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Knightian Uncertainty in Banking Crises

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Introduction. Until recently, the role of financial intermediation has been neglected in the study of macroeconomic fluctuations. The recent crisis urged economists to explicitly investigate how shocks propagates through the financial sector to affect macroeconomic variables. The subprime crisis, in fact, made it evident that financial intermediation itself is a channel for the propagation of shocks, especially for those originating in the credit market.

Roughly speaking the current literature on this topic can be divided between two lines of research. The first one focuses its attention on imperfections in the credit market. The second one focuses on the study of bank capital requirements. If banks are forced by law, or by market forces, to keep some minimum amount of capital as a fraction of their assets, shocks hitting their capital induce banks to either recapitalize or deleverage. In either case the result is a tightening of the credit supply which causes a reduction of investments and GDP.

My goal in this essay is to propose a third mechanism through which the banking sector could have contributed to the recession following the subprime crisis.

In the years preceding the crisis deregulation in the financial sector and financial innovation spurred enthusiasm in financial markets, but made also the system much more fragile.

Beside the direct losses that many institutions incurred, the unfolding of the crisis contributed to a significant rise of uncertainty, in the sense of Knight (1921), in the system.

In this essay I argue that an ambiguity shock, a sudden increase of uncertainty, in the banking sector produces a consistent tightening of credit supply with a subsequent reduction of investments and GDP. To do so, I develop a simple general equilibrium model with three agents, a worker, an entrepreneur and a banker, based on Kollmann et al. (2011). The peculiarity of ambiguity shocks are that they require no particular assumption about capital or collateral requirements and other market imperfections to generate a significant credit crunch.

Banks in Macroeconomics Since the importance of financial intermediation in the determination of the business cycle was recognized by academics, a great effort has been made to understand the functioning of the banking sector in the macroeconomic contest. Both researchers and regulators have put a lot of attention on the role of bank capital and their balance sheets as they are deemed to be among the most relevant variables to consider when studying financial stability.

Two are the main theories regarding the role of bank capital as a requirement for the well-functioning of the credit market. The first states that bank capital is fundamental to solve the moral hazard problem incurring between banks and creditors. The idea is that if banks do not have enough own resources involved in their investments, they may take investment decisions that, while optimal for shareholders, may be suboptimal from the society as a whole. The second theory sees bank capital as a safety net for deposits. Since in the presence of losses bank capital must fall to zero before any loss can pass on depositors, equity constitutes a cushion against losses for depositors. In both cases, the lack of an adequate amount of equity may make it hard for a bank to raise enough loanable funds to exploit all the profitable investment opportunities.

Despite the unquestionable importance of the banking sector as an intermediary between savings and investments, the numerous banking crises occurred in the last decades have shown that the banking system itself constitutes a source of financial and economic instability. In fact, the banking sector provides both a transmission channel for the propagation of shocks originating outside it and a source of shocks that are passed on to the whole economy.

Many macroeconomic models that aim to the study of credit markets include some version of what is called the financial accelerator. The financial accelerator is a mechanisms that explains how shock to asset values can give birth to a vicious circle depressing the economy. A very influential paper on this topic is due to Kiyotaki and Moore (1995). While the original formulations did not involve a banking sector, recent studies have reformulated the financial accelerator theory to fit a credit market where banks play a central role. Von Peter (2004) shows how a fall in asset prices affects the banks' activities even when these assets are not held directly by them. Moreover, he shows that the presence of a binding capital constraint produces a feedback from the banking system to asset prices.

The explicit inclusion of financial intermediation in macroeconomic models gives the opportunity to study other transmission mechanisms. Needless to say, bank capital plays a central role. Meh and Moran (2010) develop a model in which bank capital emerges endogenously to solve an asymmetric information model between banks and their creditors.

Bank capital requirements, though, are not only a channel for the amplification and propagation of shocks generating in the production sector, but also of shocks generating in the financial markets. Iacoviello (2011) tries to quantify the extent to which the output contraction in the Great Recession was caused by shocks generated in the financial markets. Using Bayesian methods, he estimates that these shock accounted for about a half of the output loss. Gerali et al. (2010) arrive at similar conclusions.

Given the importance of the role played by bank capital, many economists have tried to give recommendations about the optimal regulation of capital requirements, often coming to contradictory conclusions.

On the one hand, some believe that the optimal policy consists in procyclical bank capital requirements, meaning that during a recession banks should be allowed to hold less capital as a fraction of total assets.

On the other hand, other economists lean towards the idea of countercyclical capital ratio requirement as the optimal policy.

It is clear that the question about the optimal capital regulation is not of easy solution. Some economists have noticed that the optimal policy may not be as simple as the trivial imposition of a minimum capital-to-asset ratio. De Walque et al. (2010), instead, claim that not only the level of the required capital matters, but also the system for its determination. They find out that the Basel I requirements reduce the long run level of output, making the economy more resilient, while the Basel II ones increase business cycle fluctuations.

Uncertainty and Ambiguity Aversion Knghtian uncertainty takes its name from Frank Hyneman Knight that in one of his books (Knight, 1921) makes a neat distinction between risk and uncertainty. Knightian uncertainty and risk can be distinguished from each other by the fact that the latter is measurable by some parameters and that this measure can and must be used in the decision making process.

As stressed by Machina (1992), the theory of choice under risk can be considered as a "success story" in economic research. For long time the expected utility paradigm has dominated microeconomic research at first, and modern micro-based macroeconomics. In addition to its simplicity and tractability, it could rely on solid axiomatic foundations (Savage, 1972). In a few words the subjective expected utility theory (SEU) assumes that, when facing a decision in an uncertain environment, agents act as if they were maximizing their expected utility, namely the weighted average utility given by their action in all the possible states of the world using the probabilities of these states as weights.

Nevertheless, the expected utility theory is still unable to explain certain behaviors that seem to clash with the Savage's axioms. Probably the most famous example of such behaviors is offered by Ellsberg (1961) , namely the paradox that bears his name.

Following Ellsberg (1961), numerous attempts have been made to develop a decision model that allows for ambiguity-averse behaviors[1]. One of them is the multiple prior model[2] (Gilboa and Schmeidler, 1989). According to this model, an agent that has too little information to form a unique prior over uncertain events bases his/her decisions considering a whole set of priors deemed admissible. Then, while evaluating a bet an uncertainty averse agent would consider the minimal expected utility over all priors in the set (maxmin expected utility).

The concept of Knightian uncertainty has found a number of application in finance at first and in macroeconomics later on, especially after the recent crisis. Here I present some related literature.

Simonsen and Werlang (1991) show how Knightian uncertainty can produce portfolio inertia with positive quantities held of all assets.

Epstein and Wang (1994) develop a model of asset pricing involving Knightian uncertainty. They find out that uncertainty can lead to equilibria that are indeterminate. This implies that the determination of a particular equilibrium is left to "animal spirits", which can cause high volatility in the asset market.

Inspired by the current crisis, Routledge and Zin (2009) show that uncertainty reduces the liquidity in security markets. In their paper they notice that some practices in the financial world seem to clash with the Savage expected utility.

Caballero and Krishnamurthy (2008) argue that Knightian uncertainty, arising from unusual events and untested financial innovations, can cause episodes of flight to quality.

Pritsker (2013) models Knightian uncertainty in the interbank market to study how it may have contributed to its breakdown during 2007 and 2008. He shows that uncertainty can cause the collapse of the Fed Funds market and that, in such an event, private incentive may be insufficient to recover.

[1] See again Camerer and Weber (1992) for a survey.

[2] See Gul and Pesendorfer (2008) for an alternative theory.

Only recently attempts to allow for Knightian uncertainty in business cycles' models have been made.

Ilut and Schneider (2012) develop a medium-scale DSGE model with an ambiguous TFP process. The variability of the ambiguity level emerges as a major source of business cycle fluctuations.

Model Setup The model I propose is a modified version of the two-country business cycle model developed by Kollmann et al. (2011). In this economy only one homogeneous final good is produced and there are four agents: a worker, an entrepreneur, a banker and the government. The worker maximizes his expected utility from consumption and work, holding deposits to the bank and deciding how much to work. The entrepreneur owns capital, invests and buys work from the worker to produce the final good, financing himself through bank loans. Each period, part of the loans are defaulted. He maximizes his expected utility from consumption, under the assumption that he consumes all his profits after investments are made. The banker owns the representative bank that accepts deposits from the worker and lends to the entrepreneur. He maximizes his (ambiguous) expected utility from the consumption of his earning. The forth agent is the government that raises money through lump sum taxes levied on the other three agents, and spends the tax revenue on general public purchases and possibly on transfers to the bank. It is assumed that the government has no deficit or surplus and pursues no active fiscal policy. All agents are assumed to be price takers.

One peculiarity of this model is that the default rate is stochastic. In light of the last crisis, the stochastic default can be thought as a parable for investment mistakes made in the past due, for instance, to overoptimism[3]. It is easy to construct ambiguity over this parameter. The ambiguity represents the difficulty of estimation of the future losses that the bank has to bear. Financial innovations and the complexity of the credit relations made in fact almost impossible to price some instruments and to evaluate the risk exposure of some debtors.

[3] An example of a default shock is the fall in the aggregate US price index after 2006 that was largely unanticipated.

Stochastic Processes There are three sources of randomness in this model. The first is TFP (θ_t). It is assumed that

$$\log \theta_t = \rho_\theta \log \theta_{t-1} + \varepsilon_{\theta,t} \tag{1}$$

where $\varepsilon_{\theta,t}$ is a i.i.d. random variable with mean 0.
The second is the default rate Δ_t. It is assumed to follow a stationary AR(1) process of the following form

$$\Delta_t = (1 - \rho_\Delta)\Delta + \rho_\Delta \Delta_{t-1} + \varepsilon_{\Delta,t} \tag{2}$$

where $\varepsilon_{\Delta,t}$ is a i.i.d. random variable with mean 0.
Unlike the TFP process the latter is not known to all the agents. In particularly it is not know to the banker (see below) which has an ambiguous knowledge. I assume that the conditional mean of Δ_t is ambiguous to the banker, namely that for him

$$\Delta_t = (1 - \rho_\Delta)\Delta + \hat{a}_{t-1} + \rho_\Delta \Delta_{t-1} + \varepsilon_{\Delta,t} \tag{3}$$

where $\hat{a}_t \in [-a_t, -a_t + 2|a_t|]$. The collection of all these distributions for different possible values of $\hat{a}_t$ constitutes the set of admissible priors. To differentiate the banker's expectations from the other agents' expectations, I will use throughout this essay the expectation operator with an hat to indicate the banker's beliefs (e.g. $\hat{E}_t\theta_{t+1} = E_t\theta_{t+1} + \hat{a}_t$) or with a star to indicate the expectations under the optimal prior (a_t^*).

Finally I assume that the ambiguity parameter follows an AR(1) process as well:

$$a_t = (1 - \rho_a)A + \rho_a a_{t-1} + \varepsilon_{a,t} \tag{4}$$

where $\varepsilon_{a,t}$ is a i.i.d. random variable with mean 0. According to this specification, the ambiguity parameter reverts to a long run mean A. Periods of high $a_t > A$ represent unusually low levels of confidence, while low values of a_t are associated with high level of confidence.

Worker In optimizing his consumption the worker faces the following budget constraint:

$$c_t = w_t N_t + R_t^D D_t - D_{t+1} - T_t^W \tag{5}$$

where D_t is the amount of deposits carried from $t-1$ to t, T_t^W is the lump-sum tax paid by the worker, c_t is consumption, w_t is the wage rate, N_t is hours worked and R_t^D is the gross interest earned on D_t.

The worker then solves the following maximization problem:

$$\max_{\{c_t, D_{t+1}, N_t\}} E_t \sum_{s=0}^{\infty} \beta^s [u(c_{t+s}) + \psi^D u(D_{t+s+1}) - \psi^N N_{t+s}] \quad \text{sub. (5).} \tag{6}$$

where Ψ^D and Ψ^N are positive parameters, and $u(x) = (x^{1-\sigma^W} - 1)/(1-\sigma^W)$ (when $\sigma^W = 1$, I set $u(x) = \log(x)$). The fact that workers obtain direct utility from holding deposit is a technical requirement to ensure that the worker holds positive deposits. The optimization problem gives the following first order conditions:

$$R_{t+1}^D E_t \beta \frac{u'(c_{t+1})}{u'(c_t)} + \psi^D \frac{u'(D_{t+1})}{u'(c_t)} = 1 \tag{7}$$

$$u'(c_t) w_t = \psi^N. \tag{8}$$

Entrepreneur The entrepreneur faces the following budget constraint

$$d_t^E = L_{t+1} + Q_t - R_t^L L_t (1 - \Delta_t) - \xi(I_t) - w_t N_t - T_t^E \tag{9}$$

where d_t^E is the dividend received at time t, L_t is the loan received at $t-1$ to be repaid in t, R_t the corresponding gross interest rate, Δ_t the portion of that loan that is defaulted, T_t^E is a lump-sum tax and $Q_t = \theta_t K_t^\alpha N_t^{1-\alpha}$ is the production function, where K_t is the capital stock and θ_t the TFP parameter. The function $\xi(\cdot)$ is the cost of investment $I_t = K_{t+1} - (1-\delta)K_t$ where δ is the depreciation rate. Since the model will be linearized around the steady state, it is sufficient to characterize the first and second derivatives of function around the steady state investment $I = \delta K$. In particular it is assumed that $\xi'(I) = 1$ and $\xi''(I) = 1$.

The entrepreneur solves the following optimization problem:

$$\max_{\{d_t^E, L_{t+1}, N_t\}} E_t \sum_{s=0}^{\infty} \beta^s \nu(d_{t+s}^E) \quad \text{sub. (9).} \tag{10}$$

with $\nu(x) = (x^{1-\sigma^E} - 1)/(1 - \sigma^E)$ (when $\sigma^E = 1$, I set $\nu(x) = \log(x)$). The first order conditions related to this problem are:

$$w_t = (1-\alpha)\theta_t \left(\frac{K_t}{N_t}\right)^\alpha \tag{11}$$

$$R^L_{t+1} E_t \beta \frac{\nu'(d^E_{t+1})}{\nu'(d^E_t)} (1 - \Delta_{t+1}) = 1 \tag{12}$$

$$E_t \beta \frac{\nu'(d^E_{t+1})}{\nu'(d^E_t)} \frac{\alpha\theta_{t+1}\left(\frac{K_{t+1}}{N_{t+1}}\right)^{\alpha-1} + q_{t+1}(1-\delta)}{q_t} = 1 \tag{13}$$

where in the last equation $q_t = \xi'(K_{t+1} - (1-\delta)K_t)$.

Bank The banker owns the representative bank which collects deposits and makes loans to produce dividend for the banker's consumption. It is assumed that the bank faces operating costs for holding deposits (Γ_D) and for making loans (Γ_L). In the original model, it is assumed that the bank is required by law to keep a certain amount of own capital as a fraction γ of total loans. Nevertheless this legal constraint is not binding since the bank can hold less capital but this is costly[4] (e.g. it has to engage in creative accounting). Defining the amount of capital exceeding the legal requirement as $x_t = (L_{t+1} - D_{t+1}) - \gamma L_{t+1}$, $\phi(x_t)$ is the cost of breaking the legal constraint. It is assumed that $\phi(x_t) = 0$ for $x_t \geq 0$ and $\phi(x_t) > 0$ for $x_t < 0$, $\phi'(\cdot) \leq 0$ and $\phi''(\cdot) \leq 0$. This assumption capital requirements will eventually be dropped to disentangle the effects of uncertainty from those of capital requirements.

The bank faces the following budget constraint

$$d^B_t = R^L_t L_t(1-\Delta_t) + D_{t+1} - L_{t+1} - R^D_t D_t - \Gamma_D D_{t+1} - \Gamma_L L_{t+1} - \phi(x_t) + S_t - T^B_t \tag{14}$$

where T^B_t is the lump-sum tax paid by the banker and S_t is a transfer from the government.

I assume the banker maximizes his maxmin expected utility function

[4] In a similar fashion Gerali et al. (2010) assume that a deviation from an exogenously imposed capital ratio entails a quadratic cost for the bank.

under the budget constraint, namely he solves:

$$\max_{\{d^B_{t+s}, D_{t+s+1}, L_{t+s+1}\}_{s=0}^{\infty}} \min_{\hat{a}\in[-a_t, -a_t+2|a_t|]} \hat{E}_t \sum_{s=0}^{\infty} \beta^s v(d^B_{t+s}) \tag{15}$$
$$\text{sub. (14).}$$

with $v(x) = (x^{1-\sigma^B} - 1)/(1-\sigma^B)$ (when $\sigma^B = 1$, I set $\nu(x) = \log(x)$). The Bellman equation corresponding to the problem is

$$\begin{aligned} V(D_t, L_t, \Delta_t) = \max_{\{D_{t+1}, L_{t+1}\}} &\{v(L_t R^L_t (1-\Delta) + D_{t+1} \\ &- L_{t+1} - D_t R^D_t - \Gamma_D D_{t+1} - \Gamma_L L_{t+1} - \phi(x_t) + S_t - T^B_t) \\ &+ \beta \min_{\hat{a}\in[-a_t, -a_t+2|a_t|]} \hat{E}_t V(D_{t+1}, L_{t+1}, \Delta_{t+1})\}. \end{aligned} \tag{16}$$

Preposition 1. *The expected value of the value function is decreasing in Δ_t, that is:*

$$\frac{\partial \hat{E} V}{\partial \Delta_t}(D_t, L_t, \Delta_t) < 0$$

The latter preposition is sufficient to state that the worst-case scenario is obtained for $\hat{a}_t = a^*_t = -a_t + 2|a_t|$, namely for the prior that corresponds to the highest expected default rate. The first order conditions are then

$$R^D_{t+1} E^*_t \beta \frac{v'(d^B_{t+1})}{v'(d^B_t)} = 1 - \Gamma_D + \phi'(x_t) \tag{17}$$

$$R^L_{t+1} E^*_t \beta \frac{v'(d^B_{t+1})}{v'(d^B_t)} (1 - \Delta_{t+1}) = 1 + \Gamma_L + (1-\gamma)\phi'(x_t). \tag{18}$$

Government The government collects taxes and can spend the proceeds to make public purchases of the final good. Alternatively the government can directly support the banking sector through a transfer. It is assumed that the government cannot run deficits nor surpluses, namely that

$$S_t + G_t = \sum_i T^i_T \tag{19}$$

where G is public spending and $i = W, E, B$. It is assumed that each agent funds a constant share of total public spending, that is $T_t^i = \lambda^i (G_t + S_t)$ with $\sum_i \lambda^i = 1$ and $i = W, E, B$.

Solution and Results

Linearization and Calibration I assume there is no capital requirement. The steady state effective loan rate is set to 2.5% p.a., which through equation (12) pins down the value for β. This rate implies a loan rate of 3.48%. Similarly the steady state deposit rate is set to 1% p.a.. The resulting spread is 2.48%. The steady state bank capital ratio is set to 5%. The default rate is set to 0.95% p.a.. Ψ^D is set to generate a target loan-to-GDP ratio of 0.5, while Ψ^N is chosen arbitrarily since it turns out it only affects the scale of the economy and not the dynamics. Finally, I have set $\sigma^W = \sigma^B = 1$ and $\sigma^E = 0.01$.

To calibrate the behavior of the public sector I relied on Kollmann et al. (2012). The baseline public purchases is set to be always equal to the 20% of GDP in every period. The share of taxes paid by each agent is constant and equal to the ratio of own consumption to aggregate consumption.

I have set $\rho_\theta = 0.95$, $\rho_\Delta = 0.97$ and $\Delta = 0.2375$ which corresponds to a 0.95% annualized default rate. I assumed that in the steady state there is no ambiguity ($A = 0$) and that $\rho_a = 0.97$.

Impulse responses Figure 1 shows the effects of an annualized 1% shock in the default rate on some macroeconomic variables. As anticipated, without capital requirements on banks there is no sensible change in economic activity.

Figure 2 shows the responses to an annualized 1% shock in the uncertainty parameter. Here the banker's worst case scenario corresponds to an expected default rate that is 1% higher than before the shock. The uncertainty shock generates much stronger the effects on the economy. Deposits and loans start to decrease, falling by around 5% right after the shock, reaching the lowest level after about four years (roughly -30%). Investments drop immediately by almost 4%. As a consequence aggregate consumption and GDP fall by respectively 2.5% and 3%, starting immediately to catch up with the steady state values. The bank starts deleveraging. The shock causes an increase of the lending rate and a decrease of the deposit rate, that cause a decline

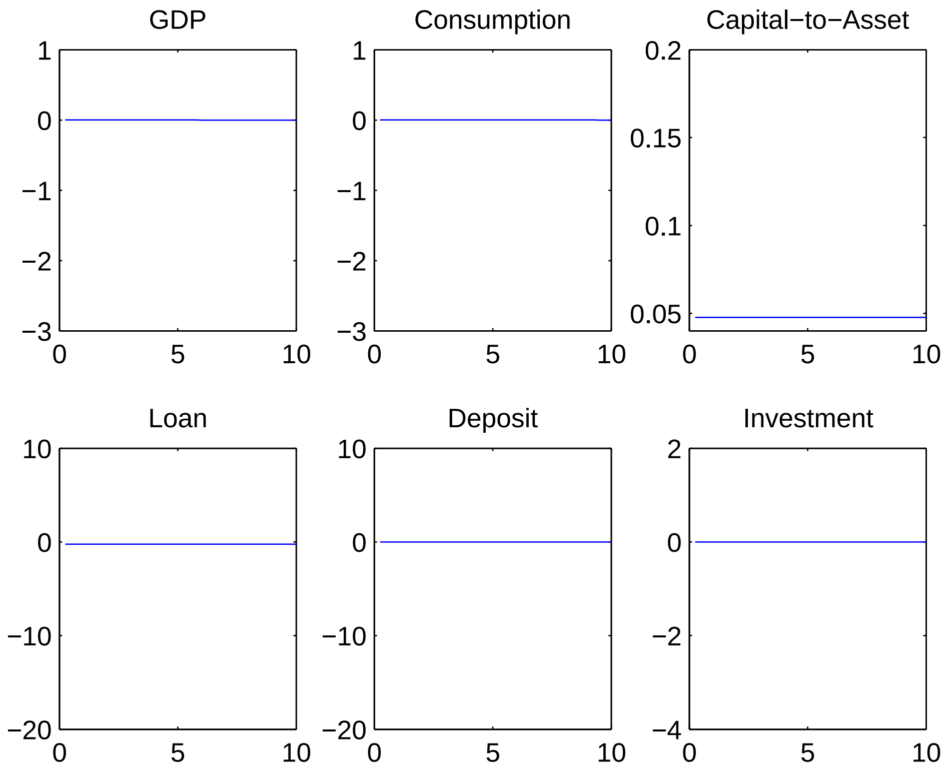

Figure 1: Response to a default rate shock. All values, except the capital-to-asset ratio, are in percentage change from the steady state. The capital-to-asset ratio is measured in absolute value.

of both loans and deposits. In order to smooth consumption the banker accumulates capital that allows him to sustain higher profits.

Policy Experiments Kollmann et al. (2012) run some policy experiments using a similar model to evaluate the impact of different fiscal policies on an economy stroke by a negative default shock. In particular, they analyze the differences between an increase in public spending and a direct transfer to banks. They find out that in the presence of capital requirements a transfer to the banking system has a stronger impact on GDP than an equivalent increase in public spending. Investments, loans and deposits raise in the first scenario and fall in the second one.

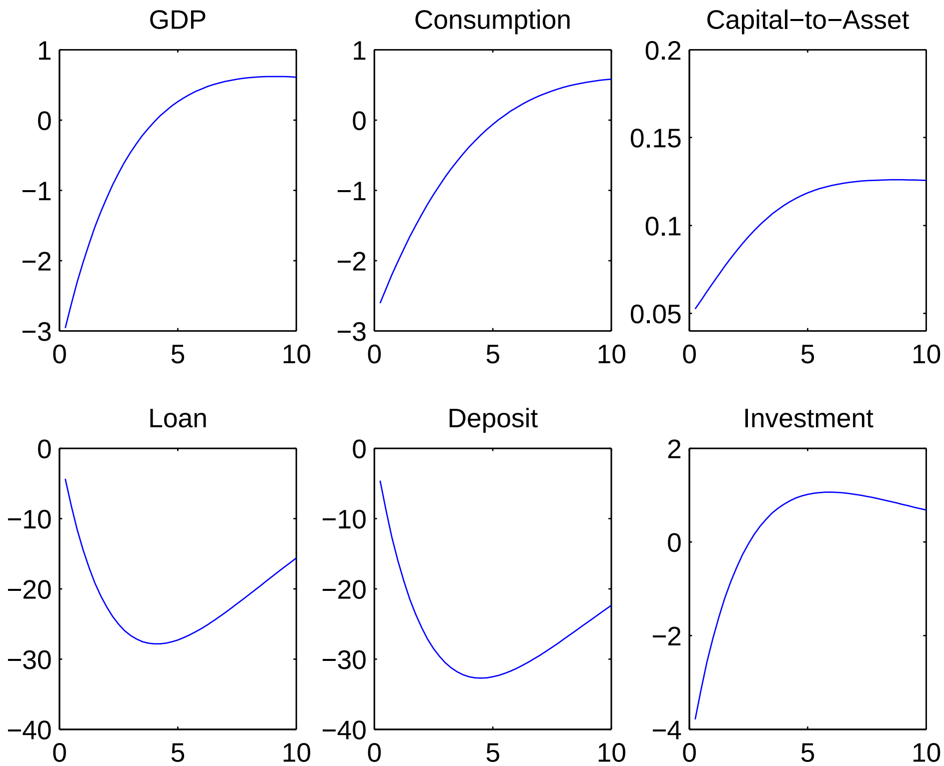

Figure 2: Response to an uncertainty shock. All values, except the capital-to-asset ratio, are in percentage change from the steady state. The capital-to-asset ratio is measured in absolute value.

Here I will run a similar experiment in an economy with no bank capital requirements that has been hit by an ambiguity shock. Figure 3 shows the differences in some variables between the two policy scenarios and the baseline case without any public intervention in the case of an uncertainty shock. It is easy to notice that a rise in public spending has a much stronger effect on GDP than a transfer to the banking system. During the year in which the stimulus is applied, the benefit on GDP generated by the first policy is more than five times that generated by the second one. Yet this is mainly due to the direct effect of public purchases on GDP. In fact, this intervention crowds out both consumption and investment. The banking activity shrinks since both loans and deposits fall, following a similar path. With a direct

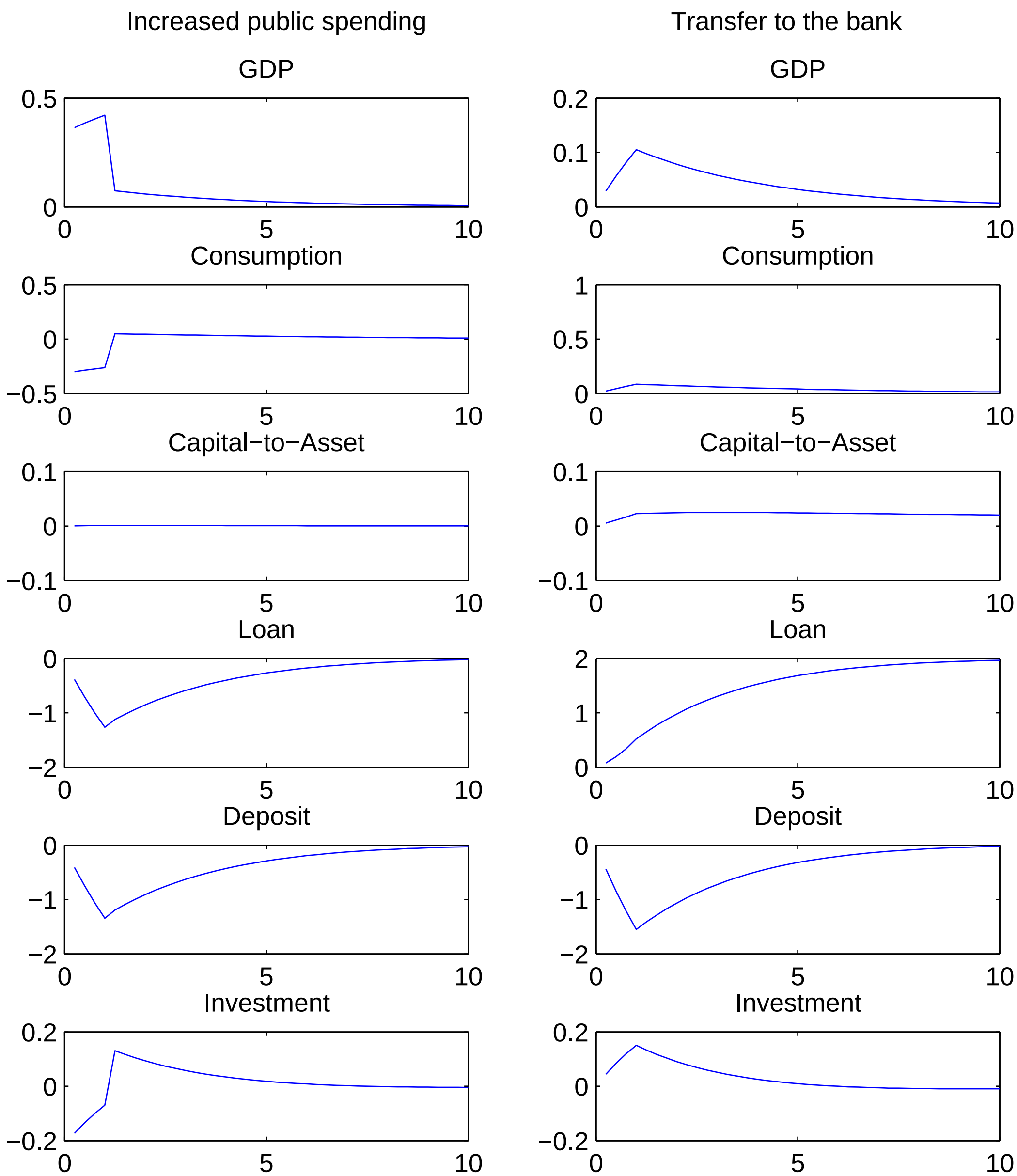

Figure 3: Policy scenarios vs. no intervention. Governement spending on the left, bank aid on the right.

transfer to the banking system, we observe a very little increase in aggregate consumption and a positive effect on investments and loan issuance. Deposits on the other hand decrease just like in the previous case suggesting the main cause of this fall is the increased tax burden to be paid by the worker.

Without capital requirements the effects of supporting the banking industry on the whole economy are much weaker. Moreover, in this case the results obtained by Kollmann et al. (2012) are reverted, since it is clear that the standard fiscal expansion is more favorable. The reason is that their findings fundamentally depend on the presence of capital requirements.

Nevertheless, the most important observation to be made here is that in both cases the positive effects are limited to the period of intervention, which is the first year. In fact after the stimuli the main macroeconomic variables revert sharply to the pre-intervention path. This suggests that the woes brought by uncertainty cannot be resolved by means of standard fiscal policies, but they are likely to require other specific interventions aiming at the reduction of uncertainty itself. However these are out of the reach of this simple model.

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