0.003	0.198	0.146	
Cap	1.167	-0.465	-0.097	-0.022	-0.034	-0.011	0.371
P-value	0.000	0.030	0.749	0.025	0.089	0.268	
CCY	0.679	-0.266	0.018	-0.015	-0.017	-0.006	0.417
P-value	0.000	0.022	0.915	0.005	0.120	0.270	
CNC	0.520	-0.117	-0.100	-0.010	-0.012	-0.003	0.267
P-value	0.000	0.235	0.485	0.026	0.206	0.558	
ENU	0.160	-0.047	0.031	-0.005	-0.002	0.000	0.406
P-value	0.000	0.080	0.421	0.000	0.332	0.737	
Fin	0.168	-0.030	0.081	-0.003	-0.002	-0.001	0.469
P-value	0.000	0.118	0.005	0.001	0.196	0.404	
TMT	2.385	-1.179	-0.831	-0.062	-0.135	-0.038	0.328
P-value	0.006	0.108	0.433	0.066	0.052	0.272	

Note: EP stands for euro/US dollar real exchange rate and IR for short term interest rate. The parameters are expressed in logs and they can be interpreted as elasticities. The last column presents the adjusted R-squared.

[16] However, we 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 did not change, we preferred to be parsimonious in the selection of explanatory variables. The results of the six and seven factor models are available upon request.

Table 1 presents the results from the estimated 5-variable satellite model for sector-median EDFs. The results show that most of the parameters are statistically significant, except in few cases. For example, the parameters for inflation and short-term interest rates are mostly insignificant at 5% level. The result that interest rates are insignificant may seem counter-intuitive particularly given that past literature has often found this variable as a significant driver of corporate sector credit quality. One explanation could be that the EDFs are generated by using the Merton (1974) model with some embedded confidential assumptions by Moody's KMV. The main driver of the EDFs is the value of the assets/equity (market capitalisation) and the default point (which is a function of liabilities). For this reason it might not be fully surprising that interest rates do not show particular explanatory power on the EDFs. [17]

Most of the parameter signs are also rather similar across the various sector EDFs. Specifically, the estimation shows that a decrease in GDP causes an increase in euro area corporate sector default probabilities in all industries, which is an intuitive result although previous literature has been somewhat inconclusive about the role of the changes in the GDP variable in explaining corporate sector credit quality. The effect is particularly strong for the BaC, Cap and CCy sectors. A decline in equity prices contributes to an increase in euro area corporate default probabilities in all industries by inducing a tightening in the corporate financing conditions. The same holds in the case of an appreciation of the euro exchange rate against the US dollar. These latter results reflect the importance of international financial developments on corporate default intensity in the euro area, particularly for the Cap and TMT sectors. The impact of inflation is more mixed and varies across sectors, with higher inflation contributing to higher EDFs in the cyclical industries. The coefficients of short-term interest rates are mostly insignificant in our sample period. Interestingly, experimenting with various non-linear specifications of the right-hand of the equation did not improve the fit of the model.

Turning to the estimations using the median-leverage firm's EDFs as the left-hand side variable, the results in Table 2 show that the median leverage firm EDF reactions receive similar signs as the sector median EDF reactions. For example, a negative one standard error shock to the euro area GDP has positive effects on individual median-leverage firms in all sectors, especially on the firms in the Cap, CCY and the ENU sectors. The impacts of shocks

[17] We also estimated a version of the satellite equation that includes the volatility of the long-term interest rate rather than the first difference in short-term interest rate as an explanatory variable. The estimated coefficients received positive signs and were highly statistically significant. These results are available upon request.

to the real equity prices and real exchange rates are slightly more mixed across sectors in the median-leverage firm case, while a positive inflation shock seems to increase the EDFs for all sectors apart from the TMT sector. The R^2 values are generally lower when this specification of the corporate EDFs is used.

Table 2. The Satellite model estimation for median-leverage firms' EDFs (1992:Q1-2005:Q4)

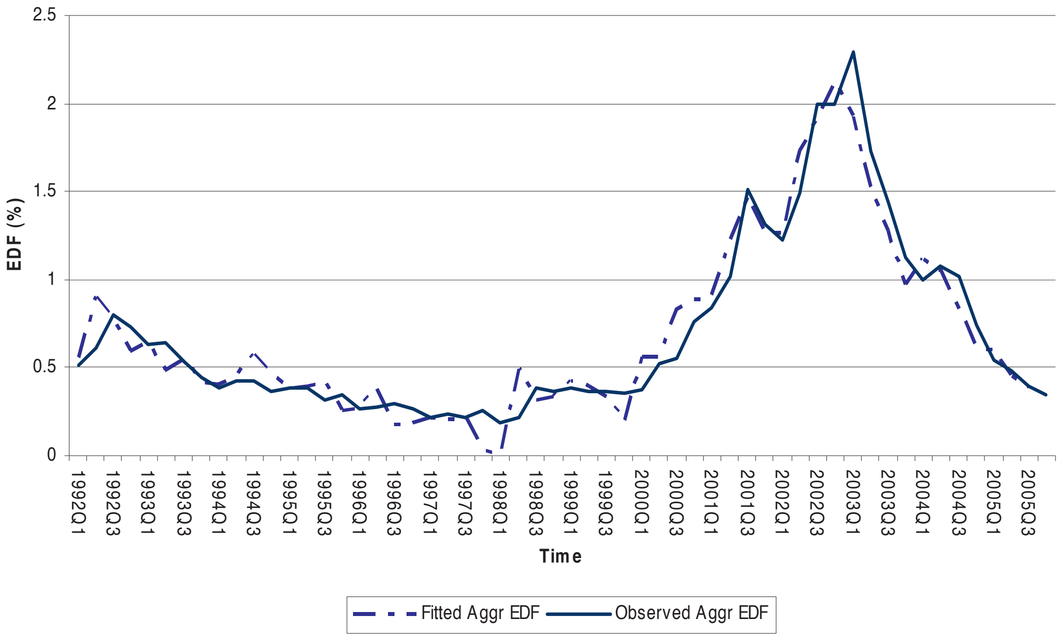
	Const	GDP	INFL	EQUITY	EP	IR	Adjusted R-squared
Aggr_Firm	-1.813	-2.622	8.881	0.039	0.056	-0.104	0.379
P-value	0.314	0.097	0.000	0.593	0.701	0.172	
BaC_Firm	0.375	-0.169	0.327	0.002	0.016	-0.004	0.110
P-value	0.078	0.358	0.222	0.770	0.357	0.618	
Cap_Firm	-0.071	-0.215	9.833	-0.072	-0.059	-0.242	0.167
P-value	0.982	0.938	0.018	0.576	0.822	0.074	
CCY_Firm	0.352	-0.388	1.208	-0.010	0.011	-0.003	0.289
P-value	0.241	0.139	0.002	0.412	0.653	0.820	
CNC_Firm	0.110	0.000	-0.002	-0.001	-0.001	0.000	0.062
P-value	0.000	0.991	0.924	0.215	0.678	0.702	
ENU_Firm	0.265	0.007	0.555	0.006	-0.007	-0.010	0.219
P-value	0.065	0.955	0.003	0.316	0.531	0.092	
Fin_Firm	0.032	-0.017	0.001	0.000	0.000	0.000	0.292
P-value	0.000	0.000	0.921	0.367	0.583	0.074	
TMT_Firm	0.686	-0.327	-0.243	-0.038	0.008	-0.015	0.287
P-value	0.022	0.202	0.512	0.002	0.751	0.224	

Notes: See Table 1. Aggr firm stands for the median leveraged firm representing the euro area, BaC firm is the median leveraged firm in the basic and construction sector and similarly for the other sectors. The last column presents the adjusted R-squared.

In order to verify the estimation results, we perform the CUSUM test for parameter stability, the White test for residual autocorrelation, and the Breuch-Pagan test for heteroskedasticity. In both cases of the two different EDF specifications, the CUSUM test implies parameter stability since the recursive parameters fall within the 95% confidence interval. The other 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.

Once estimated, the Satellite model is integrated into the GVAR model to form the Satellite-GVAR model. To graphically illustrate the goodness-of-fit, Chart 1 plots the fitted model for the aggregate sector euro area EDFs against the observed aggregate EDFs.

Chart 1. Fitted values of the Satellite-GVAR for aggregate EDF



Note: The EDFs are in levels. Actual stands for the historical EDF series, while the fitted EDF is the in-sample forecast from the Satellite-GVAR model.

5. EDF reaction to shocks: Impulse response analysis using the Satellite-GVAR model

After estimating the parameters of the satellite model, this section studies the sector median EDF reactions over a 10-year horizon to a one standard error shock to selected macroeconomic and financial variables. All the impulse responses are presented in Charts C.1-C.17, Appendix C. The figures provide a measurement of the reactions compared to the baseline.

In general, most sector median EDFs react similarly to the benchmark aggregate case, except for the technology sector median EDF, which is almost always more affected than the other EDFs in our sample period. This reflects the fact that the technology sector boom and bust period in the late 1990s is incorporated in the time series.

A negative standard error shock to the euro area GDP has a small positive effect on the median EDFs of different sectors (see Chart C.1) after 4-12 quarters. The financial sector (Fin) is the least effected compared to the other sectors. By comparison, the US and the global negative GDP growth shocks also show positive initial effects on the EDFs (i.e. higher probability to default), but the effects of the global shocks are more persistent compared to the euro area and US GDP shocks. These results indicate that euro area firms could be more sensitive to disturbances in global growth rather than the euro area and the US growth. Additionally, the consumer cyclical sector (CCy) median EDF reacts more than the non-cyclical sector (CNC) EDF to business cycle variables such as GDP, inflation, and short term interest rate, which is an intuitive output of the Satellite-GVAR model.

The technology and aggregate sector EDFs react significantly to shocks to the exchange rate, stock markets and short term interest rates (see Charts C.2-C.4). Charts C.6, C.8 and C.14 show the sector median EDF reactions to a positive one standard error shock to inflation originating from the euro area, the US, or globally. The shocks have initially a negative effect on the EDF, except in the BaC, CCy and EnU sectors. Generally, the EDF reactions are positive after 6 quarters. A positive one standard error shock to euro area inflation increases the sector median EDFs by 3.5-12.5% in the long-run.

A negative shock to the US real equity price has an impact of approximately 15-34.5% on the various sector median EDFs, except for the TMT sector for which the impact amounts to 91%. Qualitatively, there is a similar effect in the case of a euro area equity market shock. The impact of a global real equity price shock is almost similar to the US shock, which is explained by the important role of the US as the largest stock market in the world. A negative short-term interest rate shock originating from the euro area has a significantly higher effect on the EDFs than a US short-term interest rate shock (see Charts C.7 and C.9), with a negative one standard error shock to the euro area short-term interest rates having a permanent positive effect on the EDFs within the range of 9.50-16%. The EnU sector median EDF is most affected, followed by BaC sector median EDF. Finally, a positive standard error shock to oil prices has a significant effect on the aggregate and all sector median EDFs, where the reaction ranges between 16-43%. The TMT, CCy and EnU sector median EDFs react more than other sector EDFs.

6. Simulation exercise of the Satellite-GVAR model

Finally, we conduct a bootstrap experiment on the Satellite-GVAR model, to create the maximum and the minimum bounds of the EDF reactions to the Satellite-GVAR. Initially, the literature on the bootstrapping method assumes that the variables are independent and identically distributed (iid). 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 on the Satellite-GVAR model shows the euro area aggregate sector median EDF reactions within a 90% confidence interval bound (where 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 bootstrap experiment is designed as follows[18]:

(i) Draw (with replacement) a time series of length 56 quarters from the joint 'empirical' distribution of the financial risk factors (exogenous variables of the satellite model) and the EDFs. For each period we draw a 6-tuple (*i.e.* from the five risk factors and from the one EDF time series).

(ii) Re-estimate the Satellite-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.

Table 3 summarises the results of the bootstrap experiment. The Satellite-GVAR model, given a shock, is rejected (denoted by *Xs*) if the EDF reaction tends to be outside the 90% range *at least once in the 40 quarters.* The results show that the benchmark Satellite-GVAR model representing the aggregate euro area EDF is within the 90% confidence interval for all types of shocks. By contrast, under the rather restrictive conditions, the EnU, the Fin and the TMT sector median EDFs appear insignificant for all models.

[18] As an alternative to the current experiment, a residual-based parametric bootstrap exercise can be constructed.

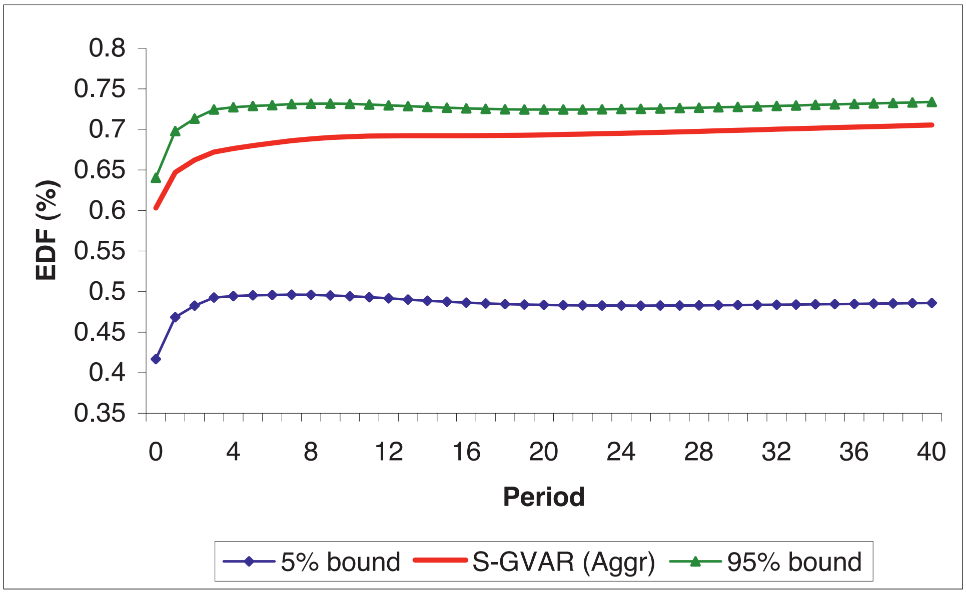
Table 3. Summary of the simulation exercise

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
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
Global_Neg_GDP				X	X	X	X	X
China_Neg_EP	X			X		X	X	X
Japan_Neg_EP		X		X		X	X	X
UK_Neg_EP				X		X	X	X

Notes: Xs denote inconsistent model given a shock. The names of the shocks show the origin country 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.

As an example, Chart 2 illustrates the Satellite-GVAR model of the euro area aggregate sector median EDF and the simulated confidence bounds for a positive oil price shock.

Figure 2. Bootstrapped Satellite-GVAR model for the aggregate sector median EDF - oil price shock



7. Conclusions

This paper provides a framework for assessing the impact of domestic and global macro-financial shocks on euro area corporate sector credit quality by analysing links between macroeconomic variables and firms' expected default frequencies. Reflecting the growing global exposure of the euro area corporate sector, we use the Global Vector Autoregressive (GVAR) model as a macroeconometric "engine". We then construct a linking equation to the GVAR model to analyse the impact of shocks to the sector level EDFs in the euro area. Additional benefits of this "Satellite-GVAR" approach are that it isolates the expected default frequency from the GVAR system, which allows one to operate with limited data on EDFs.

The results show that – at the aggregate corporate sector level - the EDFs particularly react to shocks to the GDP, the euro/US dollar exchange rate, equity prices and oil prices. The results using the sector-specific EDFs indicate that euro area firms are more sensitive to shocks to global growth compared to shocks to euro area growth. In general, most sector level EDFs react rather similarly to the aggregate EDF, except for the technology sector EDF, which is more affected than the others in our sample period. Additionally, the cyclical sector EDFs react initially more than the non-cyclical sectors to business cycle variables such as GDP and inflation, which is an intuitive output of the Satellite-GVAR model. In a simulation exercise of the Satellite-GVAR models, the aggregate EDF is found consistent, whereas the results appear somewhat weaker for some sector level EDFs.

All in all, the Satellite-GVAR model offers a promising framework for analysing the impact of a wide range of global macro-financial shocks to euro area corporate sector credit quality. For example, in financial sector stress-testing exercises, the constructed model could be conveniently linked to a credit portfolio model to stress-test banks' credit losses as a response to changes in the default probabilities of their corporate borrowers. We plan to extend the current work in these directions in the future.

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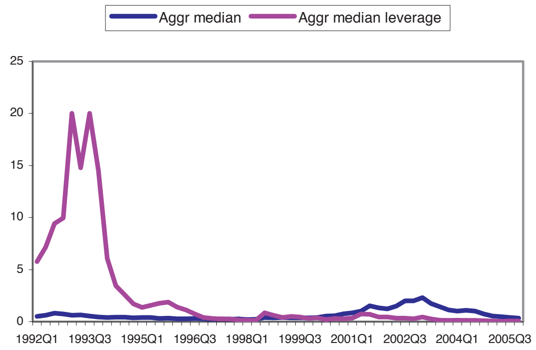
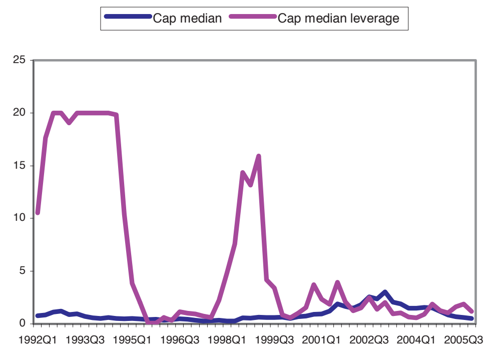
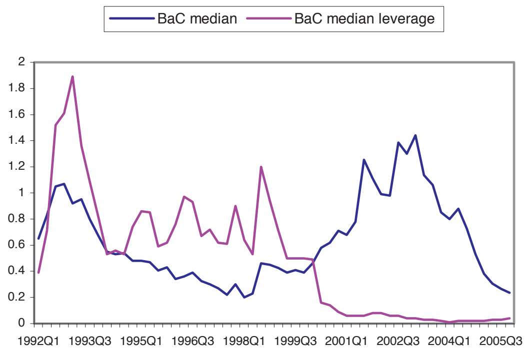
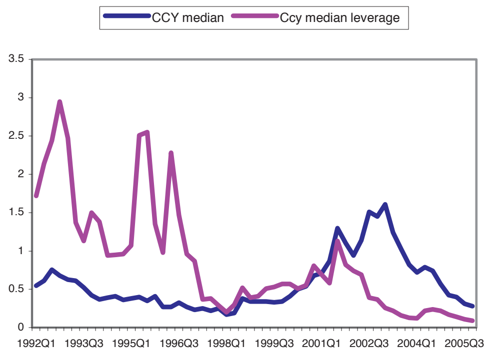
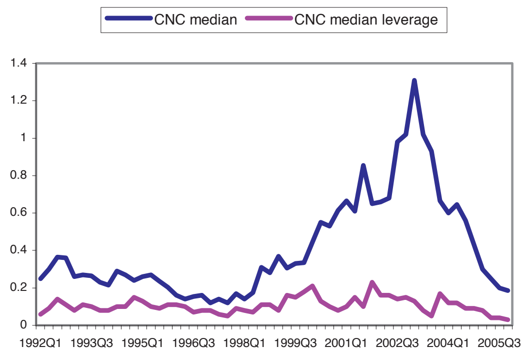
Appendix A. Plots of EDF data

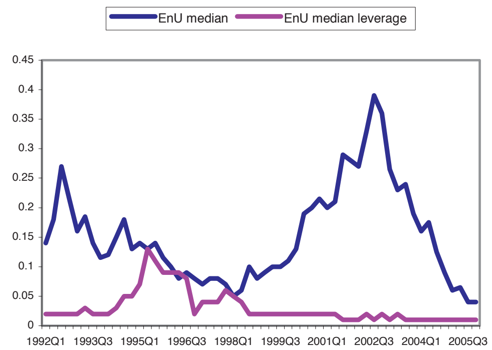


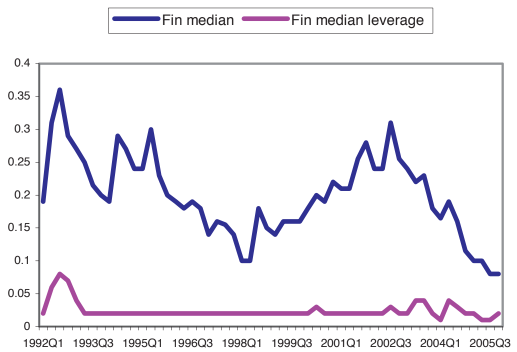


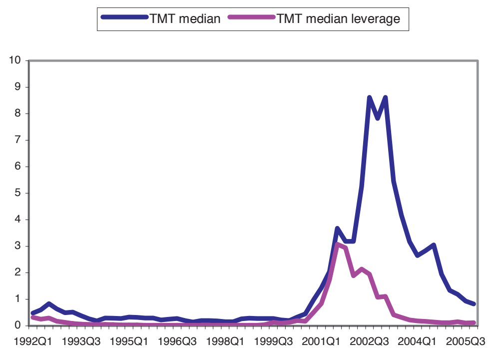












Appendix B. The GVAR model

The version of the GVAR model used in this paper covers 33 countries: 8 of the 11 countries that originally joined the euro area on January 1, 1999 are grouped together[19], while the remaining 25 countries are modelled individually (see Table A1 for the list of countries included in the GVAR model and composition of regional groups). Therefore, the present GVAR model contains 26 countries/regions estimated over the sample period 1979(2)-2005(4).

The endogenous variables included in the country specific models are the logarithm of real output (y_{it}); the quarterly rate of inflation (π_{it}), the real effective exchange rate (re_{it}), the short-term interest rate (r_{it}^{s}), and if relevant real equity prices (q_{it}), and the long-term interest rate (r_{it}^{l}). The time series data for the euro area were constructed as cross section weighted averages of y_{it} , π_{it} , r_{it}^{S} , q_{it} , r_{it}^{L} over Germany, France, Italy, Spain, Netherlands, Belgium, Austria and Finland, using average Purchasing Power Parity GDP weights over the 1999-2001 period.

The trade shares used to construct the country-specific foreign variables (the "starred" variables) are given in the 26×26 trade-share matrix provided in a Supplement to DdPS available on request. Table A2 presents the trade shares for selected economies (ten countries plus the euro area), with the "Rest" category showing the trade shares for the remaining countries.

With the exception of the US model, all individual models include the country-specific foreign variables, y_{it}^{*} , π_{it}^{*}, r_{it}^{*S} , q_{it}^{*} , r_{it}^{*L} and oil prices (po_{t}). The country-specific foreign variables are obtained from the aggregation of data on the foreign economies using as weights the trade shares in Table A2. Because the set of weights for each country reflects its specific geographical trade composition, foreign variables vary across countries. It is clearly possible to use different types of weights for aggregation of different types of variables. The problem is one of data availability and empirical feasibility. However, we do not think that the choice of the weights is critical for the results. We have addressed this issue in DdPS partly by considering time-varying trade weights. Also in the case of equity and bond prices that tend to move very closely across different economies it is unlikely that using other weights could matter much.

Subject to appropriate testing, the country-specific foreign variables are treated as weakly exogenous when estimating the individual country models (see Table A3). The concept of

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[19] Due to availability issues, we have been able to include only 8 out of the 11 countries. These countries represent however more than 93% of total euro area GDP.

weak exogeneity in the context of the GVAR is discussed in DdPS and relates to the standard assumption in the small-open-economy macroeconomic literature. Whether such exogeneity assumptions hold in practice depends on the relative sizes of the countries/regions in the global economy. Following Johansen (1992) and Granger and Lin (1995) this assumption implies no long run feedbacks from the domestic/endogenous variables to the foreign variables, without necessarily ruling out lagged short run feedbacks between the two sets of variables. In this case the star variables are said to be `long run forcing' for the domestic variables, and implies that the error correction terms of the individual country VECMs do not enter in the marginal model of the foreign variables.

For the set of selected countries, as can be seen from Table A3, the weak exogeneity assumptions are rejected only for output and long-term rates in the UK model. We would have been concerned if the weak exogeneity assumptions were rejected in the case of the US or the euro area models, for example. But as can be seen from Table A3, the weak exogeneity of foreign variables and oil prices are not rejected in the euro area model. Aggregation of the euro area countries in a single model could have violated the weak exogeneity assumptions that underlie GVAR modelling. However, the tests suggest that the foreign euro area-specific variables can be considered as weakly exogenous.

The specification of the US model differs from that of the other countries in that oil prices are included as an endogenous variable, while only $re^{*}_{US,t}$, $y^{*}_{US,t}$ and $\pi^{*}_{US,t}$ are included in the US model as weakly exogenous. The endogeneity of oil prices reflects the large size of the US economy. The omission of $q^{*}_{US,t}$, $r^{*S}_{US,t}$ and $r^{*L}_{US,t}$ from the vector of US-specific foreign financial variables reflects the results of tests showing that these variables are not weakly exogenous with respect to the US domestic financial variables, in turn reflecting the importance of the US financial markets within the global financial system. As shown by Table A3, foreign real equity prices and foreign interest rates (both short and long-term) cannot be considered as weakly exogenous and have thus not been included in the US model.

Finally, the issue of parameter instability is also dealt with in DdPS, where we conduct a number of structural stability tests along the lines of Stock and Watson (1996) and find that although there is evidence of structural instability, this is mainly confined to error variances and do not seem to adversely affect the coefficient estimates.

Table A1: Countries and Regions in the GVAR Model

Unites States	**Euro Area**	**Latin America**
China	Germany	Brazil
Japan	France	Mexico
United Kingdom	Italy	Argentina
	Spain	Chile
Other Developed Economies	Netherlands	Peru
Canada	Belgium	
Australia	Austria	
New Zealand	Finland	
Rest of Asia	**Rest of W.Europe**	**Rest of the World**
Korea	Sweden	India
Indonesia	Switzerland	South Africa
Thailand	Norway	Turkey
Philippines		Saudi Arabia
Malaysia		
Singapore		

Table A2: Trade Weights Based on Direction of Trade Statistics

Country/						Rest of W. Europe			Rest*
Region	US	EA	China	Japan	UK	Sweden	Switz.	Norway	
US	0	0.155	0.073	0.124	0.052	0.008	0.012	0.004	0.570
EA	0.227	0	0.056	0.072	0.238	0.057	0.090	0.028	0.230
China	0.236	0.164	0	0.248	0.029	0.010	0.007	0.003	0.304
Japan	0.319	0.132	0.128	0	0.032	0.007	0.009	0.003	0.369
UK	0.180	0.537	0.020	0.042	0	0.027	0.028	0.023	0.146
Sweden	0.104	0.517	0.025	0.035	0.115	0	0.017	0.099	0.089
Switz.	0.113	0.670	0.015	0.039	0.066	0.015	0	0.004	0.079
Norway	0.090	0.449	0.020	0.030	0.181	0.132	0.008	0	0.091

Table A3: F Statistics for Testing the Weak Exogeneity of the Country-specific Foreign Variables and Oil Prices

		Foreign Variables						
Country		y^*_{it}	π^*_{it}	q^*_{it}	r^{*S}_{it}	r^{*L}_{it}	po_t	$re^*_{i,t}$
United States	F(2, 83)	0.27	0.17	-	-	-	-	2.64
Euro Area	F(3, 74)	2.31	1.94	0.45	0.98	2.36	1.63	-
China	F(1, 80)	0	0.29	1.34	0.01	1.59	3.53	-
Japan	F(3, 74)	1.97	0.96	0.65	1.14	1.59	1.44	-
U. Kingdom	F(3, 74)	2.14	1.85	1.75	1.85	1.14	2.48	-
Sweden	F(3, 74)	4.43#	0.40	0.47	0.94	3.10#	1.12	-
Switzerland	F(3, 74)	1.06	0.26	0.32	0.80	0.64	0.63	-
Norway	F(3, 74)	0.56	0.74	0.22	0.20	2.72	0.70	-

Note: #denotes statistical significance at the 5% level.

Appendix C. Median sector EDF Reactions

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

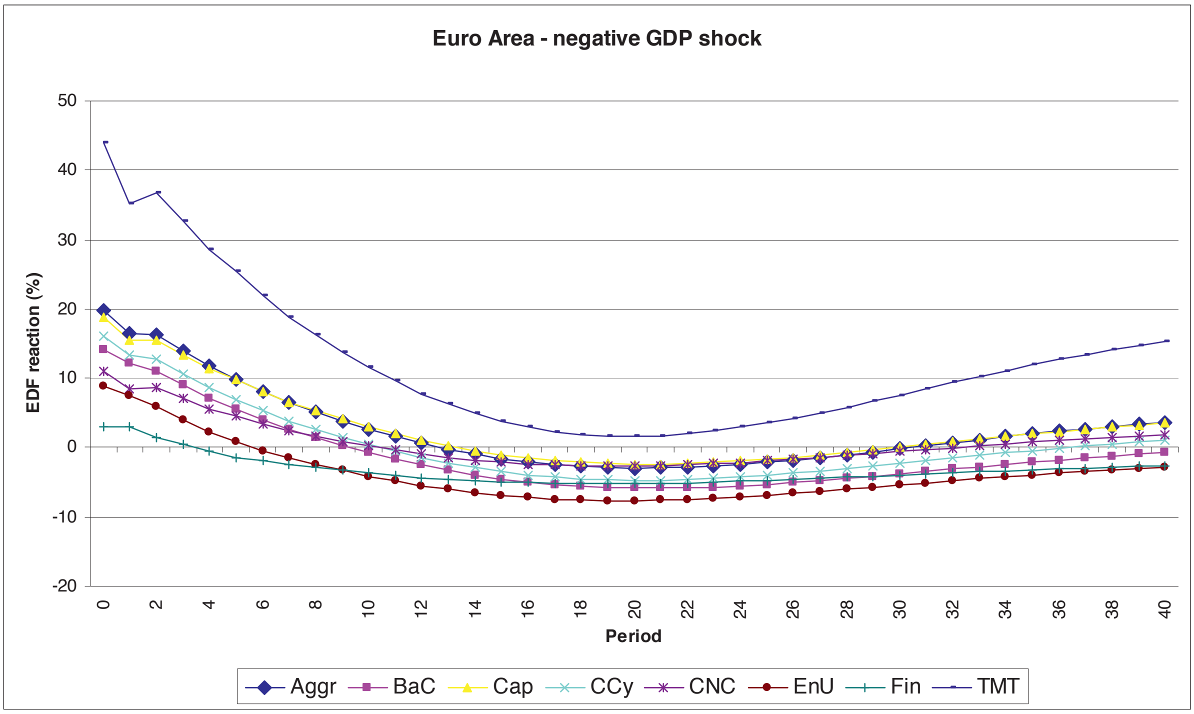


Figure C.2 One negative standard deviation shock to the euro area equity prices

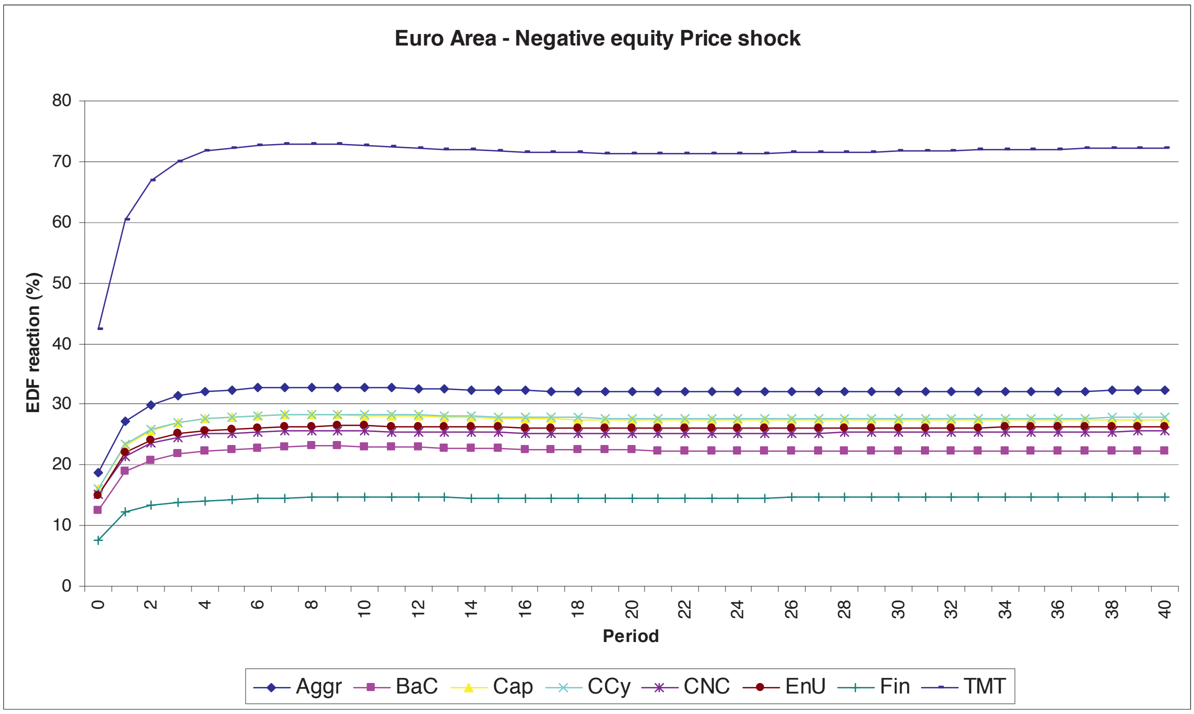


Figure C.3 One positive standard deviation shock to the euro (i.e. depreciation)

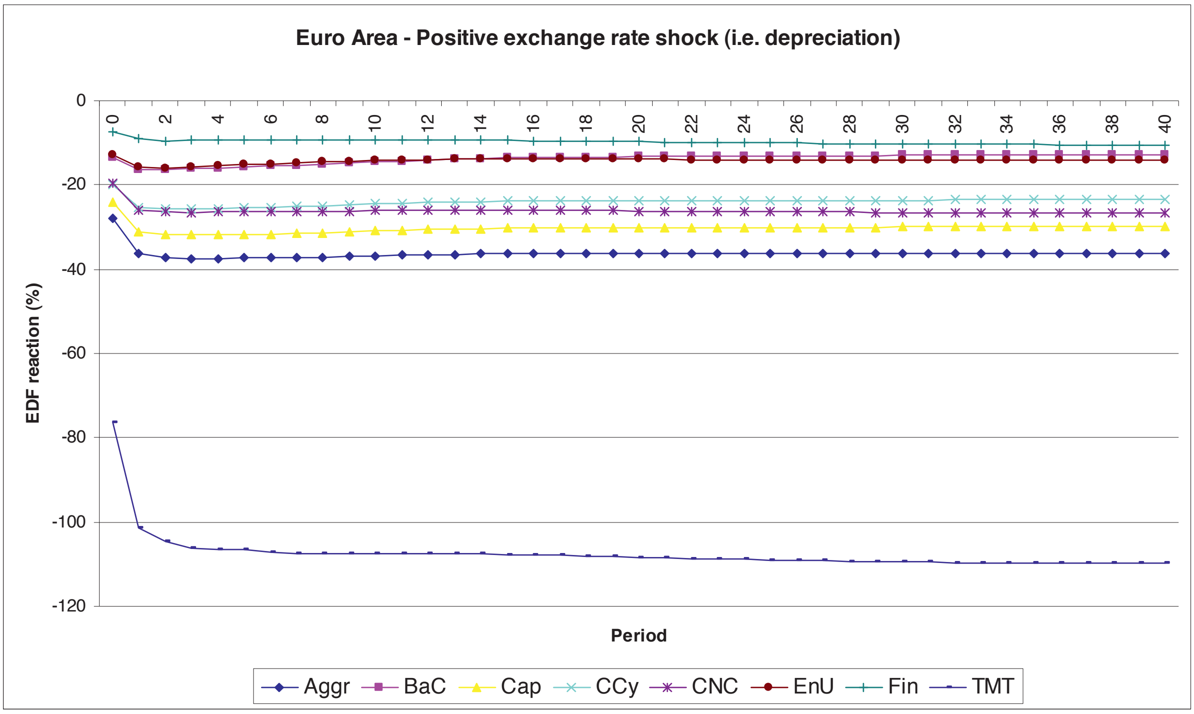


Figure C.4 One positive standard deviation shock to the euro area short-term interest rate

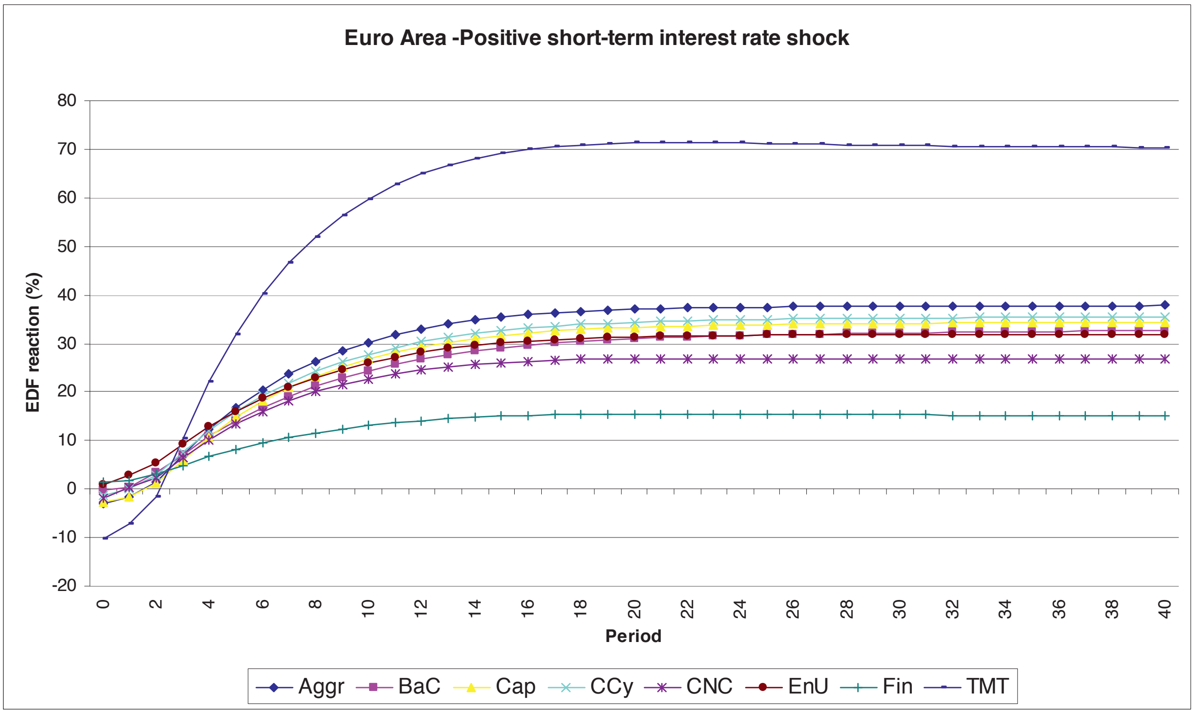


Figure C.5 One positive standard deviation shock to the euro area long-term interest rate

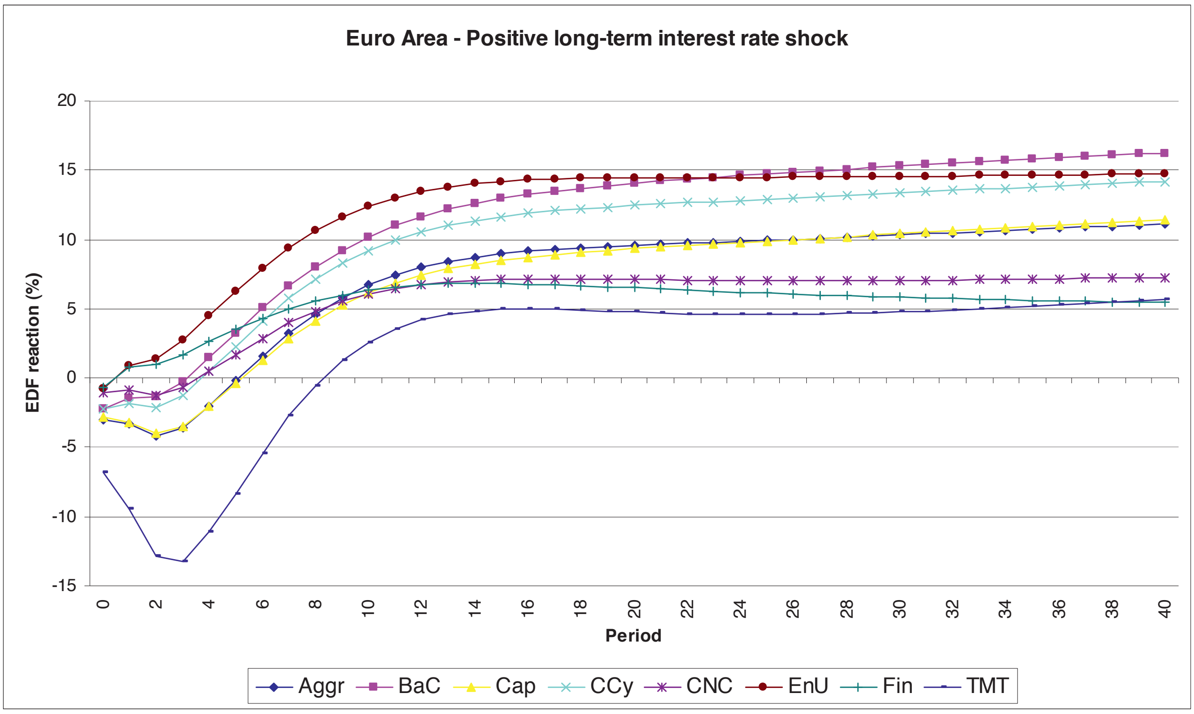


Figure C.6 One positive standard deviation shock to euro area inflation

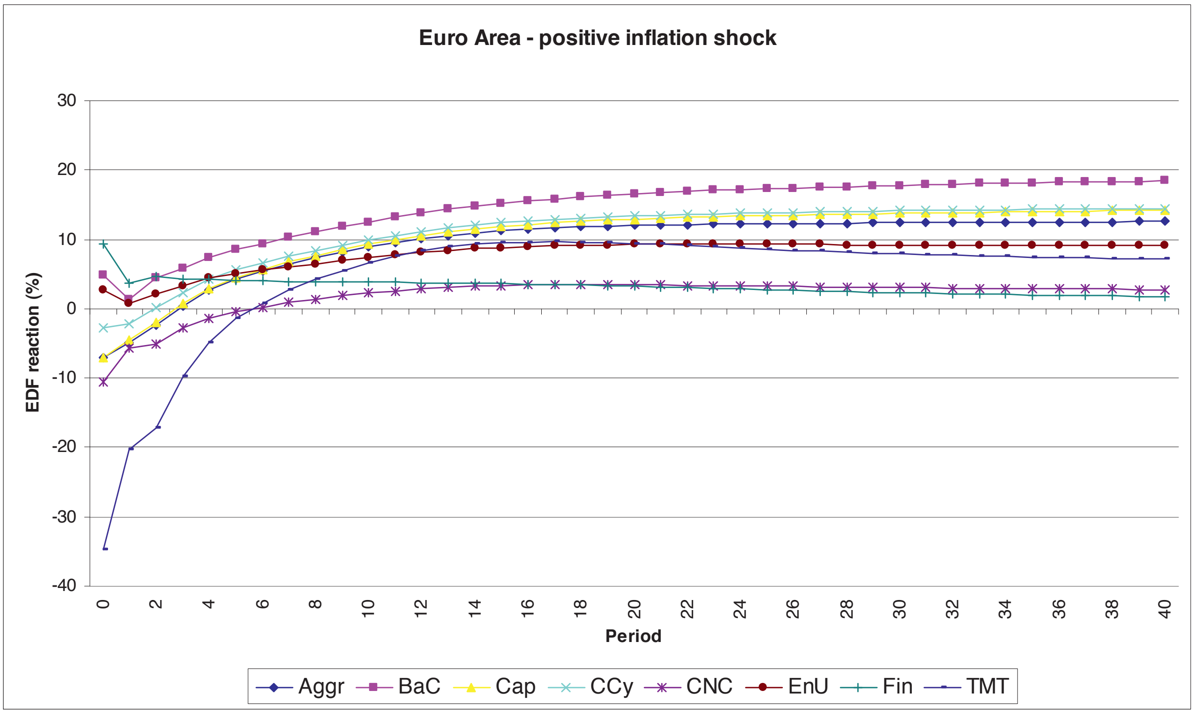


Figure C.7 One negative standard deviation shock to US GDP growth

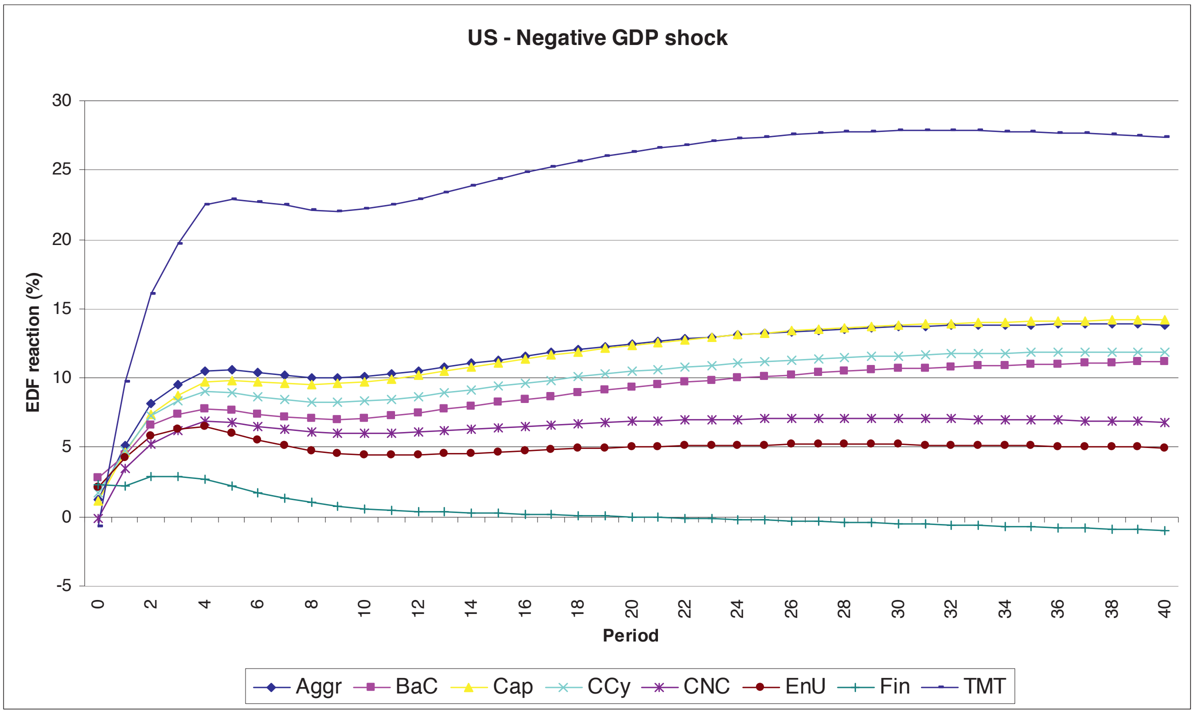


Figure C.8 One positive standard deviation shock to US Inflation

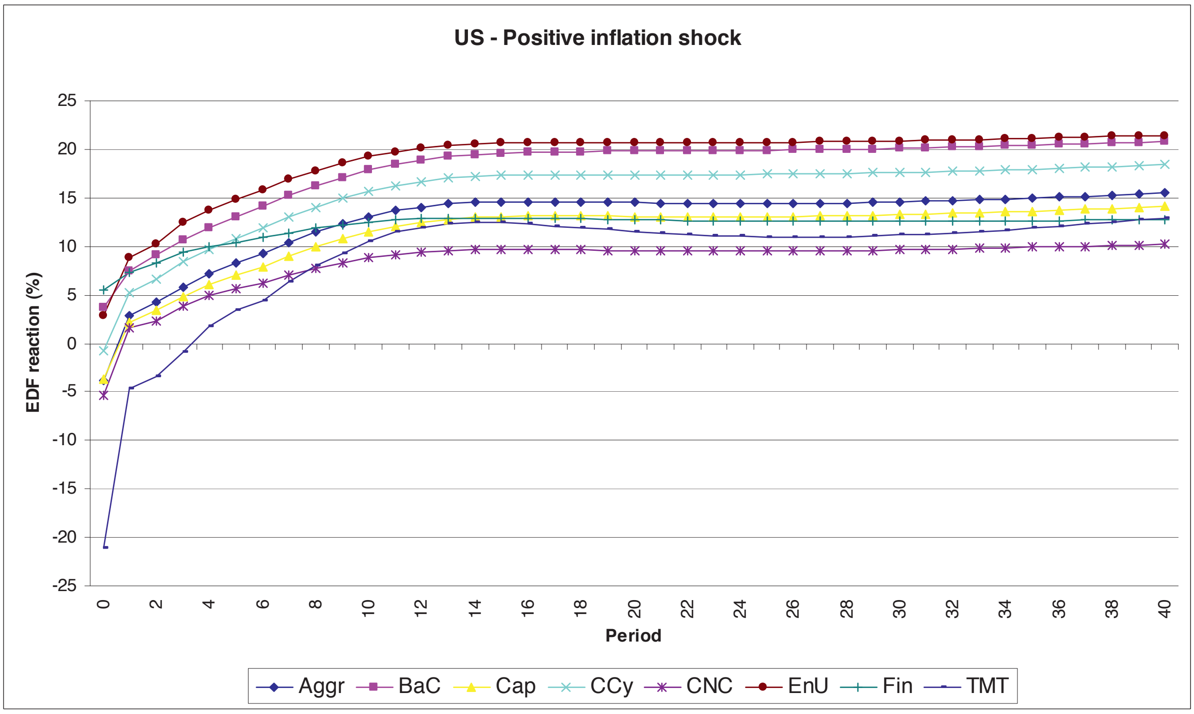


Figure C.9 One negative standard deviation shock to the US equity prices

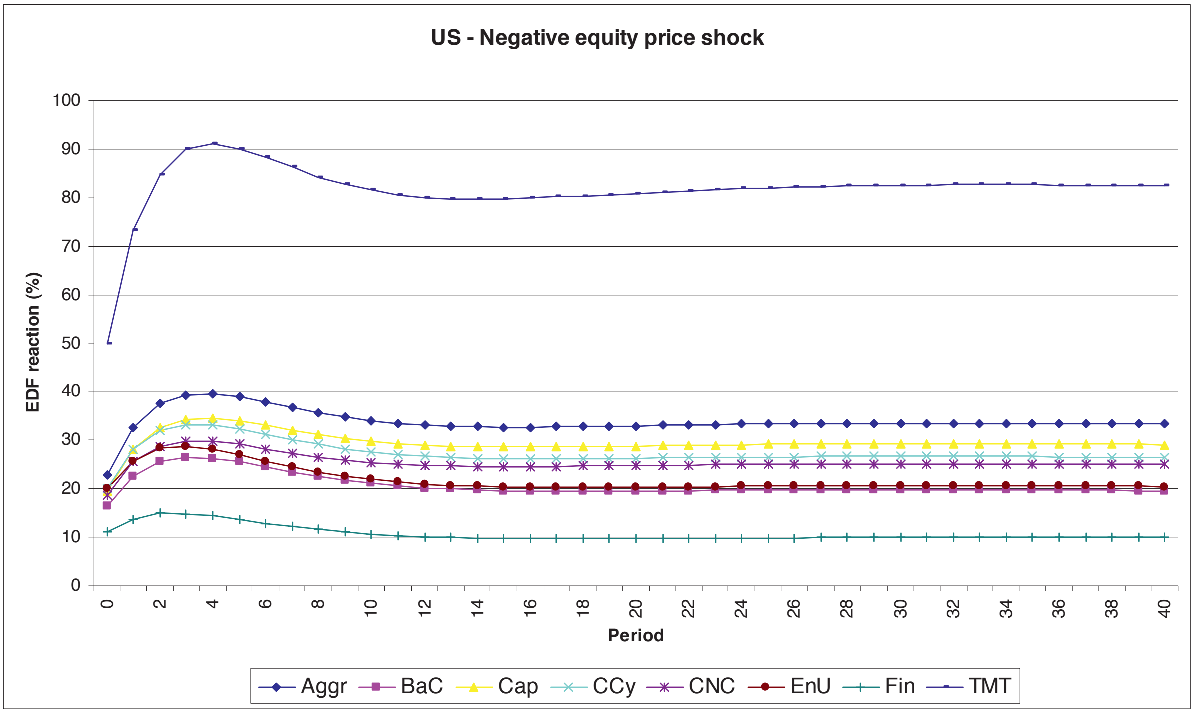


Figure C.10 One positive standard deviation shock to the US short-term interest rate

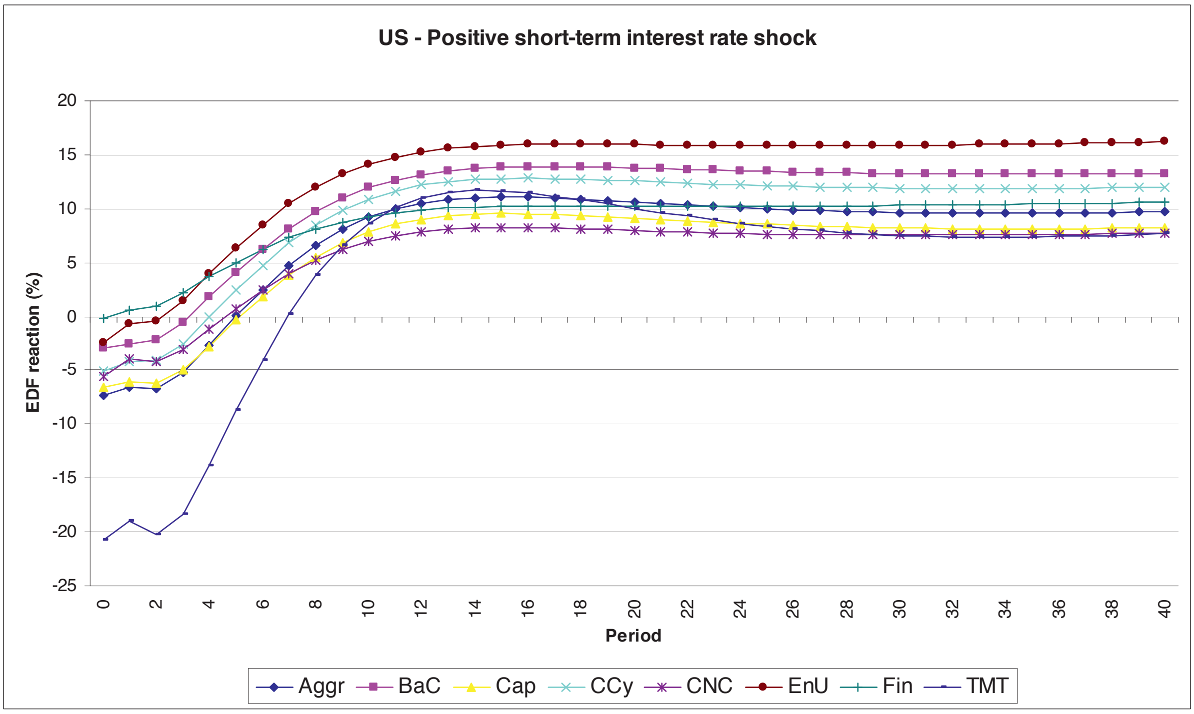


Figure C.11 One positive standard deviation shock to the global oil prices

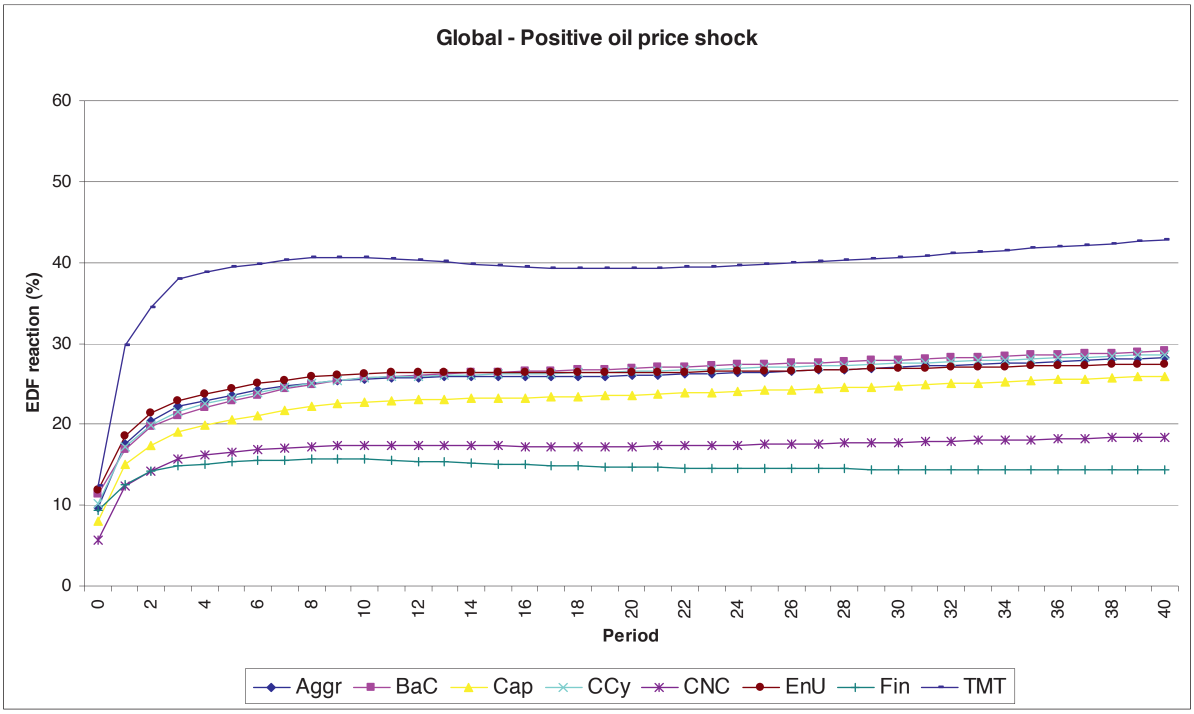


Figure C.12 One negative standard deviation shock to the global equity prices

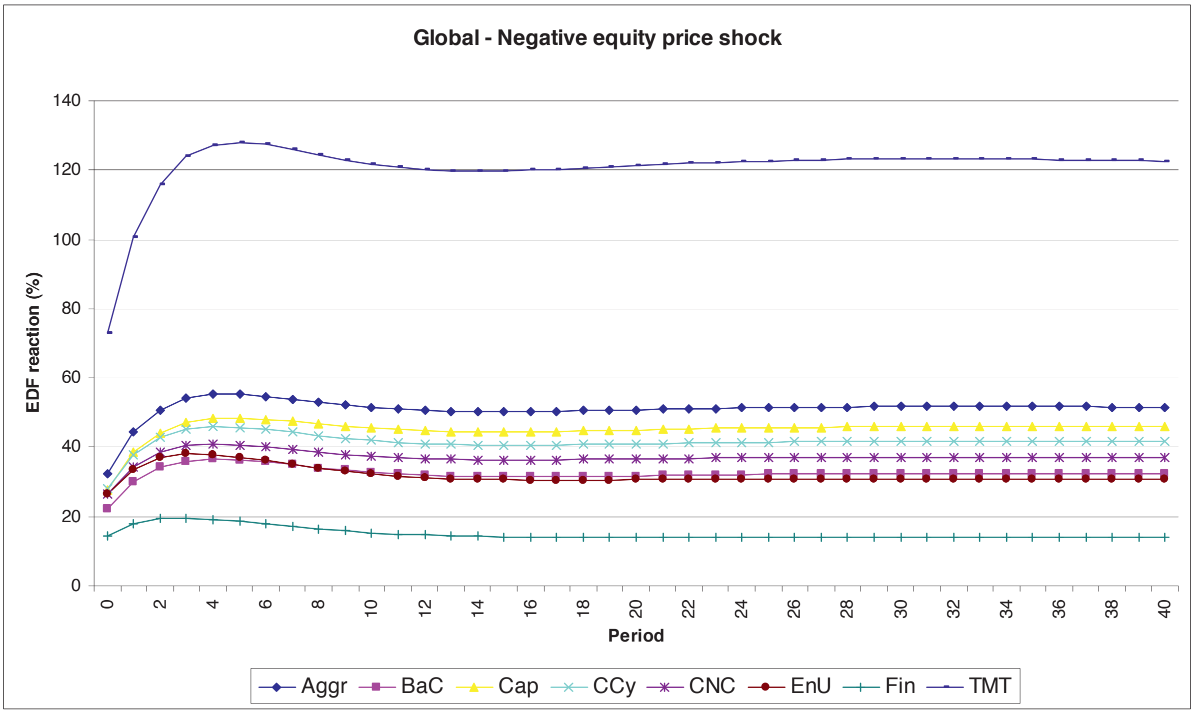


Figure C.13 One negative standard deviation shock to the global GDP growth

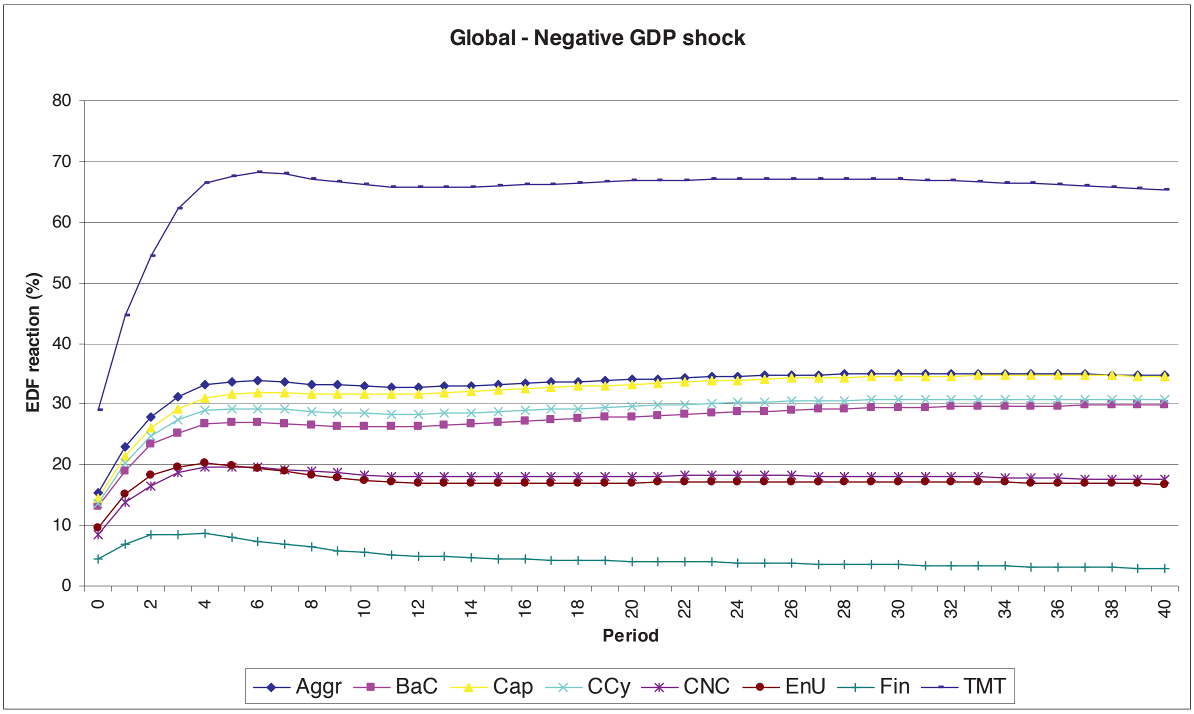


Figure C.14 One positive standard deviation shock to global inflation

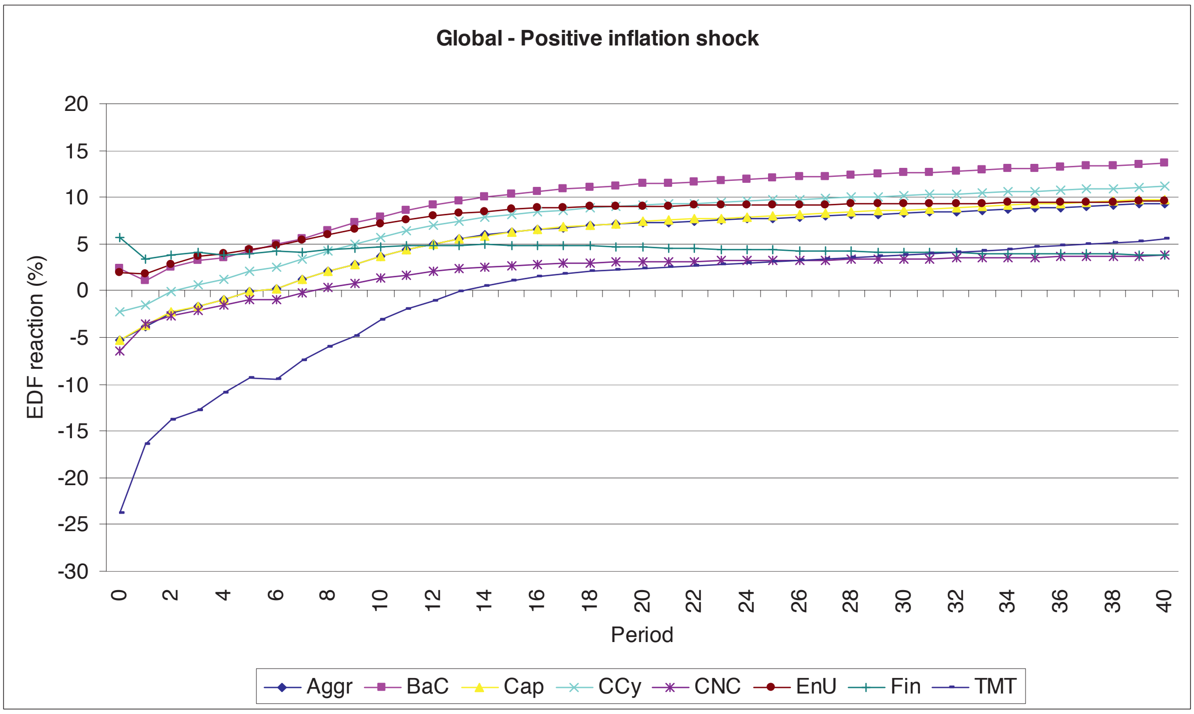


Figure C.15 One positive standard deviation shock to the Chinese renmembi

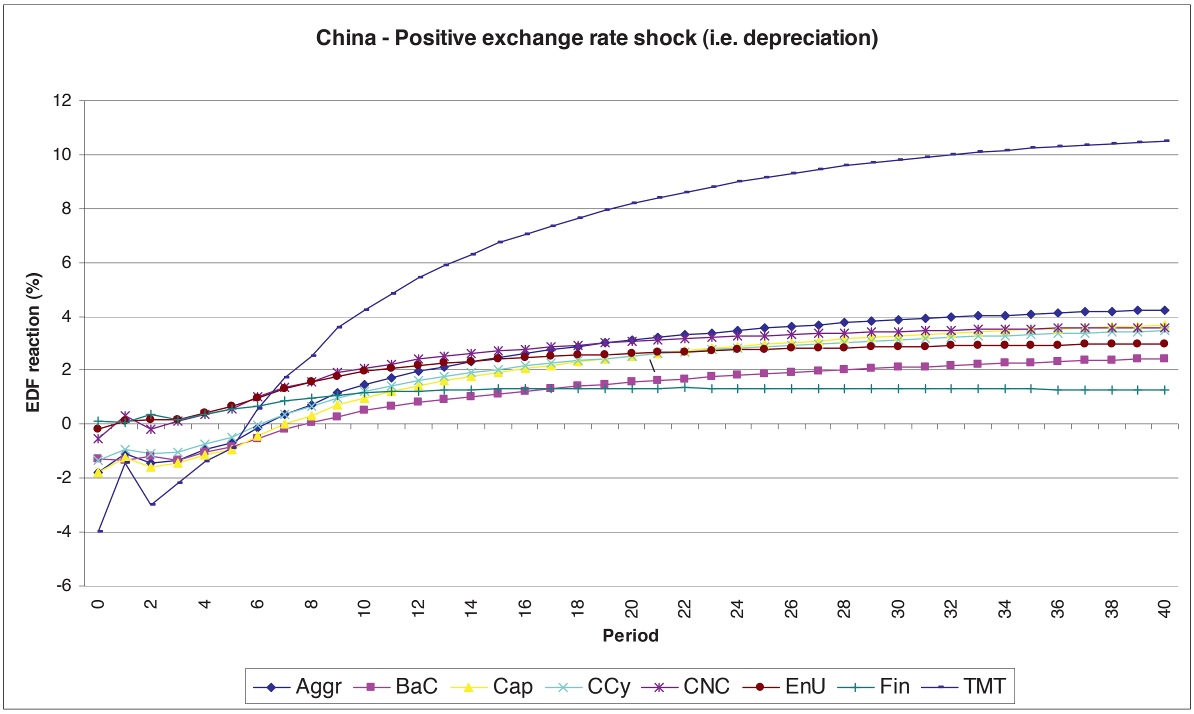


Figure C.16 One positive standard deviation shock to the Japanese yen

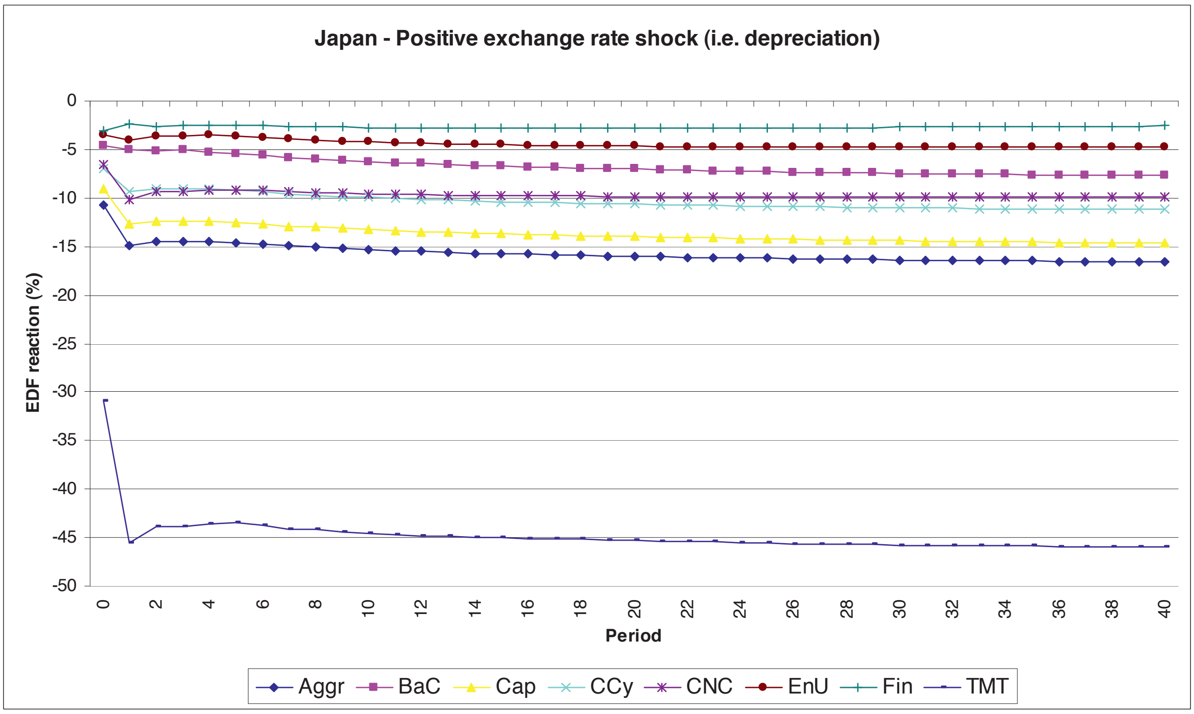
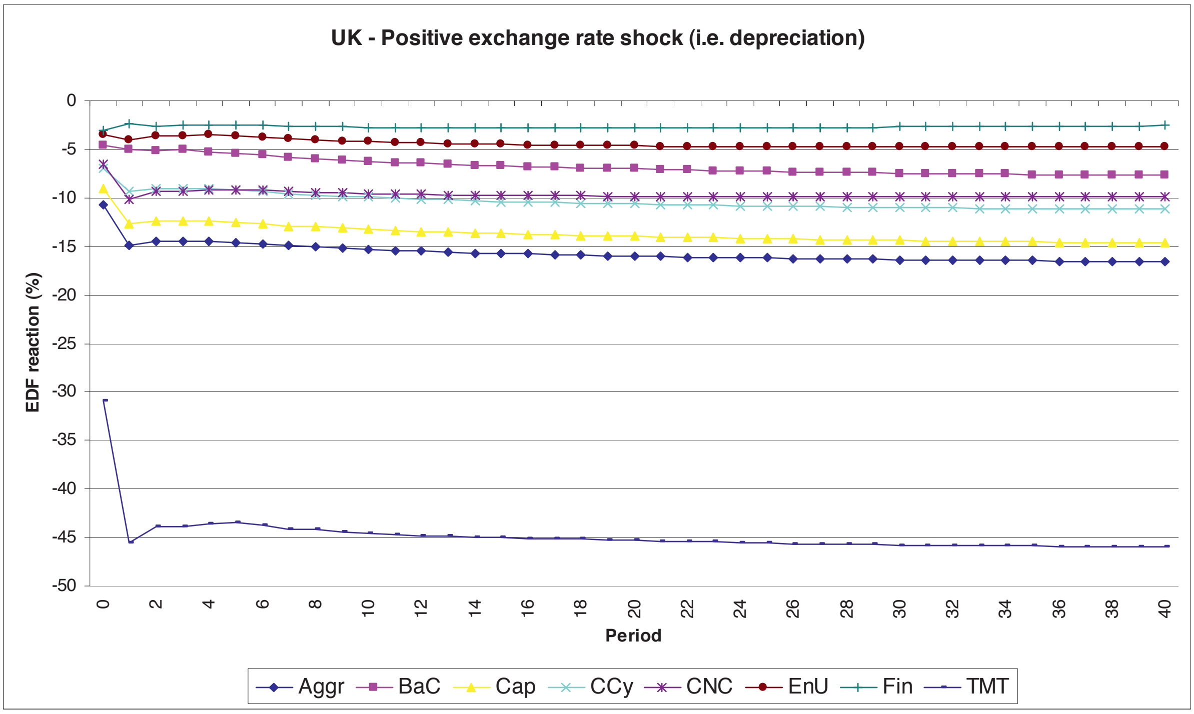


Figure C.17 One negative standard deviation shock to UK pound sterling



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