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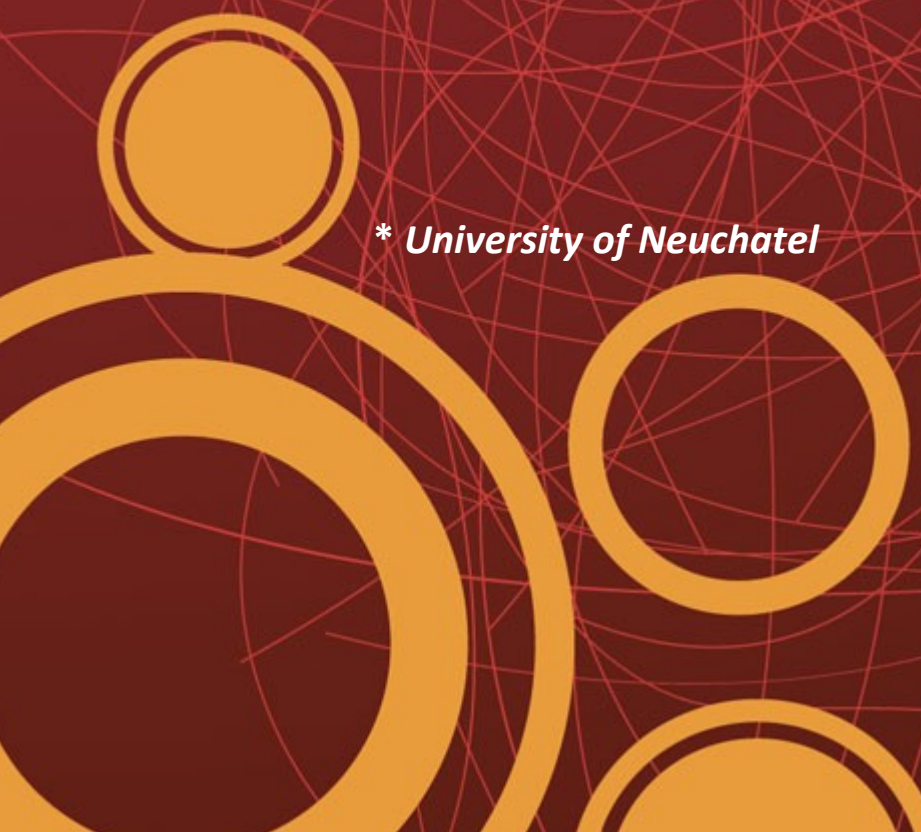
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Real Sector & Banking System: Real & Feedback Effects. A Non-Linear VAR Approach

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Real Sector and Banking System: Real and Feedback Effects. A Non-Linear VAR Approach*

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Abstract

This paper assesses the relationship between the macroeconomic system and the banking sector by estimating two separate non-linear Vector Autoregressive models (VAR) for the US and Switzerland. The model specification includes the output gap, the interest rate, the inflation rate and a banking quality measure. Impulse response functions are estimated by using the local projections approach. The results highlight the existence of the real effect (going from the macroeconomic system to the banking sector), and of the feedback effect (going from the the banking sector to macroeconomic system). The findings are robust to the sample period, the size of the shocks as well as to the Cholesky decomposition employed.

Keywords Financial Stability, Non-Linear VAR, Local Projections Methods

JEL Classification C32, E44, E47, G21, G32

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1 Introduction

The global financial crisis, which started in the second half of 2007, highlighted how a shock generated in a specific sector can spread around other sectors and eventually rebound stronger and more severe than before. As a consequence, a thorough knowledge of the mechanisms linking the real economy, the banking sector and the financial system is needed in order to avoid or at least mitigate the impact and the propagation of a shock to the entire economic system. This results can be achieved by making the policy measures, which have to be implemented in crises periods, more effective.

Several empirical contributions study the relationship between the macroeconomic system and the banking sector. The majority of them provide evidence for the real effect (how the banking sector reacts to a shock generated in the macroeconomic system), but they fail to detect the feedback effect (how the real sector reacts to a banking system shock). This can be due potential non-linearities governing the relationship between the macroeconomic system and the banking sector that are not explicitly taken into account.

In this paper, we assess the relationship between the real sector and the banking system by estimating a Vector Autoregressive model (VAR)¹, characterized by a non-linear specification, and using the local projection approach to compute the impulse response functions². A VAR approach is useful to quantify the magnitude of the effects of a shock and to estimate the period necessary to the system to absorb the shock. Moreover, the non-linear specification is of relevance because it allows us to capture potential non-linearities governing the relationship between the variables of interest. Finally, the local projection approach, based on a direct forecasts approach, it is preferred to the traditional iterated forecasts method, when the data generating process is suspected to be non-linear³. The VAR specification is based on four

¹For VAR methodology, see Sims (1980).

²Jordà (2005).

³The properties of the local projection approach have been challenged by Kilian and Kim (2009) and (2011).

variables: the output gap, the interest rate and the inflation rate refer to the macroeconomic system, while the quality of the banking sector has been measured by the percentage of non-performing loans or by a specific indicator constructed by the Swiss National Bank, depending on the case.

By running two separate VAR models, and using a quarterly dataset for the US and for Switzerland for the periods included from 1984:Q1 to 2009:Q1 and from 1987:Q1 to 2008:Q1 respectively, we find that there exist real and feedback effect. The particular shape of the impulse response functions can be explained by the prediction of several theoretical contributions referring to flexible credit policies and credit crunch behaviours⁴ adopted by banks when the banking system is hit by a negative shock. Our results are robust to the sample period selected, the size of the shocks and the error decomposition employed.

The rest of the paper is organized as follows: In section 2, we report the main contributions on this topic. In sections 3 and 4, we discuss the main features of the dataset and the macroeconomic model used, by motivating the choice of the specification as well as by discussing the main advantages of using the local projection approach to compute the impulse response functions. In section 5, we discuss the results and the robustness checks. Section 6 draws the conclusions.

2 Literature Review

There exists a huge variety of empirical contributions that assess the relationship between the macroeconomic system and the banking sector. This paper refers to the VAR literature. Hoggarth et al. (2005) estimate a hybrid linear VAR model for the UK. In their econometric specification, the output gap, the interest rate, the inflation rate and the exchange rate describe the macroeconomic system; while the write-offs ratio is employed to measure the

⁴See for instance Rajan (1994) and Ruckers(2004) for the flexible credit policy, and Bernanke and Gertler (1995) and Peek and Rosengren (1995) for the credit crunch behaviour.

quality of the banking sector. The error term has been decomposed by using the traditional Cholesky orthogonalization. They find that macroeconomic shocks affect the banking sector, but the opposite is not true.

For the Italian banking system, Marcucci and Quagliariello (2007) adopt the same specification as in Hoggarth et al. (2005), but they replace the write-offs ratio by borrowers' default rate to assess the effect of recessionary conditions on credit quality. They also take explicitly into account credit supply in order to test how a worsening of the credit quality affects the real economy. They find clear evidence for the real effect, while some findings support the hypothesis that the feedback effect works via the bank capital channel.

By using a unique dataset for German economy during the period included between 1968 and 2007, Dovern et al. (2008) assess the relationship between macroeconomic system and banking sector using a VAR. The model includes the gross domestic product growth rate, the interest rate, the write-offs and the return on equity as measures of the banking quality. The error term has been decomposed by using the Cholesky decomposition and the approach suggested by Uhlig (2005). In particular, they measure the impact of three type of shocks (contractionary monetary policy, negative demand shock, and negative supply shock) on the write-offs and on the return on equity. The main findings are that only the first two shocks lead to a significant response of the banking sector variables, while the supply shock generates results statistically not significant. The feedback effect has not be analysed.

By using UK aggregate data on corporate credit, Drehmann et al. (2006) assess the transmission of macroeconomic shocks to aggregate corporate default probability. In our knowledge, Drehmann et al. (2006) are the first that use a VAR with a non-linear specification. In particular, they focus on four variables such as the output gap, the interest rate and the inflation rate and corporate liquidation rate. They find that an increase in interest rates, that can be interpreted as a contractionary monetary policy, positively affects credit risk, and that positive GDP shocks reduces risk significantly. Moreover, they show that non-

linearities are relevant for the shape and for the magnitude of the impulse response to small and big shocks. Specifically, they find that linear and non-linear model specifications produce different results in terms of impulse response functions. These differences become more relevant if big shocks are taken into account. Previous results are driven by the fact that the impulse response functions are computed by using a direct forecast approach proposed by Jordà (2005). This approach takes explicitly into account higher order terms included in the specification when computing impulse responses.

The results of previous contributions highlight that there is evidence for real effect, but surprisingly they do not find clear evidence for the feedback effect, or they totally ignore it. This is despite the fact that from a theoretical point of view, several contributions predict the existence of an effect going from the banking sector to the macroeconomic sector. One of the reasons that can explain previous findings is the omission of non-linearities governing the relationship among the variables. On the one hand, approximating the unknown data-generating process (DGP) by a linear VAR, when the DGP is indeed non-linear, may lead to biased estimated coefficients. Therefore, the correspondent impulse response functions are biased. On the other hand, if the DGP is non-linear, then the traditional method employed to compute the impulse response functions, based on a moving average (MA) representation of the VAR model, may amplify potential misspecification errors.

The aim of this paper is to provide additional evidence to the relationship between macroeconomic sector and banking system and in particular to analyse more carefully the existence of the feedback effect. By using US and Swiss data, we assess the relationship between the macroeconomic system and the banking sector, estimating two separate VAR with a non-linear specification and computing the impulse response functions by using the local projection approach. The VAR main advantage is that it allows us to assess the impact of a shock on the variables of interest, as well as to quantify the length of time needed for the variables to absorb a shock. The local projection approach allows us to obtain different

impulse response functions depending on the size of the shock and the direction of the shock. We employ the same variables used by Hoggarth et al. (2005), with the only difference in the indicator employed to measure the banking system quality and we adopt a specification similar to that used by Drehmann et al. (2006).

Several elements distinguish our contribution from previous ones. First, while previous contributions focus on UK data, we focus on US and Swiss data. To our knowledge, this is the first contribution using these data in the context of a non liner VAR. Second, we replace the write-offs ratio and corporate liquidation rate used as banking quality indicators in Hoggarth et al. (2005), and Drehmann et al. (2006) respectively, by non-performing loans ratio for the US case and by the SNB banking index for the Swiss cases. Non-performing loans are preferred to the write-offs ratio, because the latter may be under(over)-reported during recessions(expansionary) periods to mitigate the effects on banks' equity, due to the fact that this loan status is at the banks' discretion. For the Swiss case the non-performing loans are not available, so that we were forced to employ an alternative measure, which is employed by the SNB to assess the quality of the banking sector.

Finally, we choose a non-linear specification based on a quadratic form instead of the cubic representation as employed by Drehmann et al. (2006). This choice is motivated by two reasons. From an economic point of view, a higher-order specification has the advantage being better at approximating the unknown generating process. However, its cost is the lack of economic interpretation to give to the coefficients of the variables of higher order. From an econometric point of view, a richer specification reduces the misspecification issues at the cost of wasting degrees of freedom. Therefore, the estimates are less precise. This second point is relevant when the number of observations is not large, as in our case.

3 The Dataset

This study refers to two countries: the US and Switzerland. The US dataset covers the period from 1984:Q1 to 2009:Q2, while the Swiss one refers to the period between 1987:Q1 and 2008:Q1.

The series has been obtained from Fed of St. Louis, the OECD and from the Swiss National Bank⁵. All of the series are quarterly based and have been seasonally adjusted.

According with previous contributions in this topic, four variables have been included in the econometric specification: the output gap (GAP), the nominal interest rate (INTE) and the inflation rate (INFL) refer to the real economy, while the non-performing loans or a banking distress index have been employed to measure the quality of the banking sector. The output gap has been generated by taking the difference between the log of GDP and and the log of its HP-filter component. The consumer price index for all items has been computed by taking the percentage of quarterly changes with respect to the same quarter of the previous year, and has been included in order to describe the price dynamics. Moreover, the interest rate has been measured by the 3-month treasury constant maturity rate (US) and the interbank interest rate (Switzerland).

For the US, following Gambera (2000), we use the non-performing loans as an indicator of the quality of the banking system. A loan is automatically defined as non-performing if it is in default for at least three months. In other contributions the write-offs have been employed to measure the quality of the banking sector⁶. However, this measure could not be the best choice due to the fact that it is at banks' discretion whether to define a loan as write-off. Therefore, it is possible that write-offs misreport banking sector quality. This is the main reason why we prefer to use non-performing loans instead of write-offs as a measure of the quality of the banking sector. For Switzerland, because of a lack of data,

⁵A detailed analysis of the source of the data and their definition is provided in the Table 1, Section A of the Appendix.

⁶Hoggarth et al. (2005), and Dovern et. al. (2008).

the NPTL has been replaced by the banking distress index⁷, constructed by Monnin and Henschel (2005). This index is obtained by averaging several normalized indicators, which refer to the market prices, aggregate balance-sheet data, non-public information and other structural data. Banking distress values larger than zero imply that the banking sector is experiencing a level of distress larger than the average.

In Table 2, Section A of the Appendix, we report the descriptive statistics as well as the correlations for the US and Swiss series. For the US case, we focus on the full sample as well as on a reduced sample, which refers to the same sample period in common with Switzerland. The findings highlight that the sample period does not affect the main results. The relevant differences for the two countries arise when we compare the output gap statistics: the average value for the US case is positive, while the opposite is true for Switzerland. The differences disappear if the US series is extended to 2010.

Previous divergences also characterize the comparisons among correlations. For the US, the output gap and the non-performing loans are negatively correlated, while for Switzerland between output gap and the banking distress index the opposite relationship holds. This result could depend on the fact that the banking distress index is strongly correlated to the business cycle. More homogeneous results across country relate the correlation between NPTL and the inflation rate, and between NPTL and the interest rate. In both cases, the correlations are positive, and those for the US are stronger than those for Switzerland.

⁷For the Swiss case, the closest series available to the NPTL is the write-downs and provisions series. It starts in 1996 and it is annually based. This is due to the fact Swiss banks are not required to report at a higher frequency. We compute the correlation between the annualised banking distress index and the write-downs series. The correlation (p-value) is equal to .80 (.0031). We can conclude that the distress index provides a good approximation of the write-downs. Therefore, the results of the US and Switzerland are comparable.

4 The Macro-Econometric Model

In this section we document the potential non-linear relationship between the series from a theoretical, as well as from an empirical, point of view. Moreover, we present the macro-econometric model we employed in this study, by discussing the econometric issues related to the econometric specification chosen, and by analysing the error term decomposition employed. Finally, we discuss the advantages of the local projection, which is used to compute the impulse response functions.

4.1 A non-linear world

The existence of non-linearities that govern the relationship between the macroeconomic system and the banking sector has been documented in several theoretical contributions.

Blinder (1987) develops a theoretical model based on credit regimes and shows that monetary shocks have a stronger impact in a credit-rationing regime. Bernanke and Gertler (1989) show that the dynamics of the business cycle are not linear: weaker borrowers' conditions lead to a more powerful propagation effects via cash flows. They also show that temporary shocks may have a persistent and accelerated effect on the economic system.

Rajan (1995), Direr (2003) and Ruckers (2004) show that, in the context of moral hazard problems, credit supply is affected by economic conditions. In particular, they show that the banking system, by using a switching credit policy, may amplify the booming and busting phases of the economic cycle.

Azariadis and Smith (1998) construct a dynamic equilibrium model to study the relationship between credit and production. They assume that the economic system can switch credit regime. Their findings suggest that a decline in real interest rates, an increase in credit rationing and the withdrawal of savings from banks are more important during cyclical downturns. Finally, Brunnermeier and Sannikov (2011) analyse a macroeconomic model

that is characterized by financing frictions. They show that negative shocks have important non-linear effects in the form of adverse feedback loops and liquidity spirals away from the steady state. Shocks amplifications are due to volatility effects and precautionary motives behaviours.

Additional to the theoretical reasons, the choice of a non-linear specification may be justify by the following findings. For the US and Switzerland, Figures 9 and 10, Section B of the Appendix report the scatter plots of the banking quality indicator and the output gap, the interest rate and the inflation rate respectively. The graphs in the upper part of the Figures refer to the linear pairwise (y_t, x_{t-1}) scatter plot, and the corresponding linear fit, linear power fit and kernel fit. In the lower part, we include the scatter plots of the quadratic pairwise (y_t, x_{t-1}^2) together with the corresponding linear fit and kernel fit. The graphs highlight that linear fit provides the poorest approximations of the relationship among the variables of interest. Power linear fit and kernel fit lead to better approximations.

Another way to look at the non-linear specification is related to the volatilities of the series. In particular, if the variance of y_t conditional on y_{t-1} takes the form of $\text{var}(y_t | y_{t-1}) \equiv \sigma^2 = \alpha_0 + \alpha_1 y_{t-1}^2$, then adding a quadratic term in the specification is equivalent to take explicitly into account the volatility of the series⁸.

Apart from previous arguments, there are also technical reasons to justify the choice of including non-linear terms in the model specification. Specifically, by estimating a linear model when the relationship among a set of variables is non-linear may lead to biased results. In order to check previous claims, we run a Monte Carlo simulation. Specifically, we generate two series with 1000 observations each, by assuming a non-linear relationship. We compute the impulse response functions associated to linear and non-linear estimations. We repeat the simulation 1000 times. The results, reported in Section D of the Appendix, highlight that the impulse response functions referring to the linear and non-linear model specifications show

⁸For GARCH-VAR models, see for instance Calzolari and Fiorentini (1994), Bauwens et. al. (1997) and Iglesias and Phillips (2003).

different shapes and magnitudes. The differences are more important when the size of the shock is large.

4.2 The econometric specification

Previous theoretical and empirical arguments justify the specification chosen for describing the relationship between the macroeconomic system and the banking sector, which takes the following form:

$$y_t = \alpha + B_1 y_{t-1} + Q_1 y_{t-1}^2 + \epsilon_t^0 \quad (1)$$

As mentioned earlier the main difference with respect to Drehmann et al. (2005) is that we exclude the cubic term from the specification, for interpretative reasons as well as parsimonious motivations (wasting degrees of freedom).

Consistently with Hoggarth et al. (2005), our model includes four endogenous variables. The vector of the dependent variables, defined as $y_t \equiv [g_t, \pi_t, r_t, b_t]^T$, includes the banking indicator, the output gap, the inflation rate and the interest rate, respectively. Moreover, the non-linear vector takes the following form $y_t^2 \equiv [g_t^2, \pi_t^2, r_t^2, b_t^2]^T$ and finally B_1 and Q_1 are the matrices of the coefficients that refer to the linear and the quadratic part of the specification. The system of equations that characterizes our model can be interpreted as an IS curve, the supply curve, a modified Taylor rule, and an extra equation that links the real variables and the banking indicator⁹.

We estimate the model for the period from 1987:Q1 to 2008:Q1. In this way, it is also possible to compare our results with those of previous contributions¹⁰.

⁹For more details see Batini and Haldane (1999), Blacke and Westaway (1996), Hoggarth et al. (2005).

¹⁰Hoggarth et al. (2005), Drehmann et al. (2005) Marcucci and Quagliariello (2006).

4.2.1 Lag order, unit root and error identification

According to the results of Table 3, Section A of the Appendix, the criteria employed to determine the lag order of the specification lead to different results, both for the US and for Switzerland. Moreover, the results are sensitive to the period selected. Therefore, we prefer to adopt a specification with only one lag term. Limiting the lag order to one could generate potential mis-specification issues¹¹, but at the same time, the parsimonious specification reduces the waste of degree of freedom. In our particular case, this aspect is relevant because of the small number of observations.

Unit root tests results, reported in Table 4, Section A of the Appendix, are not robust to the period selected. Specifically, for the US, by taking into account the entire sample (part A of the table) all the series are non-stationary, while by excluding from the sample the observations after 2008:Q1 (part B of the table), the output gap and the inflation rate are stationary. The interest rate series is always non-stationary, while the non-performing loans series is stationary only after 1995:Q4, when it experiences a structural break. For Switzerland, the results highlight that output gap and banking quality distress are stationary, while the interest rate, as well as the inflation rate, show unit roots.

In general, the results of the stationary series tests unable to assess clearly whether a series is stationary. This is particularly true in the case of small samples. Moreover, as shown by Phillips (1998) and Pesavento and Rossi (2006) local projection method mitigates potential issues related to non stationary series when computing the impulse response functions. The ambiguity of the empirical tests together with the above-mentioned theoretical arguments convinced us to employ, in the baseline model, the series at level.

In order to identify the shocks, consistent with the economic theory and the other studies on the same topic, the following endogenous order has been ascribed to the variable: bank

¹¹As shown by Marcellino et al. (2006), the local projections approach, employed to compute the impulse response functions, prevents potential problems related to misspecification issues, related to lag order.

fragility indicator, output gap, inflation rate and interest rate. This order implies that, at the impact, the bank fragility indicator reacts only to its own shock. The output gap reacts contemporaneously only to those shocks generated by the banking variable and to itself. The inflation rate reacts at the impact to its own shock as well as to the shocks that refer to the banking distress measure and to the output gap. Finally, the interest rate reacts at the impact to all the shocks associated with the variables included in the VAR.

In the robustness checks, we impose the Cholesky decomposition of the error term by employing other endogenous orders ascribed to the variables. The findings show that the results are robust to this type of change.

4.3 Impulse response functions

The traditional approach for computing impulse response is based on a moving average (MA) representation of the VAR model. This approach suffers from important drawbacks.

First, it can result in a waste of degrees of freedom, because a large lag length may be required in order to compute true impulse responses. This requirement can become a problem if the sample size is too small, as pointed out by Kapetanios, Pagan and Scott (2007). Second, there is a problem of non-uniqueness of the MA representation of the VAR model specification, and a multiplicity of impulse responses. Lippi and Reichlin (1993) show that for a given estimated VAR, a variety of MA representations lead to plausible results from an economic viewpoint. Third, if the series are non-stationary, then the impulse response functions are no more consistent when long horizons are taken into account and the model is estimated at level as shown by Phillips (1998) and Pesavento and Rossi (2006). Moreover, as we work with a non-linear VAR, another important problem can arise. Specifically, as pointed out by Koop, Pesaran and Potter (1996) and Jordà (2005), the linear VAR can be considered as a first-order Taylor approximation of the unknown DGP. Therefore, the non-linear VAR can be interpreted as a more flexible approximation of the DGP. It follows that it is not possible

to use the traditional approach to calculate the impulse response functions, because it can lead to misspecification errors. Moreover, this is true when the model is misspecified.

Jordà (2005) suggests to employ the local projections approach, instead of the traditional approach, to calculate the impulse response functions. The local projection is a method that estimates, by OLS, a model for each point (s) in time of the period length of interest. For each s the dependent variable is led by one period, while the explanatory variables do not change. Based on the regression results, the corresponding impulse response value is computed. Therefore, the impulse response functions estimated by the local projections are based on a direct forecasts approach¹².

Jordà (2005) proves that if the true and unknown DGP is linear, then the local projections approach leads to impulse response functions that are consistent but not efficient. Furthermore, if the DGP is non-linear, then the local projections approach leads to the best approximation at each horizon in time. Several studies¹³ compare the performance of the direct and iterated forecasts. The former outperforms the latter in several cases: when the negative component of the MA specification is large; when the sample data is too small and it displays unit root and structural breaks; when the lag order is low and a short horizon is taken into account. In light of these facts, and following Drehmann et al. (2005) and Haug and Smith (2007), among others, we compute the impulse response functions using a local projections approach.

¹²The traditional way to compute the impulse response functions is based on iterated forecasts. For a technical analysis of the local projection method, see section E of the Appendix.

¹³Lippi and Reichlin (1993), Phillips (1998), Kapetanios, Pagan and Scott (2007) and Pesavento and Rossi (2006). As previously mentioned, the properties of the local projection approach have been challenged by Kilian and Kim (2009) and (2011).

5 Results

5.1 Regression results

In Table 5, Section A of the Appendix, the results of the linear and non-linear VAR model for the US (upper part) and for the Swiss (lower part) cases are reported. Even if they do not provide an exhaustive assessment of the relationship among the variables, their analysis offers a general idea of the phenomenon studied¹⁴.

Focusing on the linear VAR (columns 1 to 4), the results highlight the relevant role played by the non-performing loans and by the stress index, respectively. The banking quality indicators affect all the variables but the inflation rate. The other relevant variables are the output gap and the interest rate, while the inflation rate plays a marginal role. The results reported in Table 6, Section A of the Appendix are more interesting. Specifically, they show the marginal effect of the variables of interest according to the estimation of the non-linear VAR, reported in Table 5, Section A of the Appendix (columns 5 to 8). The results highlight that, for the US, the marginal impact of the macroeconomic variables on the non-performing loans is not different from zero, while the results show the statistically significant impact of the non-performing loans on the output gap and the interest rate. Different results, possible due to the different variable employed for measuring the quality of the banking system, characterize the Swiss case. All the macroeconomic variables positively affect the banking distress indicator, while it has been shown that a deterioration in the banking quality, negatively affects the output gap and positively affects the interest rate. For the US case as well as for the Swiss case, the inflation rate plays a minor role in describing the dynamics linking the macroeconomic system and the banking sector.

Previous analysis, even if interesting, is not able to address the relevant questions of this study. Specifically, in order to assess and measure how the variables react to a shock and how

¹⁴In order to have results comparable between the US and Switzerland, the baseline findings for the US are based for the period from 1987:Q1 to 2008:Q1.

long it takes to absorb it, the impulse response functions have to be estimated and analysed.

5.2 Impulse Response Functions Results

From a general view-point, we can conclude that there is evidence for real and feedback effects. These results are robust with respect to the country analysed, the sample period taken into account, the size of the shocks, as well as the endogenous order ascribed to the variables.

5.2.1 Real and feedback effects

Figure 3, Section B of the Appendix, upper part, shows the real effect for the US case. The three graphs highlight that a shock generated in the macroeconomic system, independently of its origin, has a relevant impact on the non-performing loans. More precisely, the non-performing loans ratio increases after a positive shock in the output gap (graph 3.a), an increase in the interest rate (graph 3.b) or after an unexpected increase in the inflation rate (graph 3.c).

The NPTL response to an output gap shock reaches its peak after five periods before starting to converge again to the equilibrium. The maximum impact of the shock is equivalent to .1 NPTL standard deviations. The NPTL reacts negatively to an unexpected increase in the interest rate. As shown by the results, it takes more than eight quarters for the non-performing loans to return to the equilibrium state. Finally, a positive shock in the inflation rate generates a positive response of the non-performing loans. The peak is reached after five periods, with values approximately equivalent to .15 NPTL standard deviations. Thenceforth, the impulse response function converges to the equilibrium value.

Figures 3.d, 3.e and 3.f, document the impulse response functions of the output gap, the interest rate and the inflation rate, respectively, after an unexpected deterioration of the banking sector conditions. The results highlight the existence of the feedback effect. More

precisely, the output gap negatively reacts: its lower bound is equivalent to .05 output gap standard deviations and is reached after four periods. The same patterns are reproduced by the interest rate, which reaches its minimum value after three periods, achieving a value approximately equivalent to -.1 interest rate standard deviations. The inflation rate reacts positively to a deterioration of the banking conditions. The peak is reached after three periods, and the value attained corresponds to .15 inflation rate standard deviations.

The results that refer to Switzerland confirm the findings for the US, even if some differences in the magnitude and in the shape of the impulse response functions arise. Figure 4.a, Section B of the Appendix documents the reaction of the banking distress indicator after a positive output gap shock. The maximum is reached after one quarter, when the response function attains a value of .3 stress standard deviations. Figure 4.b, Section B of the Appendix, shows similar patterns for the response of the quality measure of the banking sector after a increase in the interest rate. The impulse response exhibits a U-shaped reaction before showing a rebound effect. The maximum value is around .6 and is achieved after two periods. Finally, figure 4.c, Section B of the Appendix, reports the response of the quality measure of the banking sector after an increase in the inflation rate. The results are not consistent with those of the US. The figure documents that the reaction draws a U-shaped curve, its minimum is equivalent to .45 stress standard deviations and is attained after two quarters.

The feedback effect results for Switzerland are in line with those obtained for the US: the three macroeconomic variables show a negative reaction, as documented by the Figures 4.d, 4.e and 4.f, Section B of the Appendix. For the output gap, the minimum value is reached after three quarters, attaining a level that is equivalent to .3 output gap standard deviations. The same is true for the interest rate, which attains a minimum value equivalent to around .2 interest rate standard deviations. Finally, the response of the inflation rate reaches its minimum value, which is equivalent to .2 inflation rate standard deviations, after

four periods. In this last case, the results for Switzerland are not consistent with those obtained for the US.

5.2.2 Interpreting the results

For the US, a better comprehension of the findings can result in the analysis of the determinants of the non-performing loans. More precisely, the non-performing loans over total loans is equal to the ratio of bad loans over total loans. Therefore, NPTL increases according to three cases: (i) if good loans decrease slower than bad loans; (ii) if bad loans increase faster than the good loans; or finally, if (iii) good loans decrease and bad loans increase.

As documented in Figure 3.a, Section B of the Appendix, after an unexpected increase in the output gap, the non-performing loans show an inverted U-shaped curve. The output gap shock can be interpreted as a temporary positive productivity shock. According to the financial accelerator hypothesis, suggested by Bernanke and Blinder (1988) and Bernanke and Gertler (1989), the first consequence of the shock is that the external financial premium decreases: firms find it easier to raise new funds by using external sources. Therefore, banks face a larger number of potential clients. Banks, according to the information available, classify their clients depending on their quality, and therefore banks meet clients' demand until the output gap is positive. It follows that the average quality of the borrowers decreases as time goes on. In other words, banks are adopting a flexible credit policy that is affected by economic conditions. Previous scenario corresponds to the situation described in case (ii). The above-mentioned arguments are consistent with the results documented in Figure 3.a, Section B of the Appendix. A non-constant supply credit policy implemented by banks can be justified by assuming rational banks' managers who only consider the short term, and banks earnings as the only source of information available in the market, as shown by Rajan (1994) and Ruckers (2004). Moreover, the banking flexible credit policy hypothesis also finds empirical support, as documented by Salas and Saurina (2002) and Jiménez and

Saurina (2005), using Spanish data.

For the Swiss case, we have to adapt the arguments, previously employed, because the variable to measure the banking distress level is not the same as that used for the US. Also in this case, it is useful to take a closer look at the definition of the banking distress index. The variables employed by Hanschel and Monnin (2005) refer to market prices, aggregate balance-sheet data, non-public information and other structural data. In particular, the following variables have been included: banks' stock price index, the return on assets, the bank capital and the yield spreads for bank-issued bonds. More precisely higher, levels of the first three indicators reduce the level of banking distress, while the opposite is true for the yield spreads.

After a positive shock in the output gap, monetary authorities react by increasing the interest rate in order to avoid inflation pressures. Higher interest rate reduces the stock price of the banks. At the same time, the return on assets of the bank can fall, due to the fact that banks are meeting the demand of borrowers, whose quality, in terms of profitability, decreases as the output gap converges again to the equilibrium. The combination of these effects leads to a behaviour of the banking distress indicator that is consistent with the graph reported in Figure 4.a, Section B of the Appendix.

From previous findings, it follows that banks are crucial in the amplification of economic booms and busts, by lending too much during booms and by reducing credit supply in recessionary periods more than necessary. Moreover, banks are, at least partially, responsible for making the banking sector more fragile, by meeting the demand of borrowers of lower quality.

The real effect also works via interest rate. This is true for the US as well as for Switzerland, even if the two impulse response functions do not look like similar. However, the findings agree about the increase in the banking fragility after an unexpected increase in the interest rate, which can be interpreted as a tightening monetary policy measure. For the

US, the response of the non-performing loans can be explained by the cost-of-capital channel. Specifically, a higher interest rate worsens the lending conditions for current borrowers. They have to face a more demanding lending requirement, so the fraction of non-performing loans increases. The cost-of-capital channel may be amplified through the balance-sheet channel. An increase in the interest rate leads to a decrease in the value of assets. Borrowers' net creditworthiness decreases, and therefore the borrowers have to satisfy more demanding lending requirements. As a consequence, the non-performing loans ratio increases.

For Switzerland, a similar argument applies. A higher interest rate leads to a decrease in the banks' stock price and, at the same time, to a worsening of the borrowing conditions. The return on assets and the bank credit decrease. Therefore, the banking distress indicator shows values larger than on average.

Finally, the inflation rate also contributes to the transmission of a shock from the macroeconomic system to the banking sector. In this third case, the results of the US and Switzerland diverge. This may be due to the different variables employed for measuring the quality of the banking system. From a theoretical view-point, an unexpected increase in the inflation rate implies a restrictive response of the monetary authorities by an increase in the interest rate. Therefore, the level of the non-performing loans may increase, showing patterns similar to those reported for the US in Figure 3.c, Section B of the Appendix. For the Swiss case, the results could be driven by the variables classified as non-public, which have been employed in the definition of the index, so that the findings are difficult to interpret using the information available.

In the context of the feedback effect, from a general point of view, the results for the US and Switzerland are consistent, even if some differences arise.

The results can be explained by using the credit crunch hypothesis suggested by Bernanke and Gertler (1995). The output gap reaction to a negative banking sector shock can be explained by the balance-sheet channel, which provides a demand-side view-point of the dynamics

analysed. Specifically, for the US, an increase in the non-performing loans implies a lower quality of the loans. Therefore, it follows that borrowers' creditworthiness deteriorates. This implies that the external finance premium increases, so that raising funds externally becomes more costly. The lowered ability of raising new funds implies a lower number of investments, decreasing the output gap.

The deterioration of the banking quality can also be analysed from a supply-side perspective, through the capital requirement channel. Specifically, if the quality of the banking sector worsens, and banks' capital requirements become more demanding, banks can react in two different ways. They can raise new capital, or they can decrease their lending. As shown by Peek and Rosengren (1995), the former measure is more costly in a period of crisis than the latter, so banks prefer decreasing loans. As a consequence, there are fewer investment possibilities and the economic system suffers a contraction.

In the Swiss case, an increase of the level of banking distress may be due to a reduction in the return on assets, an increase in provisions for future losses or to a decrease in banks' capital. By employing a supply-side view-point, it follows that the amount of capital for lending available in the market decreases, so that the output gap reacts negatively. Previous arguments lead to impulse response functions as those reported in Figures 3.d and 4.d, Section B of the Appendix. The monetary authorities respond to a deterioration of the quality of the banking sector, by decreasing the interest rate. This measure accelerates the recovery of the economic system. The US and Switzerland show similar response functions. Finally, the unexpected worsening of the banking sector leads to a decrease in the inflation rate. This finding can be driven by the fact that after a shock in the banking sector, the output gap reacts negatively, as previously documented. This result is different than that found for the US. In the latter case, the reaction of the inflation rate is positive after an unexpected increase in the fraction of the non-performing loans.

5.3 Robustness

We test the robustness of the results in several ways. First, in the US case, we modify the sample period, by including the period before 1987:Q1. The results, reported in Figure 5, Section B of the Appendix, confirm the baseline findings.

Second, for Switzerland, we test the robustness of the results with respect to the size of the shock, by considering a three standard deviations shock. From a theoretical view point, due to the nature of the local projections approach, the impulse response functions could be different with respect to the size as well as to the shape. However, Figure 6, Section B of the Appendix supports the main findings.

Finally, we also test the relevance of the assumptions about the relationship among the variables at the impact of the shock. We flip the endogenous order ascribed to the variables, and the most important results do not change, as reported in Figures 7 and 8, Section B of the Appendix.

We can conclude that our results are robust to sample period taken into account, the size of the shocks, as well as the endogenous order ascribed to the variables.

6 Conclusion

In this paper, we estimate a VAR model with a non-linear specification, based on four variables in order to capture the real and feedback effects linking the macroeconomic system to the banking sector. The variables we employed to characterize the macroeconomic system are the output gap, the interest rate, and the inflation rate, while banking sector quality has been summarized by the non-performing loans or by a banking distress index, depending on data availability. Our analysis focuses on US and Swiss data. Finally, the local projection method has been employed to compute the impulse response functions.

The non-linear specification of the VAR has been employed to capture potential non-

linearities, which govern the relationship among the variables and which were missed in previous studies. The employment of the local projection method mitigates several econometric issues, such as unit root, lag order, and model misspecification, which could, potentially, affect the analysis.

The findings suggest that there is evidence for real and feedback effects. The results can be supported by the flexible credit policy hypothesis and the credit crunch effect. To our knowledge, this is the first contribution where both effects are clearly detected. These findings are robust to the country analysed, the sample period taken into account, the size of the shocks and the endogenous order ascribed to the variables.

Finally, this study also has relevant policy implications. Specifically, it seems that the banking sector is at least partially responsible for the amplification of the business cycle components, in addition to the fact that, due to their flexible credit policy, they reduce the quality of the banking sector during booms. The subsequent policy implication is that, on the one hand, regulators should impose countercyclical cautionary mechanisms on the banking sector. At the same time, the regulators should develop mechanisms with the aim to guarantee a constant credit supply policy, so that borrowing requirements standards stay at high levels.

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Appendices

A Tables

Table 1: Variables description

Variable	Definition	Source
Output gap	It is defined as the difference between the cycle and the trend component of the GDP in local currency, at current price and seasonal adjusted. HP-filter has been used.	OECD
Infl. Rate	Inflation rate based on the CPI for all items.	OECD
Int. Rate	3-month treasury constant maturity rate and the interbank interest rate.	OECD
Nptl	% of non-performing loans over total loans for commercial banks.	Federal Reserve of St. Louis
Stress	Hanschel and Monnin (2005) indicator.	Swiss National Bank

Table 2: Descriptive statistics and correlations

US (1984:Q1-2009:Q1, 101 obs.)	mean	sd	min	max	Correlations	Nptl
Output Gap	.0516226	1.0827	-3.226736	2.354277	Output Gap	-.1614
Inf. rate	3.10495	1.130431	-.2	6.3	Infl. rate	.4408
Int. rate	5.288812	2.375815	1.053333	11.44	Int. rate	.4257
Nptl	1.994951	1.077277	.7	3.91	Nptl	1
US (1987:Q1-2008:Q1, 85 obs.)	mean	sd	min	max	Correlations	Nptl
Output Gap	.0598536	1.068714	-2.3576	2.354277	Output Gap	-.1425
Inf. rate	3.096471	1.057113	1.2	6.3	Infl. rate	.5953
Int. rate	4.996863	2.119029	1.053333	9.6	Int. rate	.411
Nptl	1.826471	1.083507	.7	3.91	Nptl	1
Switzerland (1987:Q1-2008:Q1, 85 obs.)	mean	sd	min	max	Correlations	Stress
Output Gap	-.0816057	1.477636	-3.102049	2.841467	Output Gap	.3419
Inf. rate	1.792727	1.634216	-.0775665	6.249964	Infl. rate	.2926
Int. rate	3.361364	2.611714	.2516667	9.333333	Int. rate	.3163
Stress	0	1	-2.261173	2.807612	Stress	1

Notes: In the first four columns, for all the series, the mean, standard error, the minimum and maximum values are reported. In the last column the correlations between the banking sector variable and the macroeconomic indicators are reported. For the US we report the results for two sample with different time length. The first one takes into account all the observations available, while the latter employs the same period for which the data for Switzerland are available.

Table 3: Selection order criteria

US (1984:Q1 - 2009:Q1)	lag	LR	FPE	AIC	HQIC	SBIC
	1	.	.000923	4.36351	4.53422	4.78555
	2	78.961	.000572	3.88431	4.22572*	4.72838*
	3	36.756*	.000547*	3.83578*	4.34789	5.10189
	4	19.705	.000625	3.96124	4.64406	5.64938
US (1987:Q1 - 2008:Q1)	lag	LR	FPE	AIC	HQIC	SBIC
	1	.	.000318	3.29709	3.48204*	3.75689*
	2	46.434	.000269	3.12728	3.49717	4.04687
	3	33.175*	.000266*	3.11346*	3.66828	4.49284
	4	17.162	.000321	3.28802	4.02779	5.1272
Switzerland (1987:Q1 - 2008:Q1)	lag	LR	FPE	AIC	HQIC	SBIC
	1	.	.008687	6.60523	6.79499	7.0782*
	2	48.514	.007101	6.40135	6.78088*	7.34731
	3	39.844*	.006485*	6.30451*	6.87381	7.72345
	4	21.929	.007435	6.42885	7.18791	8.32076

Notes: LR, FPE, AIC, HQIC and SBIC refer to the sequential modified Log likelihood ratio test, the Final Prediction Error, the Akaike Information Criterion, the Hannan-Quinn Information Criterion and the Schwarz Bayesian Information Criterion respectively. * refers to the lag order selected at 95%.

Table 4: Unit root test

Part A: US (1984:Q1 - 2001:Q2)	test stat	1%	5%	10%
Output gap	-1.174	-2.6	-1.95	-1.61
Infl. Rate	-2.052	-3.51	-2.89	-2.58
Int. Rate	-1.071	-3.509	-2.89	-2.58
Nptl.B	.408	-3.628	-2.95	-2.608
Nptl.A	9.123	-3.569	-2.924	-2.597
Part B: US (1987:Q1 - 2008:Q1)	test stat	1%	5%	10%
Output gap	-1.708*	-2.606	-1.95	-1.61
Infl. Rate	-2.579*	-3.532	-2.903	-2.578
Int. Rate	-1.104	-3.532	-2.903	-2.578
Nptl.A	.408	-3.628	-2.950	-2.608
Nptl.B	-1.02	-3.577	-2.928	-2.599
Part C: Switzerland (1987:Q1 - 2008:Q1)	test stat	1%	5%	10%
Output gap	-1.661*	-2.606	-1.95	-1.61
Infl. Rate	-1.48	-3.532	-2.903	-2.586
Int. Rate	-.984	-3.532	-2.903	-2.586
Stress	-3.42***	-2.606	-1.95	-1.61

Notes: Augmented Dickey-Fuller test performed. Null hypothesis: the series shows unit root. B and A: before and after the structural shock.

Table 5: Linear and quadratic specification

US	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L.gap	.845*** (.059)	-.100* (.052)	.039 (.086)	.040* (.022)	.853*** (.056)	-.074 (.068)	.120 (.082)	.022 (.018)
L.inte	.063* (.037)	1.007*** (.032)	.071 (.058)	-.005 (.016)	-.071 (.065)	.986*** (.118)	-.059 (.081)	.090*** (.029)
L.yoy	.009 (.065)	.056 (.055)	.856*** (.105)	-.011 (.030)	.720*** (.174)	.321 (.215)	1.444*** (.309)	-.357*** (.092)
L.nptl	-.191** (.075)	-.149** (.060)	-.008 (.084)	1.031*** (.035)	-1.125*** (.313)	-.449 (.291)	-.528 (.522)	1.330*** (.136)
L.gap2					-.027 (.027)	-.044 (.034)	.067 (.048)	.041*** (.008)
L.inte2					.013* (.007)	.001 (.014)	.010 (.009)	-.008*** (.002)
L.infl2					-.113*** (.032)	-.046 (.039)	-.110* (.060)	.057*** (.013)
L.nptl2					.230*** (.068)	.081 (.068)	.136 (.120)	-.079*** (.028)
Observations	85	85	85	85	85	85	85	85

Switzerland	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L.gap	.948*** (.051)	-.025 (.060)	-.021 (.029)	.175*** (.050)	.938*** (.053)	-.027 (.054)	-.022 (.038)	.167** (.072)
L.inte	.019 (.047)	.974*** (.043)	.103*** (.039)	.087 (.053)	.074 (.081)	.970*** (.070)	.046 (.066)	.194* (.107)
L.infl	.008 (.075)	.045 (.056)	.819*** (.062)	-.127 (.093)	-.095 (.153)	-.045 (.117)	.729*** (.111)	-.312 (.189)
L.stress	-.181*** (.049)	-.143** (.069)	.008 (.042)	.629*** (.116)	-.189*** (.049)	-.153** (.064)	.011 (.043)	.641*** (.113)
L.gap2					-.001 (.033)	.023 (.038)	.052** (.025)	.036 (.038)
L.inte2					-.007 (.013)	.001 (.013)	.011 (.011)	-.012 (.011)
L.infl2					.023 (.027)	.012 (.025)	.002 (.024)	.034 (.030)
L.stress2					.009 (.024)	.056 (.047)	.017 (.026)	-.109 (.067)
Observations	85	85	85	84	85	85	85	84

Notes: Robust s.e. in parentheses. *** = $p < .01$, ** = $p < .05$, * = $p < .1$

Table 6: Marginal effect, quadratic specification

	US		Switzerland	
Marginal effects on stress	t-value	F-test	t-value	F-test
Output gap	1.33	1.5	.64**	5.37
Int_rate	1.93	.048	.87**	4.11
Infl_rate	1.665	.4728	.76*	3.27
Marginal effects of stress on other variables	t-value	F-test	t-value	F-test
Output gap	-.194***	7.653	-.1508***	15.061
Int_rate	-.123*	3.04	.07372**	5.6823
Infl_rate	.02	.06	.081	.0645

Notes: Robust s.e. in parentheses. *** = $p < .01$, ** = $p < .05$, * = $p < .1$. Given the following general non-linear model $y_t = \alpha + \beta_1 x_t + \beta_2 x_t^2 + \eta_t$, the marginal effect of the explanatory variable x_t , on the dependent variable y_t , has been computed in accordance with $\frac{\partial y_t}{\partial x_t} = \hat{\beta}_1 + 2\hat{\beta}_2 \bar{x}$, where $\bar{x}$ is the average value for variable x .

B Figures

Figure 1: US series

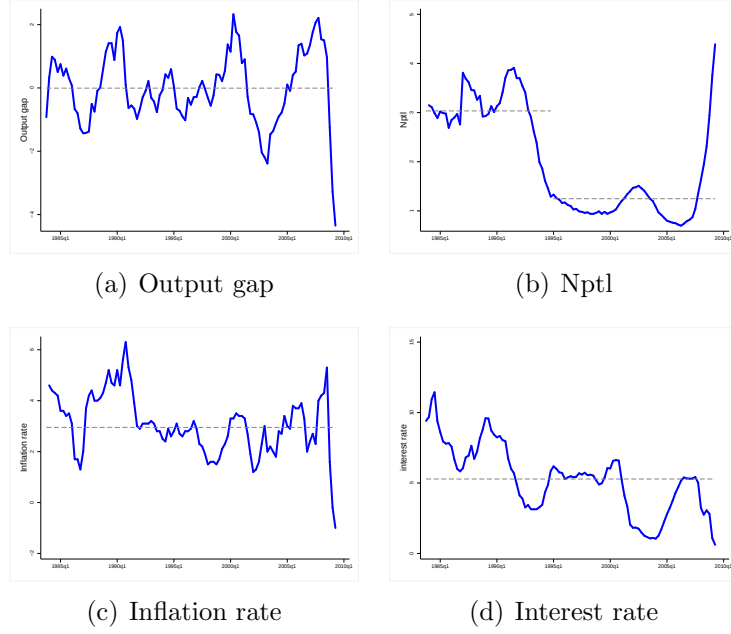


Figure 2: Swiss series

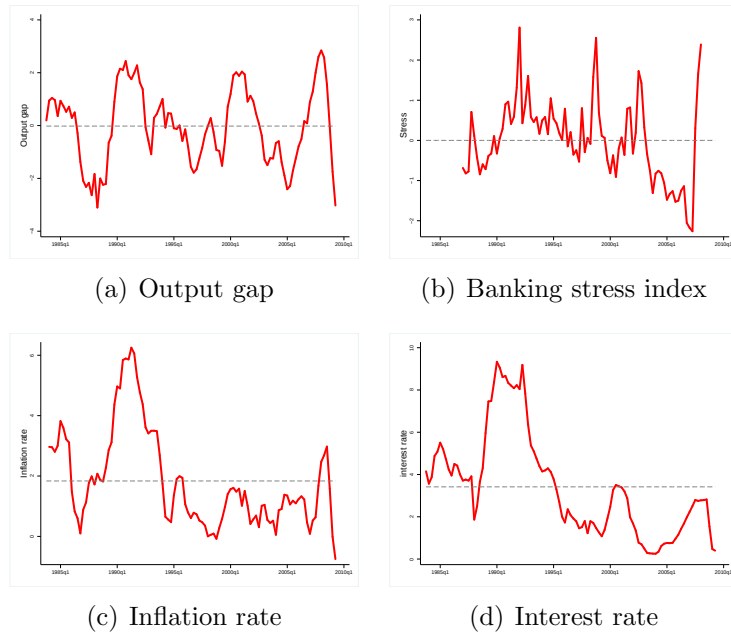


Figure 3: Real and feedback effect, US -baseline-

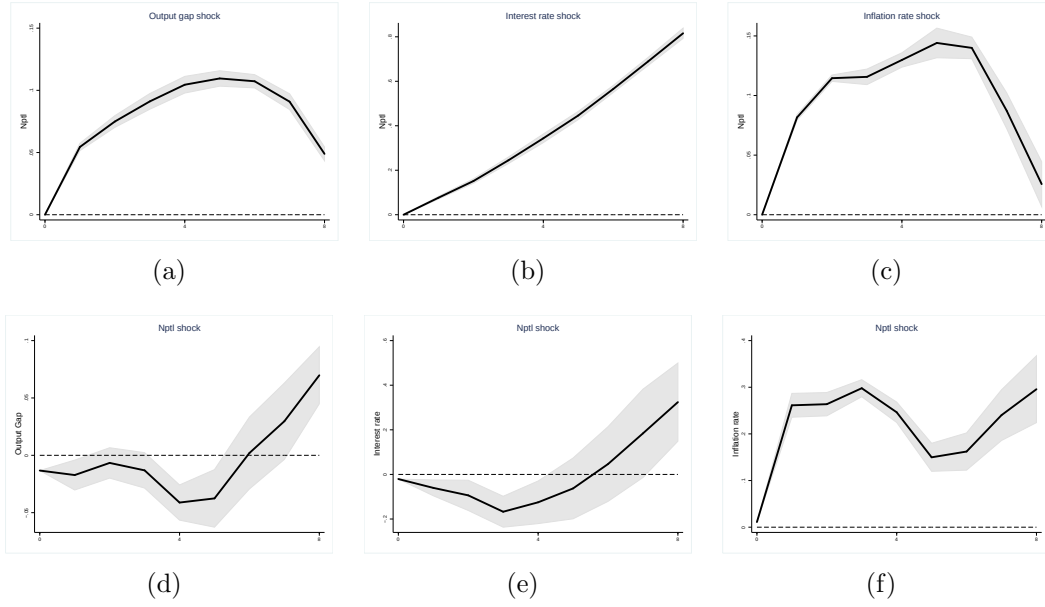
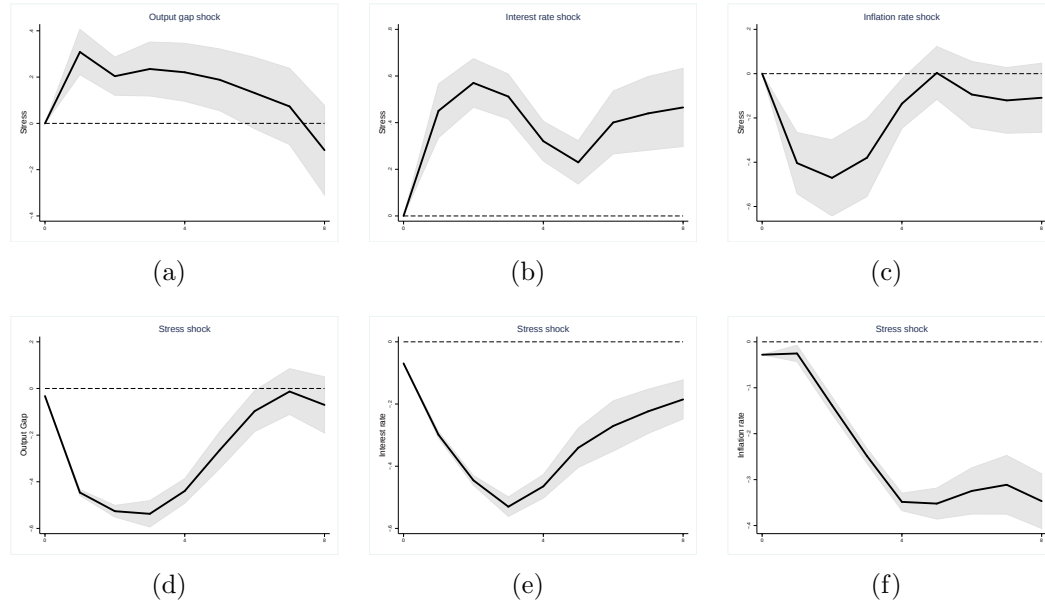
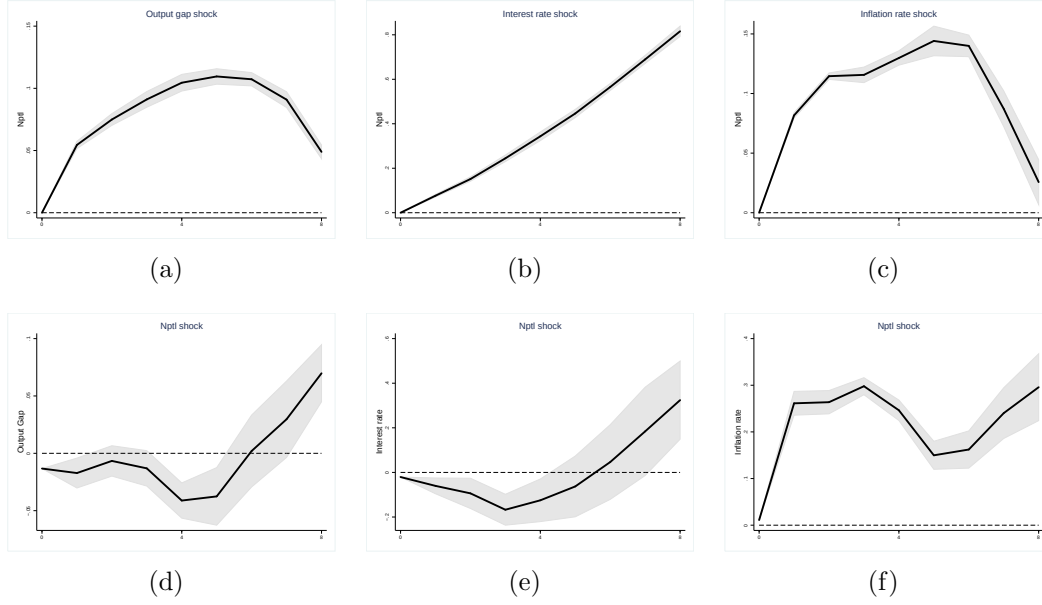


Figure 4: Real and feedback effect, Switzerland -baseline-



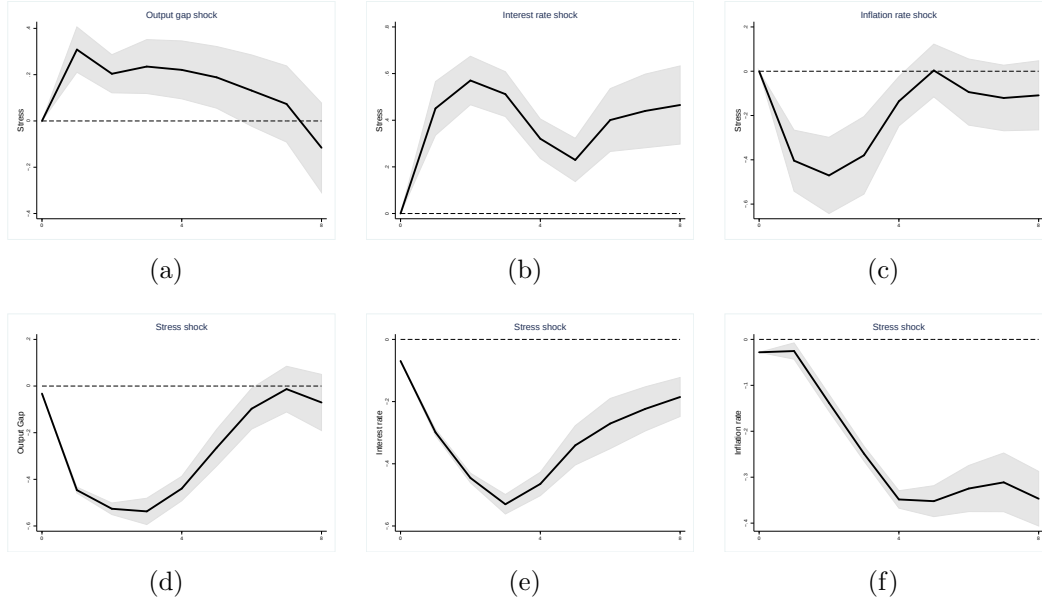
Notes: Graphs in Figures 3 and 4 show the impulse response functions referring to real (upper part) and feedback effects (lower part) for the US and Switzerland, obtained using a quadratic specification. Shock size: 1σ . Sample period: 1987:Q1 - 2008:Q1. The shadow area: 95% confidence interval.

Figure 5: Real and feedback effect, US -robustness I-



Notes: Graphs in Figure 5 show the impulse response functions referring to real (upper part) and feedback effects (lower part) for the US, obtained using a quadratic specification. Shock size: 1σ . Sample period: 1984:Q1 - 2008:Q1. The shadow area: 95% confidence interval.

Figure 6: Real and feedback effect, Switzerland -robustness I-



Notes: Graphs in Figure 6 show the impulse response functions referring to real (upper part) and feedback effects (lower part) for Switzerland, obtained using a quadratic specification. Shock size: 3σ . Sample period: 1987:Q1 - 2008:Q1. The shadow area: 95% confidence interval.

Figure 7: Real and feedback effect, US -Robustness II-

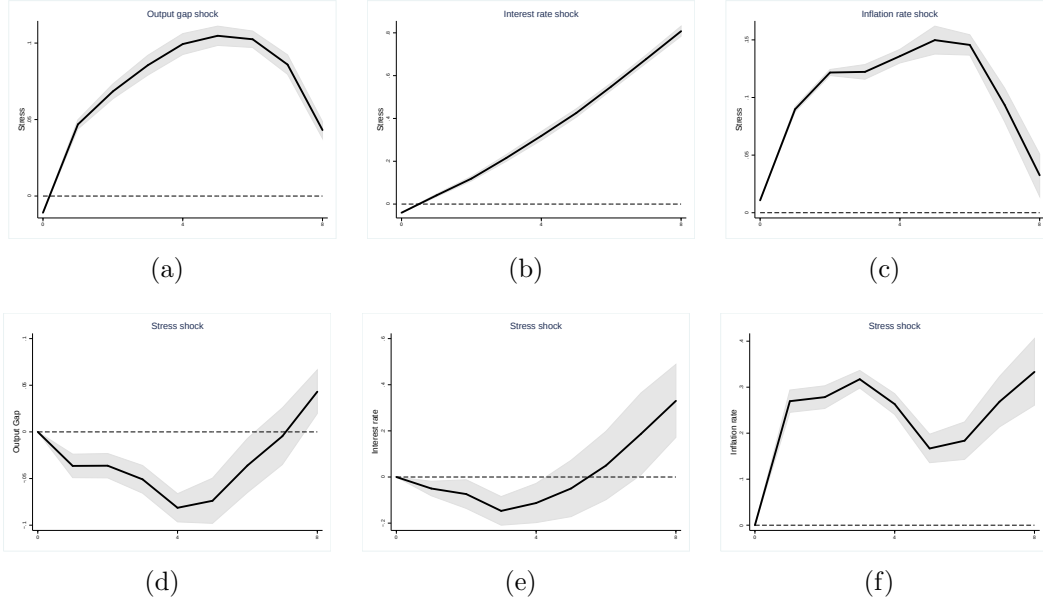
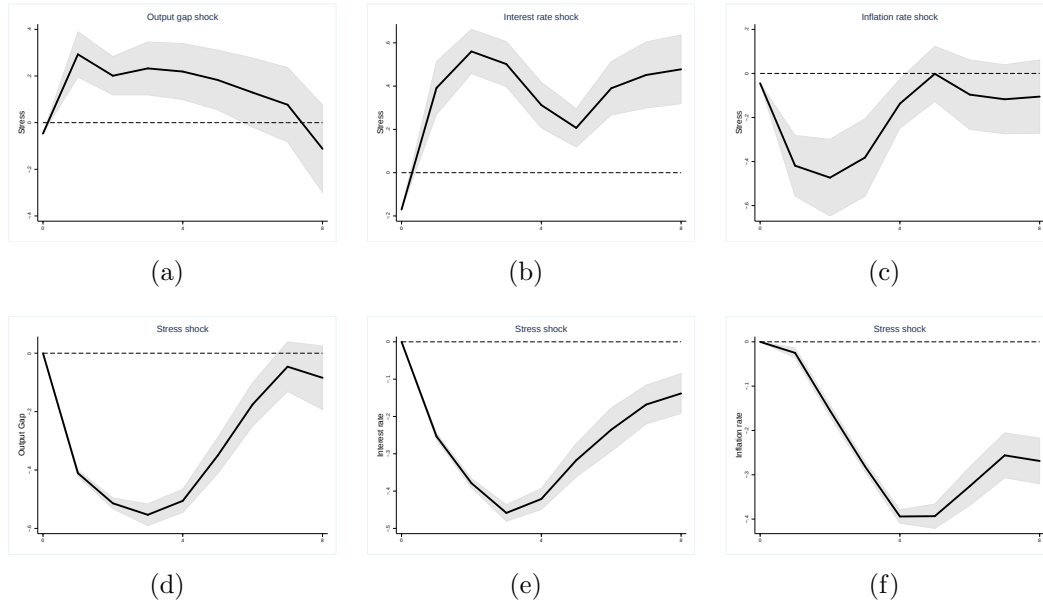


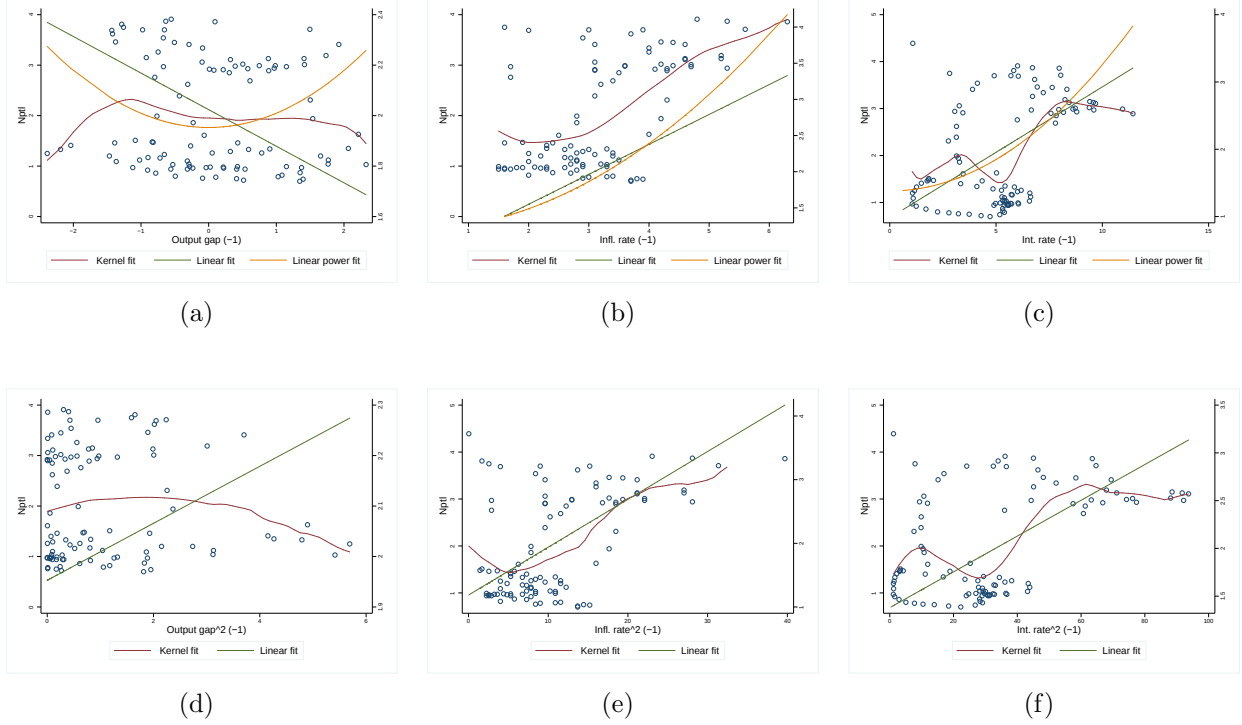
Figure 8: Real and feedback effect, Switzerland -Robustness II-



Notes: Graphs in Figures 7 and 8 show the impulse response functions referring to real (upper part) and feedback effects (lower part) for Switzerland, obtained using a quadratic specification. Variables endogenous order: output gap, inflation rate, interest rate and banking distress index. Shock size: 1σ . Sample period: 1987:Q1 - 2008:Q1. The shadow area: 95% confidence interval.

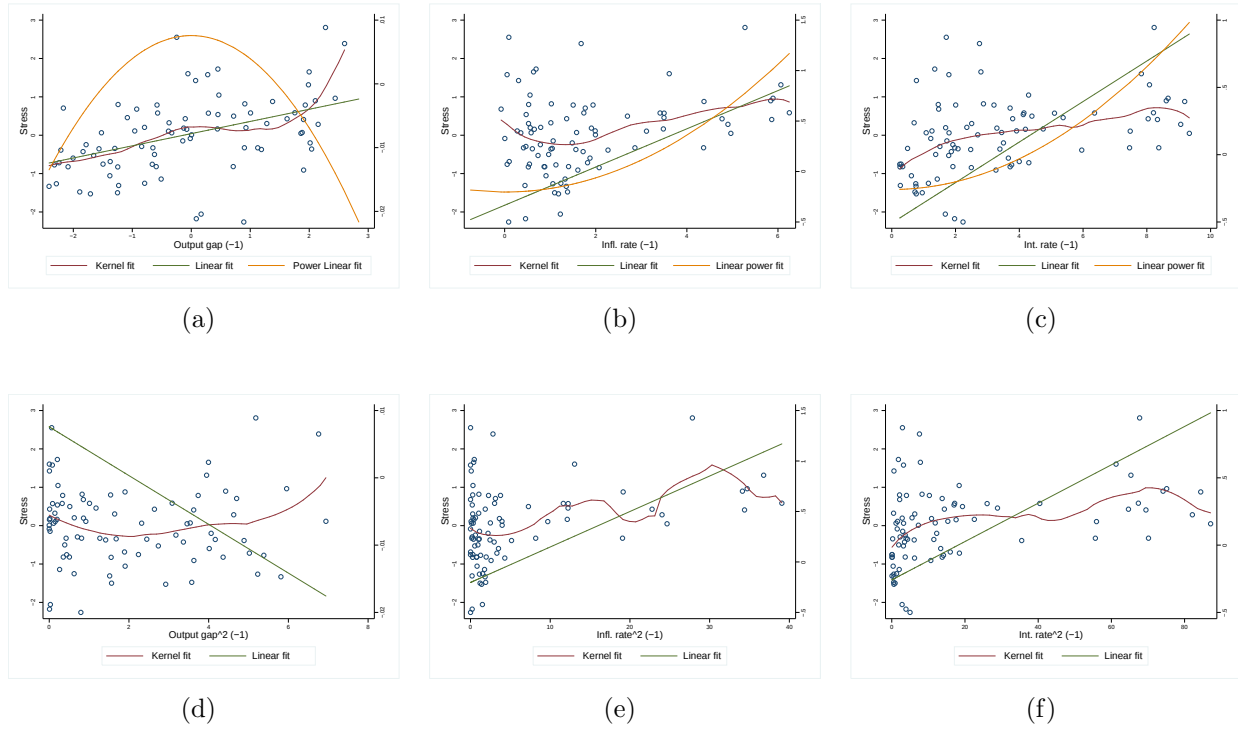
C Non-linear scatter plots

Figure 9: Scatter plot of Nptl vs the other lagged variables with Kernel fit, linear fit and linear power fit. (US data)



Notes: The graphs in Figure 9 report the scatter plot of output gap, computed as the difference between the $\log(\text{GDP})$ and the HP-filtered $\log(\text{GDP})$, the non-performing loans (NPTL), the inflation rate, computed as the yoy percentage change of US CPI, and the 3-month treasury constant maturity rate. In the upper part for each pair (y_t, x_{t-1}) , the Kernel fit, the linear fit and the linear power fit (i.e. the fit between y_t and x_{t-1}^2) are reported. In the lower part for each pair (y_t, x_{t-1}^2) , the Kernel fit and the linear fit are shown. Source FRED, period covered 1984:Q1-2009:Q2.

Figure 10: Scatter plot of Stress vs the other lagged variables with Kernel fit, linear fit and linear power fit. (Swiss data)



Notes: The graphs in Figure 10 report the scatter plot of output gap, computed as the difference between the $\log(\text{GDP})$ and the HP-filtered $\log(\text{GDP})$, the Stress indicator of the SNB, the inflation rate, computed as the yoy percentage change of Swiss CPI, and interbank interest rate. In the upper part for each pair (y_t, x_{t-1}) , the Kernel fit, the linear fit and the linear power fit (i.e. the fit between y_t and x_{t-1}^2) are reported. In the lower part for each pair (y_t, x_{t-1}^2) , the Kernel fit and the linear fit are shown. Source OECD and SNB, period covered 1987:Q1-2008:Q1.

D Monte Carlo simulation

In order to measure the possible bias in the impulse response functions caused by the estimation of a linear model when the DGP is non-linear, we run a Monte Carlo simulation, repeating the estimations 1000 times. More precisely, we simulate a bivariate vector autoregressive model assuming that the two variables, x and z , are characterized by the following non-linear relationship:

$$Y_t = \delta + B Y_{t-1} + Q Y_{t-1}^2 + \eta_t \quad (2)$$

$Y_t \equiv [x_t, z_t]^T$, and $Y_t^2 \equiv [x_t^2, z_t^2]^T$. Finally, B and Q are the matrices of the coefficients referring to the linear and quadratic parts of the specification.

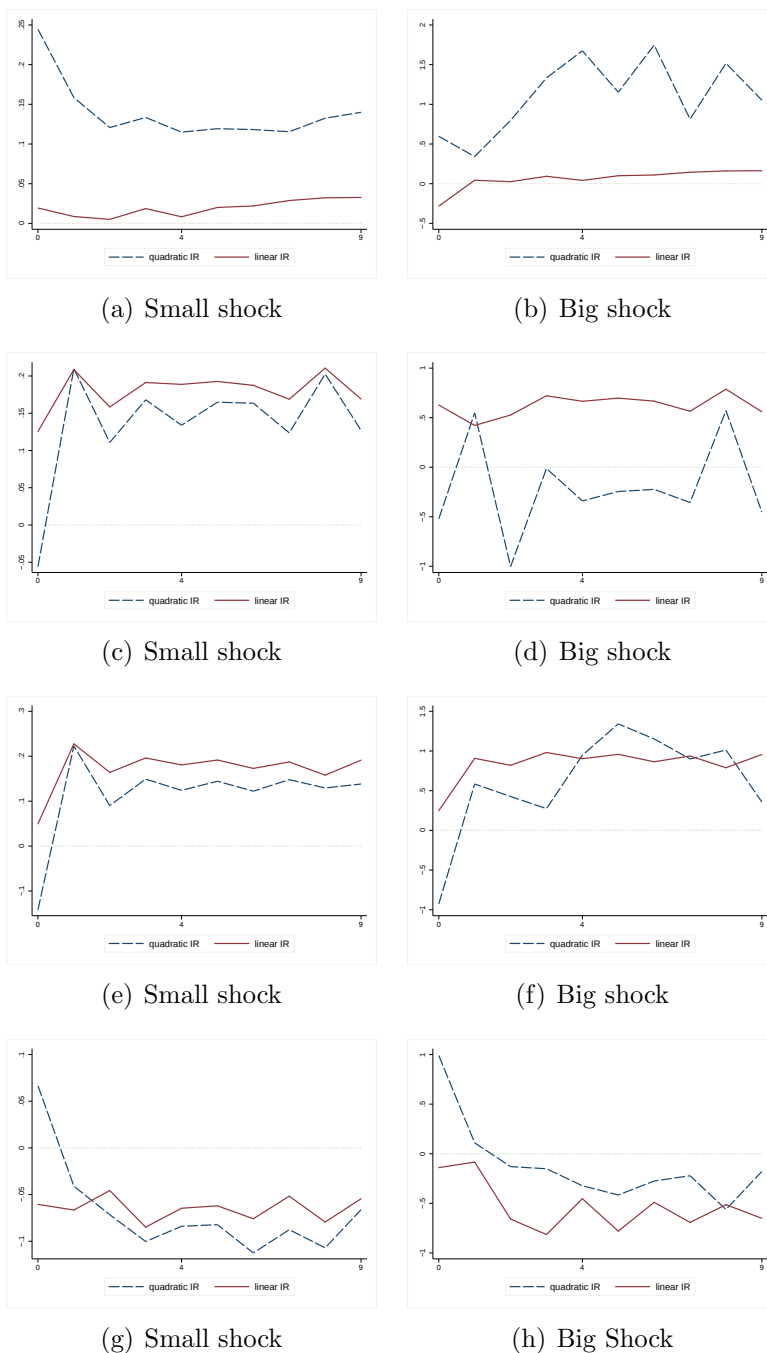
For each repetition, given the initial random values x_0 and z_0 as well as the matrices B and Q we generate two series with 1000 observations each, according to equation (2).

According to the coefficients of the linear and the quadratic part of the specification, four main cases are possible: B and Q positive definite, B and Q negative definite, B negative definite and Q positive definite and finally B positive definite and Q negative definite.

For each repetition, for each point in time of the horizon we are interested in, we approximate the true impulse response function by the impulse response obtained using local projections by estimating a non-linear (dash line) specification. Moreover, we compare the non-linear impulse response function with the corresponding linear impulse response function (solid line). The right-side column graphs refer to the response of x to a five times z variable standard deviation shock (big), while the left-column graphs report the response of x to a unit z variable standard deviation shock (small).

The results highlight that the impulse response functions referring to the linear and non-linear model specifications show different shapes and different magnitudes. The differences are more important when the size of the shock is large. The bias is persistent, and the differences are absorbed after 4 or 6 quarters depending on the case.

Figure 11: Monte Carlo Simulation



Notes: In graphs of Figure 11 we report the four main cases depending on the matrices B and Q . Figures 11a and 11b: B and Q positive definite. Figures 11c and 11d: B and Q negative definite. Figures 11e and 11f: B negative definite and Q positive definite. Figures 11g and 11h: B positive definite and Q negative definite.

E Local Projections

According to Jordà (2005), local projection is a method that estimates, by OLS, a model for each point in time of the period length of interest. Based on the regression results, the corresponding impulse response value is computed. Let us assume that we have a system of n equations and n dependent variables. Moreover, the model specification in its reduced form is characterized by lagged values of the dependent variables as well as their lagged quadratic values. Furthermore, the length of the horizon is S , so that we have s periods, corresponding to s models to be estimated¹⁵.

The model, in its reduced form, is defined by the following specification:

$$y_{t+s} = \alpha^s + B^{s+1}y_{t-1} + Q^{s+1}y_{t-1}^2 + \epsilon_t^s \quad (3)$$

with $s = 1, 2, \dots, S$, where $y_t \equiv [y_{1,t}, y_{2,t}, \dots, y_{n,t}]^T$ and $y_t^2 \equiv [y_{1,t}^2, y_{2,t}^2, \dots, y_{n,t}^2]^T$. For each s , we compute the impulse response generated by the innovation vector d_i at $s = 0$. For each s , the dependent variable is led by one period, while the explanatory variables are always the same. The impulse response can be considered as the marginal effect of the dependent variable for $s = 1, 2, \dots, S$ with respect to an innovation that occurred at $s = 0$:

$$IR(t, s, d_i) = \frac{\partial y_{t+s}}{\partial \epsilon_t} = E(y_{t+s} | \epsilon_t = d_i; Y_t) - E(E(y_{t+s} | \epsilon_t = 0; Y_t)) \quad (4)$$

with $s = 1, 2, \dots, S$ and where $E(\cdot)$ is the conditional expectation, y_{t+s} is the $n \times 1$ vector of the dependent variables at period $t + s$, $Y_t \equiv [y_{t-1}, y_{t-1}^2]^T$ is the set of the explanatory variables, ϵ_t is the $n \times 1$ vector of innovations expressed in the reduced form. Finally, d_i is the column i of the $n \times n$ matrix D that contains all the shocks. Combining equations (3) and (4) leads to

$$IR(t, s, d_i) = B^s d_i + Q^s (2y_{t-1} d_i + d_i^2) \quad (5)$$

for $s = 1, 2, \dots, S$

where y_{t-1} can be approximated by the correspondent vector of average values $\bar{y}$.

¹⁵In our specific case, the length horizon of interest is twelve periods, $S = 8$, which corresponds to two years, while the macroeconomic model is characterized by four variables, $n = 4$.

The system in equation (3) can be estimated using normal OLS. At each point in time in the horizon of interest, it is possible to compute the values of the impulse response functions if the estimated parameters are different from zero. For $s = 0$, the impulse response values are obtained imposing $B = I$ and $Q = 0_n$. Finally, from equation (5) it is possible to construct a confidence interval for the impulse response functions working with the variance-covariance matrix of the estimated coefficients for each s .