Online-Appendix to the paper: "Bubbles, Crashes and the Financial Cycle: The Impact of Banking Regulation on Deep Recessions"

A Robustness analysis

The generic robustness of the result presented in the paper in Figure 5 is illustrated by Figure 6, which shows a two-dimensional parameter sensitivity analysis for a 15-by-10 grid of parameter values $\alpha = 4, ..., 32$ and $\beta = 0, ..., 1.0$. Each grid cell contains the value of the lower whisker of the box plot of the amplitude of recessions (across 20 runs). The generic result is that a tighter Reserve Requirement Ratio of 50 percent works much better to contain the severe downturns than a tighter CAR constraint.

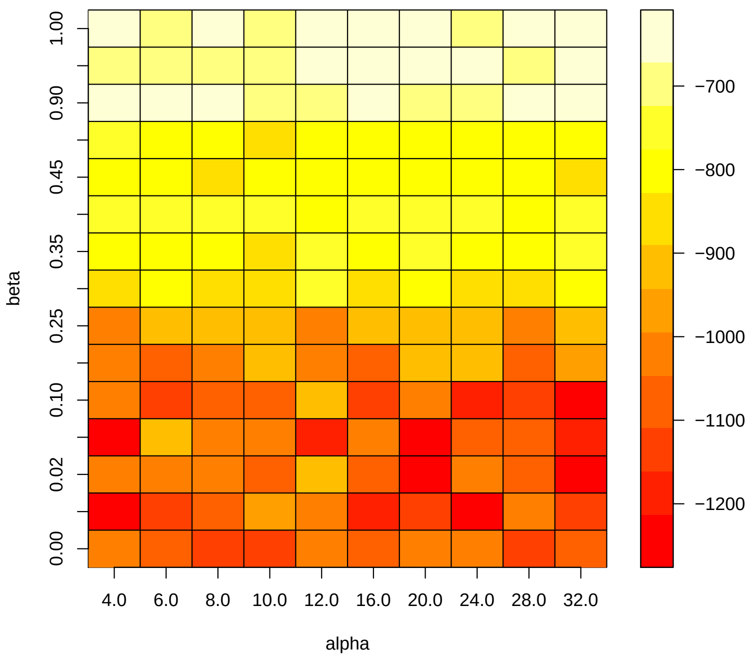


Figure 6: Two-parameter sensitivity analysis for (α, β)-pairs, with the colour-coding showing the amplitudes of recessions. Parameter values: $\alpha = 4, ..., 32$ and $\beta = 0, ..., 1.0$ (a 10×15-grid, 20 runs per cell). Each cell in the grid contains the value of the lower whisker of the box plot of the distribution of the recession amplitudes, measured across the 20 simulation runs (20 random seeds) corresponding to the (α, β)-pair in that grid-cell. The plot shows that varying the value of α does not greatly reduce the amplitudes of severe recessions, while varying the β-parameter does seem to work, provided β is set above 25%.

B Business Cycle Analysis

The algorithm that was used to obtain the results for this paper is based on well-established methods from the empirical literature to study macroeconomic time series data. A classic reference to business cycle dating algorithms is the original BB algorithm developed by Bry and Boschan (1971). A quarterly Bry-Boschan algorithm, known as the BBQ-algorithm, was proposed by Harding and Pagan (2002). We adopt a similar methodology to time series data analysis as in Claessens et al. (2012). The only difference is that we use *synthetic* data generated by our simulation model, while they use empirical data.[13]

B.1 Terminology and Definitions

The meaning of the statistics are the same as in Claessens et al. (2012). The definitions can either be based on the time series of units of output produced, or on the actual sales levels. In our time series analysis, we have used the output-based definitions.[14]

- The determination of peaks and troughs is based on output [or sales] (in units).
- Duration of a recession is the number of quarters between peak and trough.
- Duration for recoveries is the time it takes to attain the level of the previous peak (in quarters).
- The statistics "amplitude" and "slope" are based on output [or sales] (in units).
- The amplitude for a recession is the decline in output [or sales] during the peak to trough decline.
- The amplitude of recoveries is the change in output [or sales] from the trough level to the level reached in the first four quarters of an expansion.
- Cumulative loss is the combination of duration and amplitude and measures the cost of recessions as the foregone output that was not produced (it is calculated as an integral above the output curve).
- The slope of recession is the amplitude divided by duration. The slope of a recovery is the amplitude from the trough to the period when sales reach the level of the last peak, divided by duration.

The following definitions are taken from Claessens et al. (2012, p.10-12):

Peaks and troughs A peak in a timeseries y_t occurs at time t if there are 2 periods of increase before, and 2 periods of decrease after t:

$$(y_t - y_{t-2} > 0, y_t - y_{t-1} > 0) \text{ and } (y_{t+2} - y_t < 0, y_{t+1} - y_t < 0) \tag{23}$$

[13]The code for the recession analysis is included in the source code that is available from our website.

[14]The results are robust against using the output levels or actual sales. The consumption goods producing firms adjust their output based on forward-looking estimation of demand, by so called market research. Planned output therefore is a function of the actual sales over a previous history. If inventories are accumulating, the firm reduces its output, and if there are decreasing inventories, or no inventories at all, the output is increased (if production capacity allows). There can be excess production capacity, implying that the capacity utilization rate is below 100 percent.

A trough in a timeseries y_t occurs at time t if there are 2 periods of decrease before, and 2 periods of increase after t:

$$(y_t - y_{t-2} < 0, y_t - y_{t-1} < 0) \text{ and } (y_{t+2} - y_t > 0, y_{t+1} - y_t > 0)) \tag{24}$$

Recession A recession/downturn is the period between a peak a trough.

Expansion An expansion/upturn is the period between a trough and a peak.

Recovery A recovery is the early part of the expansion phase, defined as the time it takes for output to rebound from the trough to the peak level before the recession.

Duration of recession The duration of a recession/downturn is the number of quarters, k, between a peak (y_0) and the next trough (y_k) of a variable.

Duration of recovery The duration of a recovery/upturn is the number of quarters (r) it takes for a variable to reach its previous peak level after the trough: $\{r > k : y_r \geq y_0\}$.

Amplitude for recession The amplitude of a recession/downturn A_c, measures the change in y_t from a peak (y_0) to the next trough (y_k): $A_c = y_k - y_0$

Amplitude for recovery The amplitude of a recovery/upturn, A_u, measures the change in y_t from a trough to the level reached in the first four quarters of an expansion (y_{k+4}): $A_u = y_{k+4} - y_k$.

Slope for recession The slope of a recession/downturn is the ratio of the amplitude to the duration of the recession/downturn: $S_c = A_c/D_c$.

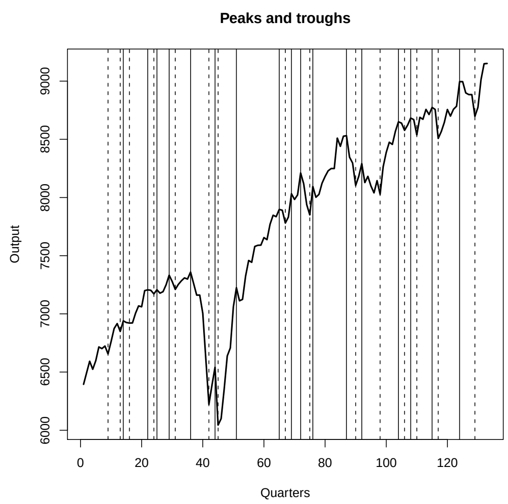
Slope for recovery The slope of a recovery/upturn is the ratio of the change of a variable from the trough to the quarter at which it attains its last peak divided by the duration: $S_r = (y_r - y_0)/D_u$.

Cumulative loss for recession The cumulative loss for a recession with duration k combines the duration and amplitude as a measure for the overall costs of the recession: $F^c = \sum_{j=1}^{k}(y_j - y_0) - A^c/2$, where y_0 is the level of output at the start of the recession, and y_j are the successive terms during the recession.

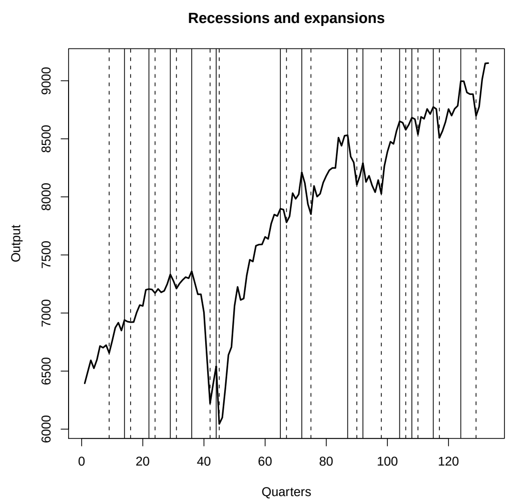
B.2 Detecting peaks and troughs

Fig.7 shows the detection of peaks and troughs in the time series of output for the business cycle (Panel a) and for the time series of total debt for the financial cycle (Panel c). Fig.7 (Panel b) shows expansions and recessions from peak to trough for the business cycle. This plot does not coincide exactly with the peaks and troughs detected in Fig.7 (a) due to the fact that sometimes two peaks can follow each other without having a trough in the middle. This is because the trough does not necessarily signal a recession, since it might be too short. In such cases the event is censored, i.e. removed from the plot. Fig.7 (c-d) provides the same type of analysis for the credit cycle. Here the solid lines coincide with peaks in the credit cycle, i.e. with the start of a downturn. Dotted lines indicate troughs in the credit cycle, i.e. the start of an upturn or recovery.

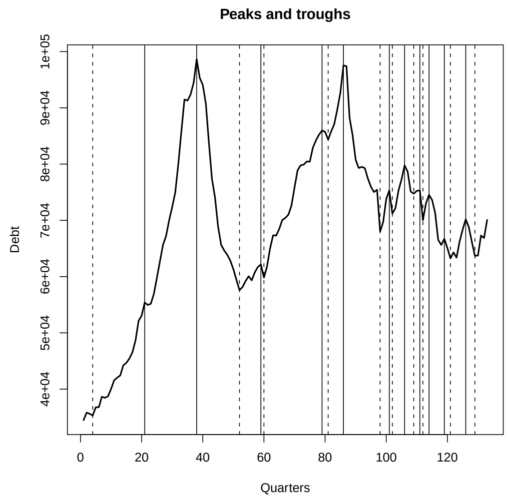
(a) Business cycle, peaks and troughs



(b) Business cycle, recessions and expansions



(c) Credit cycle, peaks and troughs



(d) Credit cycle, downturns and recoveries

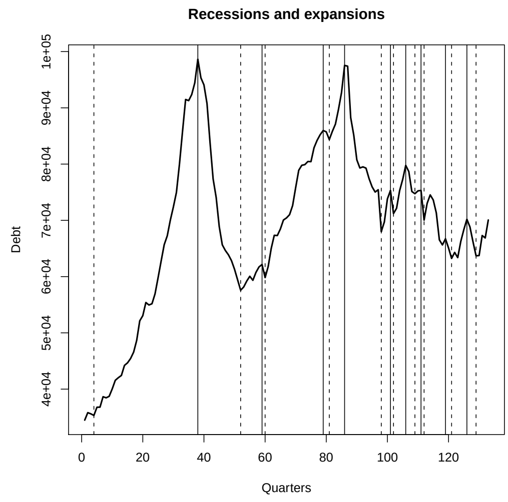


Figure 7: Peaks and troughs for the business cycle and the financial cycle, for 500 months (167 quarters). Solid lines: peaks, or start of a recession; dotted lines: troughs, or start of an expansion. (a-c) Detection of peaks and troughs. (b-d) Recessions and expansions (for the business cycle), and upturns and downturns (for the financial cycle).

C Rationing effects: Credit congestion and Zombie lending

The rationing of credit is caused either by banks' capital requirement becoming binding (an equity effect) or by a binding reserve requirement (a liquidity effect). The main mechanisms are illustrated in Figure 8, which shows how the equity constraint and the liquidity constraint operate differently as transmission channels of financial instabilities. We now look at both channels in turn.

In the example below, we suppose there is one financially unsound firm F (a failed firm) with high default risk and large liquidity needs to satisfy its financial commitments. Further we consider one bank B at which this high-risk firm is requesting a loan. To provide for some contagion, we assume there are other banks C at which firm F also has existing debt. Finally, there also exist other firms G (good firms) that are all financially sound, with a low risk of default and very low liquidity requirements. So neither banks B nor C will by itself ration the credit to the good firms G, but may do so if there are some financial contagion effects due to their exposure to the failed firm F.

C.1 Credit congestion effect

First consider the left-hand panel in Fig. 8 which illustrates the liquidity channel. If bank B accommodates large liquidity requirements of the financially unhealthy firm F, this quickly will deplete its excess liquidity. Under a tight liquidity constraint, this could lead to credit rationing of the failed firm F. This then leads to bad debt of firm F, written of the balance sheets of both bank B and C. Bank B might ration credit to the good firms G as well, due to its binding liquidity constraint, since our banks do not discriminate between firms with small or large liquidity needs; the credit supply is simply a function of the credit risk. However, the healthy firms G with small credit requests might still be able to secure loans with the other, non-liquidity-constrained banks C since those banks are not affected by B's liquidity constraint. And also banks C do not have binding equity constraints.

Hence, the fact that some bank in the economy restricts liquidity does not affect the supply of credit by the other banks to the rest of the economy. This credit congestion effect is therefore a locally contained effect, the supply of credit stops at a single bank, but this does not spread. The credit congestion effect can be associated to the bank lending channel. There is also no negative feedback effect from the liquidity constraint on bank B itself, and more importantly there is no contagion effect on the liquidity constraint of the other banks G.

C.2 Zombie lending effect

We now consider the right-hand panel in Fig. 8 that illustrates the equity channel. Suppose that bank B now has a tight equity constraint. Since firm F has a high default risk it is again credit rationed. Now the risky firm writes off bad debt, this affects the equity of bank B and all other banks C. Hence, bank B now also restricts lending to all other firms G, even though these are low risk. Since these firms cannot get funding, they now become illiquid and start to write off debt with the other banks C as well. Since all banks are under the same strict regulatory regime as bank B, these banks now also get in trouble. The financial contagion is thus not contained, but rather gets transmitted and amplified through the balance sheets of the banks.

The main culprit is the over-extending of loans to firms that are already highly leveraged, that should basically be allowed to go insolvent. But the banks keep extending new loans to roll-over the debt (this was called 'ever-greening' in Japan). This zombie-lending effect causes the financial equivalent of a "cardiac arrest", in which a central organ of the financial system gets paralysed. On top of that, the zombie-lending effect is highly contagious, and can quickly spread from one economy to another.

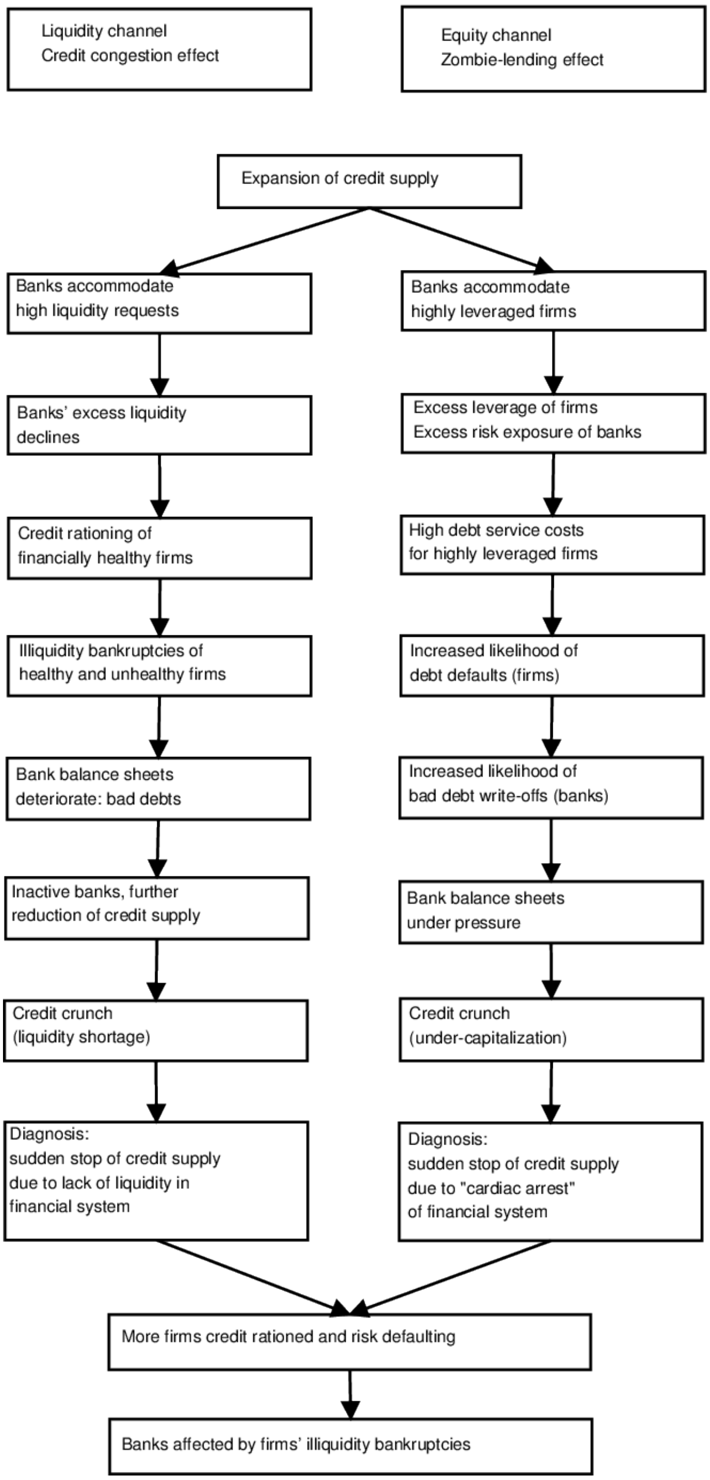


Figure 8: Liquidity and equity channels of financial contagion.