We appreciate the reviewer's deliberate comments on our work. Thanks to these helpful insights, we have made some small revisions to the manuscript in order to be clearer about our argument. Next, we will respond to specific suggestions point by point.

1. **"Stylized facts: To improve the motivation of the paper could be interesting add some evidence of the change in money creation after the introduction of the new Basel regulations."**

   We are grateful to the reviewers for pushing us to link our theoretical conclusions with the stylized facts. Nevertheless, due to the novelty and incomplete implementation of the Basel III regulations (See the following table for the phase-in arrangements for the implementation of the Basel III regulations), there exist little direct empirical evidence regarding the impact of the new Basel regulations on money creation. Therefore, one of the key motivations for the current paper is to provide a theoretical prediction for the potential changes in the determinants of the broad money aggregate and the money multiplier as a result of the implementation of the Basel III accord. We hope our theoretical analysis could be of inspiration for future empirical studies in this regard.

Table 1. Basel III phase-in arrangements. Source: BIS

	Phases	2013	2014	2015	2016	2017	2018	2019
Capital	Leverage Ratio		Parallel run 1 Jan 2013 – 1 Jan 2017 Disclosure starts 1 Jan 2015				Migration to Pillar 1	
Capital	Minimum Common Equity Capital Ratio	3.5%	4.0%	4.5%				4.5%
Capital	Capital Conservation Buffer				0.625%	1.25%	1.875%	2.5%
Capital	Minimum common equity plus capital conservation buffer	3.5%	4.0%	4.5%	5.125%	5.75%	6.375%	7.0%
Capital	Phase-in of deductions from CET1*		20%	40%	60%	80%	100%	100%
Capital	Minimum Tier 1 Capital	4.5%	5.5%	6.0%				6.0%
Capital	Minimum Total Capital		8.0%					8.0%
Capital	Minimum Total Capital plus conservation buffer		8.0%		8.625%	9.25%	9.875%	10.5%
Capital	Capital instruments that no longer qualify as non-core Tier 1 capital or Tier 2 capital		Phased out over 10 year horizon beginning 2013					
Liquidity	Liquidity coverage ratio – minimum requirement			60%	70%	80%	90%	100%
Liquidity	Net stable funding ratio						Introduce minimum standard	

* Including amounts exceeding the limit for deferred tax assets (DTAs), mortgage servicing rights (MSRs) and financials.
-- transition periods

   Despite the lack of readily available direct empirical evidence, our theoretical analyses are built on three indirect stylized facts, which are listed in the first and second sections of the current paper: 1) the money multiplier is not a constant as assumed in the traditional fractional reserve theory of banking but decreases with the expansion of monetary base as a result of the quantitative easing policy in countries such as the U.S.; 2) the tightening of capital requirement will have a negative impact on bank lending, at least in the short-term; 3) expansionary monetary policy are less effective for capital-constrained banks. Because the risk-based capital requirement was proposed before in previous Basel accords since the 1990s, there are more existing empirical investigations regarding its impact on bank behaviours than those for the LR and the LCR regulation, let alone the collective impacts when multiple regulations are simultaneously imposed.

As elaborated in the second section, commercial banks are not merely financial intermediaries who lend out what is saved with them. Instead, the stocks of deposits and loans expand when the bank issues a loan. Due to the business model of the bank, its decision of issuing a loan depends on the profit and risk associated with the loan. In order to prevent the accumulation of excessive risk in the banking system, the Basel III accord requires that the bank should hold sufficient amount of high quality liquid assets and bank capital as the credit base to guard against liquidity and insolvency risk. Because increasing the level of credit base is often expensive or even unfeasible for the bank, prudential regulations render a constraining effect on bank lending, which thus affect the money creation process. As indicated by our results, when the bank is constrained by the prudential regulations of CAR, LR and LCR, the money multiplier will be a decreasing function of the monetary base, rather than being a constant as in the case where the bank is constrained by the reserve requirement. This provides a possible theoretical explanation for the collapse of the money multiplier observed in many countries after the implementation of the quantitative easing policy. For instance, in the case of the U.S. during 2008-2014, although the new Basel III regulations have not been all implemented, risk-based capital requirement that conforms with the Basel II accord was already implemented and there is a lot of market pressure on bank deleveraging, which eventually result in the sluggish response of bank lending and the broad money supply to the expansion of monetary base.

In order to make these points clearer for readers, we make two revision in the manuscript:

- We change the title to be “The impact of Basel III on money creation: a synthetic theoretical analysis” so as to highlight the theoretical nature of the current paper.
- We add the above figure regarding the empirical movement of the money multiplier in the U.S. as an illustration for the collapse of the money multiplier.

Exact revisions in the manuscript are highlighted in blue and shown as follows:

(QE). In consequence, there has been commensurate increase in the monetary base together with a tripling or quadrupling of the size of central bank balance sheets. However, these actions have had much less impact on bank lending and the broad money aggregate. In particular, the money multiplier, which used to be reasonably stable in normal times, experienced unprecedented plumbing to less than half of its pre-crisis level (See Figure 1 for the empirical movements of the M0 stock, the M2 stock and the money multiplier in the U.S. [1]).

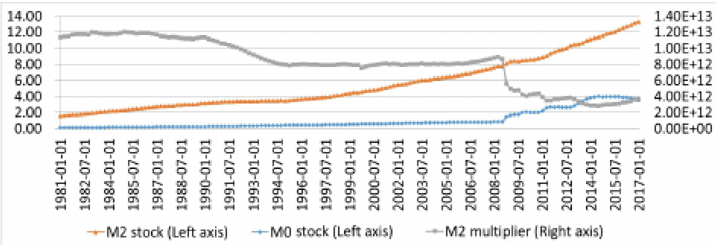


Figure 1: The M0 stock (US dollar) , the M2 stock (US dollar) and the money multiplier in the U.S. from 1981-01-01 to 2017-01-31. Data source: https://fred.stlouisfed.org.

2. "Model: the reasons behind the equation (27) is not clear to me. Could you better explain that and show what happen if you change this assumption. "

The assumption of $\mathrm{IF(t)} = 0.5 * \mathrm{RP(t)}$ is based on the definition of the calculation of cash inflows in stressed condition given in the official document regarding the LCR regulation provided by the Basel committee (https://www.bis.org/publ/bcbs238.htm).

As indicated by the following tables, different inflow rate set by the Basel III accord for different types of bank assets. In general, the bank should only include contractual non-contingent inflows (including interest payment) from outstanding exposures that are fully performing and for which the bank has no reason to expect a default within the 30-day time horizon. The accord indicates that a bank should assume that maturing reverse repurchase or securities borrowing agreement secured by Level 1 assets will be rolled-over and will not give rise to any cash inflows (0%). In our model, government bonds and bank reserves are qualified as Level 1 assets which bears 0% inflows. On the other hand, the inflow rate for non-HQLA assets varies from 0%-100% for different types of counterparties. Here we take 50% as an exemplary inflow rate for the repayments received from outstanding bank loans, which hence gives the expression of $\mathrm{IF(t)} = 0.5 * \mathrm{RP(t)}$. Indeed, this assumption could be relaxed and the inflow rate for the repayments from bank loans could take other values.

Table 2. Calculation of cash inflows for different type of assets. Left column: asset type. Right column: inflow rate. Source: BIS.

Cash Inflows	
Maturing secured lending transactions backed by the following collateral:	
Level 1 assets	0%
Level 2A assets	15%
Level 2B assets • Eligible RMBS • Other assets	 25% 50%
Margin lending backed by all other collateral	50%
All other assets	100%
Credit or liquidity facilities provided to the reporting bank	0%
Operational deposits held at other financial institutions (include deposits held at centralised institution of network of co-operative banks)	0%
Other inflows by counterparty: • Amounts to be received from retail counterparties • Amounts to be received from non-financial wholesale counterparties, from transactions other than those listed in above inflow categories • Amounts to be received from financial institutions and central banks, from transactions other than those listed in above inflow categories.	 50% 50% 100%
Net derivative cash inflows	100%
Other contractual cash inflows	National discretion
Total cash inflows	
Total net cash outflows = Total cash outflows minus min [total cash inflows, 75% of gross outflows]	
LCR = Stock of HQLA / Total net cash outflows	

Table 3. Definition of asset type and calculation of the HQLA. Source: BIS.

Item	Factor
Stock of HQLA	
A. Level 1 assets:	
• Coins and bank notes • Qualifying marketable securities from sovereigns, central banks, PSEs, and multilateral development banks • Qualifying central bank reserves • Domestic sovereign or central bank debt for non-0% risk-weighted sovereigns	100%
B. Level 2 assets (maximum of 40% of HQLA):	
Level 2A assets	
• Sovereign, central bank, multilateral development banks, and PSE assets qualifying for 20% risk weighting • Qualifying corporate debt securities rated AA- or higher • Qualifying covered bonds rated AA- or higher ***Level 2B assets (maximum of 15% of HQLA)***	85%
• Qualifying RMBS • Qualifying corporate debt securities rated between A+ and BBB- • Qualifying common equity shares	75% 50% 50%
Total value of stock of HQLA	

To further explore this point, we generalized this assumption with the equation of $\mathrm{IF(t)} = \omega\mathrm{RP(t)}$, where ω is denoted as the inflow rate of the repayments for outstanding bank loans. ω is generally higher when the counterparty to which bank loans are made has higher credit ratings and can successfully fulfil its debt obligations in stressed condition. Injecting this equation back to the model, we could obtain the following expression for the money multiplier m and money supply M under the LCR regulation:

$$\mathrm{M} = \begin{cases} \dfrac{4(R+G)}{\mu r_{LCR}}, \mu \leq \dfrac{8\omega(1+g)}{(3+3\theta+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \dfrac{(1+\theta-2\omega r_{LCR})(R+G)+2\omega r_{LCR}C}{[\mu(1+\theta)-2\omega]r_{LCR}}, \mu > \dfrac{8\omega(1+g)}{(3+3\theta+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}} \end{cases}.$$

$$\mathrm{m} = \begin{cases} \dfrac{4(1+g)}{\mu r_{LCR}}, \mu \leq \dfrac{8\omega(1+g)}{(3+3\theta+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \dfrac{(1+\theta-2\omega r_{LCR})(1+g)+2\omega r_{LCR}c}{[\mu(1+\theta)-2\omega]r_{LCR}}, \mu > \dfrac{8\omega(1+g)}{(3+3\theta+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}} \end{cases}.$$

It is straightforward to know that if $\mu > \frac{8\omega(1+g)}{(3+3\theta+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}} (i.e. IF < 0.75 * OF)$, then $\frac{\partial M}{\partial \omega} > 0, \frac{\partial m}{\partial \omega} > 0$. In other words, if bank loans are made to borrowers with higher credit ratings who can provide larger cash inflows for the bank during stressed condition, the banking system has greater capacity to create money when constrained by the LCR regulation.

For the convenience of readers with similar interest in this assumption, we add an appendix in the manuscript that provides a better illustration of this point, i.e.

C The more generalized expressions for the money supply and money multiplier under the LCR regulation after relaxing the assumption of 50% inflow rate for bank loans

This assumption of 50% inflow rate for bank loans used in Equation 25 can be relaxed by the following equation:

$$IF(t) = \omega * RP(t), \tag{69}$$

where ω is denoted as the inflow rate of the repayments for outstanding bank loans. ω is generally higher when the counterparty to which bank loans are made has higher credit ratings and can successfully fulfil its debt obligations in stressed condition. Following similar procedures elaborated in Section 4.1, we can obtain the corresponding expressions for the money supply M and money multiplier m when the bank is constrained by the LCR regulation, i.e.

$$M_{LCR} = \begin{cases} \frac{4(R+G)}{\mu r_{LCR}}, \ \mu \leq \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \frac{(R+G)(1+\theta-2\omega r_{LCR})+2\omega r_{LCR} C}{r_{LCR}[\mu(1+\theta)-2\omega]}, \ \mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}. \end{cases} \tag{70}$$

$$m_{LCR} = \begin{cases} \frac{4(1+g)}{\mu r_{LCR}}, \ \mu \leq \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \frac{(1+g)(1+\theta-2\omega r_{LCR})+2\omega c r_{LCR}}{r_{LCR}[\mu(1+\theta)-2\omega]}, \ \mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}. \end{cases} \tag{71}$$

It is straightforward to know that if $\mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}$ (i.e. $IF < 0.75 * OF$), then $\frac{\partial M}{\partial \omega} > 0$, $\frac{\partial m}{\partial \omega} > 0$. In other words, if bank loans are made to borrowers with higher credit ratings who can provide larger cash inflows for the bank during stressed condition, the banking system has greater capacity to create money when constrained by the LCR regulation.

3. **”More in general, I think that the model needs some robustness check. The author should relax some assumption and show the results.”**

We appreciate the reviewer’s advice on further proving the robustness of our conclusions. As indicated by our revised title, the current paper presents a theoretical attempt to understand the potential impact of the Basel III accord on the money creation process. In order to zoom in on the complexity of the multi-polar regulatory framework in the new Basel accord, we build our analysis on a parsimonious model that is centred on the commercial bank and conforms with the stock-flow consistency. We consider a simplified bank balance sheet and assume that its structure in different economic states can be characterized by the average loan maturity θ, average default risk γ, run-off ratio of deposits μ, the capital-to-reserve ratio c and the government-bond-to-reserve ratio g.

When discussing the standalone impact of each individual regulation, we first obtain the corresponding theoretical expressions for the broad money aggregate and the money multiplier and examine their dependence on the minimum policy requirement, r_{LCR}, r_{CAR}, r_{LR}, the monetary base, the structure of bank balance sheet and general economic condition by taking the derivatives with respect to corresponding variables and parameters. Thanks to the reviewer's previous comment, we relax the assumption of $IF(t) = 0.5 * RP(t)$ by considering $IF(t) = \omega * RP(t)$ and thus make our analysis more complete.

As for the collective impact when multiple prudential regulations are simultaneously imposed, we use Figure 3 to show the transition of the effective binding constraint and the corresponding changes in the money multiplier. For the purpose of the simplest and clearest illustration, we demonstrate parameters related to the bank's uses of funds on the horizontal and the vertical axis, i.e. $\theta \in [1,180]$(month) and $\gamma \in [0,1]$, and vary the values of the parameters related to the bank's sources of funds, i.e. c and μ, in the panels of (a-d). We consider c=0.8 and c=2 respectively as low and high capital level, and regard $\mu = 0.1$ and $\mu = 0.55$ as low and high deposit run-off ratio. The choice of these values are based on the empirical data of the U.S. banking system from 1992 to 2009 shown in Appendix C. Admittedly, this choice is subjective and is a specific case used for illustration purpose. Nevertheless, changing their values will not have big impacts our main conclusions that 1) the effective binding regulation, by which the bank's ability to create money is constrained, varies across different economic states and bank balance sheet conditions; and 2) due to the transition of the effective binding regulation, the money multiplier depends on the parameters related to the economic state and bank balance sheet condition in a nonlinear way; and 3) in general, the money multiplier gets higher when the banking system holds higher level of capital, assets with shorter maturity and lower default or depreciation risk, and more stable debt-based financing source. To demonstrate this point, we present the result for other values of c, μ, g in the document of "Robustness test. pdf". There are no qualitative difference between these results and the ones we show in the manuscript.

Revisions in the manuscript that correspond to this comments are shown as follows:

To summarize, when multiple prudential regulations are simultaneously taking effect, we find that 1) the effective binding regulation, by which the bank's ability to create money is constrained, varies across different economic states and bank balance sheet conditions; and 2) due to the transition of the effective binding regulation, the money multiplier depends on the parameters related to the economic state and bank balance sheet condition in a nonlinear way; and 3) in general, the money multiplier gets higher when the banking system holds higher level of capital, assets with shorter maturity and lower default or depreciation risk, and more stable debt-based financing source.

Lastly, although the simplicity of the model is considered as a merit in the current analysis, it is also important to be aware of its limitations, including the assumption of representative bank, abstractions of interest rate and non-passive response of other economic entities. An extension of the model into more general stock-flow consistent models incorporating heterogeneous agents and more serious data calibration would be a fruitful possibility for future research.

4. **"Figure 3: The results in Figure 3 are similar when we change the values used for rLCR rCAR and rLR"**

All results shown in Figure 3 are obtained for $r_{LCR} = 100\%, r_{CAR} = 7\%, r_{LR} = 3\%$. These values are set according the new Basel requirements. The reviewer is right about that our main conclusions will not change much if we vary these values.

5. **"Table 2: The Table 2 is useful to summarize the results in the first part of the model. The author can try to discuss more and compare the results."**

In response to this comments, we make the following revision in the manuscript:

Heretofore, we have examined the standalone impact of each individual regulation on the bank's ability to lend and create money. To conclude, we summarize these results in Table 2. We find that 1) the tightening of both the prudential requirements and the reserve requirement will have a negative impact on the banking system's ability to create money; and 2) in contrast to the constant money multiplier based on the reserve requirement, the money multiplier under the Basel III accord is a decreasing function of the monetary base and the broad money supply may or may not expand when there is a positive shock to the monetary base; and 3) due to the different constraining effects of different regulations to which the bank is subject, the money creation process are sensitive to different types of economic changes. For instance, the variation of the level of bank capitals can affect the money supply and the money multiplier only when the banking system is constrained by capital-based requirements of the CAR and the LR regulations. On the other hand, the stability of the bank's debt-based financing source and the maturity structure of loans only matter when the LCR regulation is taking effect.

6. **"Li et al. (2017): As the paper seems to be an extension of the model in Li et al. (2017), the authors should better explain the novelty of this paper respect to the other."**

We appreciate the reviewer's suggestion that we should clarify the novelty of the current model compared to the one proposed in Li et al. (2017). There are two major difference between the two models:

1) Regarding the balance sheet of the representative commercial bank, we consider three types of assets (reserves, government bonds and loans) and two types of liabilities (deposits and bank capital), while government bonds and bank capital are not taken into account in the model of Li et al. (2017). Such modification allows us to analyse capital based requirements such as the CAR and LR regulation in addition to the LCR regulation.

2) Li et al. (2017) only discuss the standalone impact of the LCR regulation on the money creation process whereas our work analyse the collective impacts of the simultaneous imposition of the LCR, CAR and LR regulations. This extension is an important step forward in enhancing the comprehensive evaluation of the Basel III accord as a multi-polar regulatory framework.

Corresponding to this suggestion, the following footnote is added to the manuscript:

3 The model

To demonstrate the impacts of Basel III regulations on the credit creation process, we employ a stock-flow consistent dynamical model modified based on the work of Li et al. (2017)[6]. We consider a representative commercial bank with a simplified

[5] In order to increase the actual LCR,CAR and LR, banks may also increase the share of safe or short-term loans and raising more stable funds. However, the effects of these actions are marginal compared with the overall quantity control of loans and deposits.

[6] Compared with the model in Li et al. (2017), we make a more realistic assumption about the commercial bank's balance sheet structure by considering bank capital and government bonds in addition to reserves, deposits and loans. Such extension allows us to explore the constraining effects of different prudential regulation including the LCR, CAR and LR regulations.

7. "Minor comment: In the references, there are some typos. For example, the first line starts with (2004), or for same paper, the author leave the expression et al. (e.g., Botos et al., 2016)"

Thanks for pointing out the typos. We have made corresponding revisions to the references in the revised manuscript. We will be more careful next time.

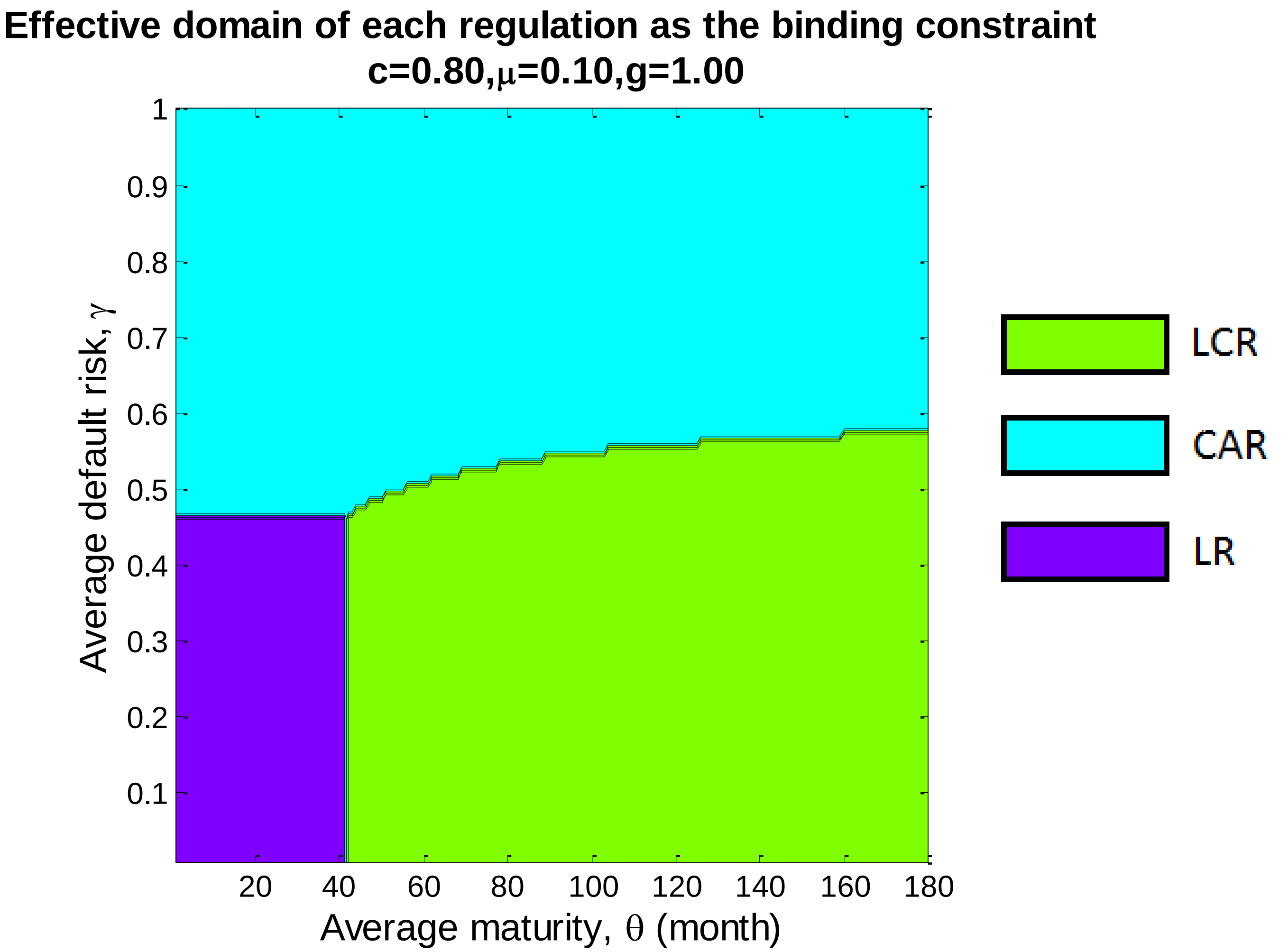
To sum up, we thank the reviewer a lot for the deliberate comments that help us make improvements of the current manuscript. For the reviewer's convenience, we attach a revised manuscript along with this reply. Revisions related to the reviewer's comments are marked in blue. Since we have also made some revision based on the comments from other anonymous readers, we mark these changes in red so as to make distinction.

Notes:

- **Left panels show the transition of the effective binding requirement by which the bank is constrained. The effective domain for each regulation as the binding constraint is indicated by different colors with green for the LCR regulation, cyan for the CAR regulation and purple for the LR regulation.**
- **Right panels illustrate the corresponding changes of the money multiplier for the same parameter combination.**
- **Changes in the average default risk $\gamma \in [0, 1]$ and the average maturity $\theta \in [1, 180]$ are shown respectively on the horizontal and the vertical axis.**
- **Different combinations for the capital-to-reserve ratio c$\in \{0.8, 1.6, 2.4\}$, the run-off ratio $\mu \in \{0.1, 0.5, 0.9\}$ and the government bonds-to-reserve ratio g$\in \{1, 1.8, 2.6\}$ are demonstrated in each page.**

Main conclusions:

- **The effective binding regulation, by which the bank' s ability to create money is constrained, varies across different economic states and bank balance sheet conditions.**
- **Due to the transition of the effective binding regulation, the money multiplier depends on concerned parameters in a nonlinear way.**
- **In general, the money multiplier is higher with high capital-to-reserve ratio c, low run-off ratio μ, low default risk γ and short loan maturity θ.**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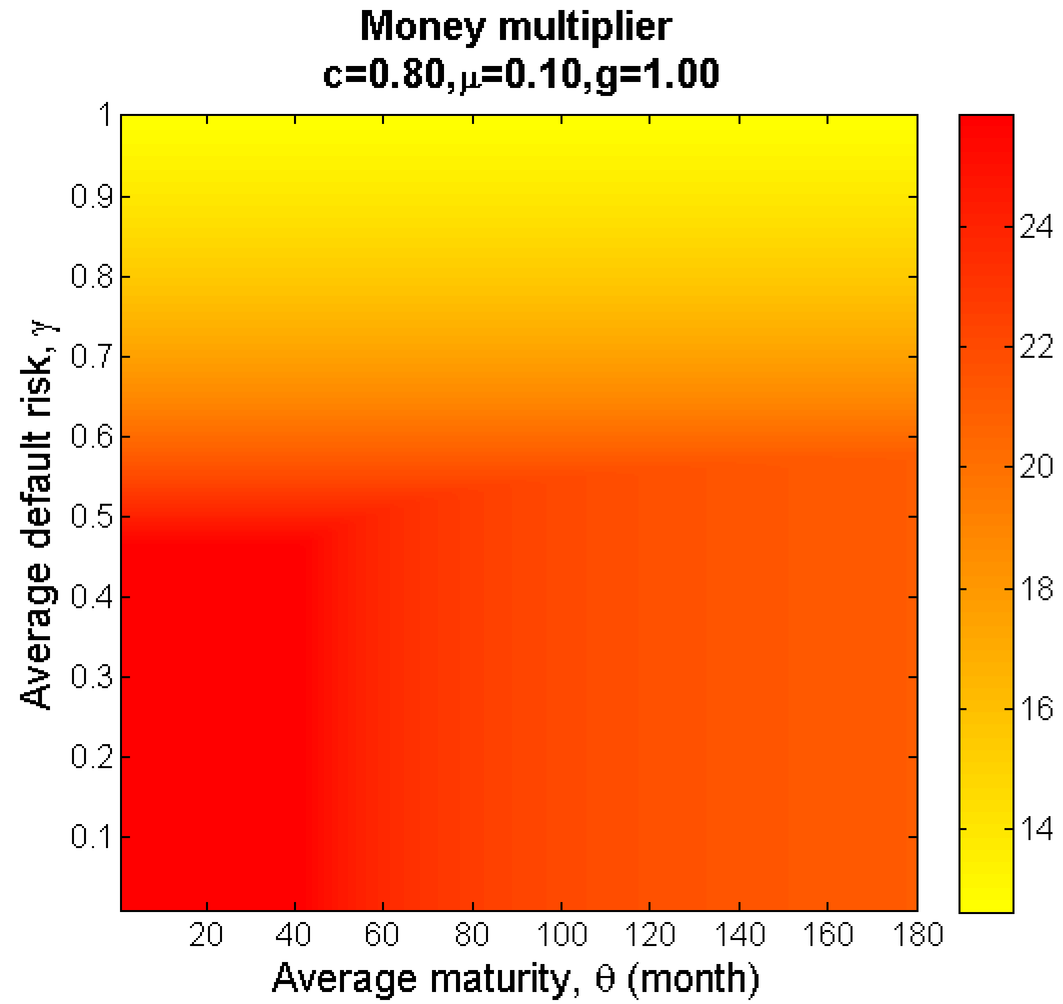
Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR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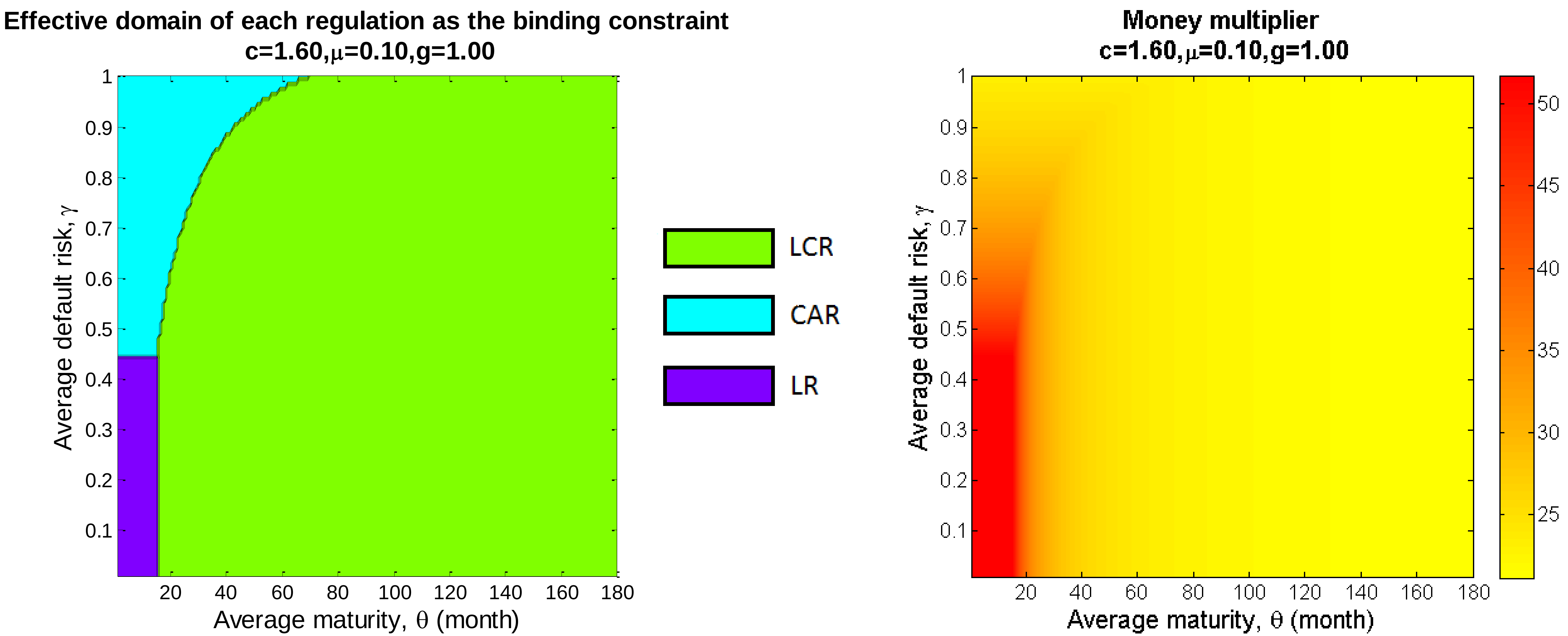
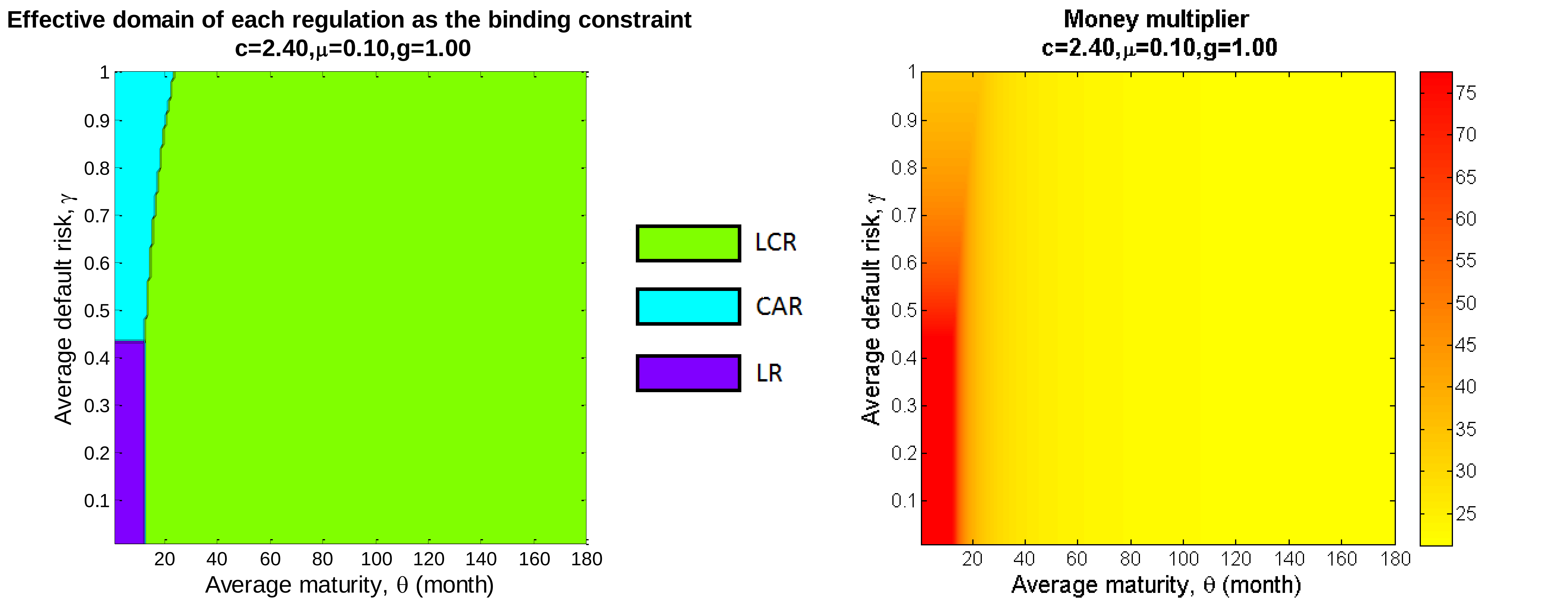
Average default risk, γ
Average maturity, θ (month)


Effective domain of each regulation as the binding constraint
c=1.60,μ=0.10,g=1.00
Average default risk, γ
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
20 40 60 80 100 120 140 160 180
Average maturity, θ (month)
LCR
CAR
LR
Money multiplier
c=1.60,μ=0.10,g=1.00
Average default risk, γ
Average maturity, θ (month)
50
45
40
35
30
25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Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR
Money multiplier
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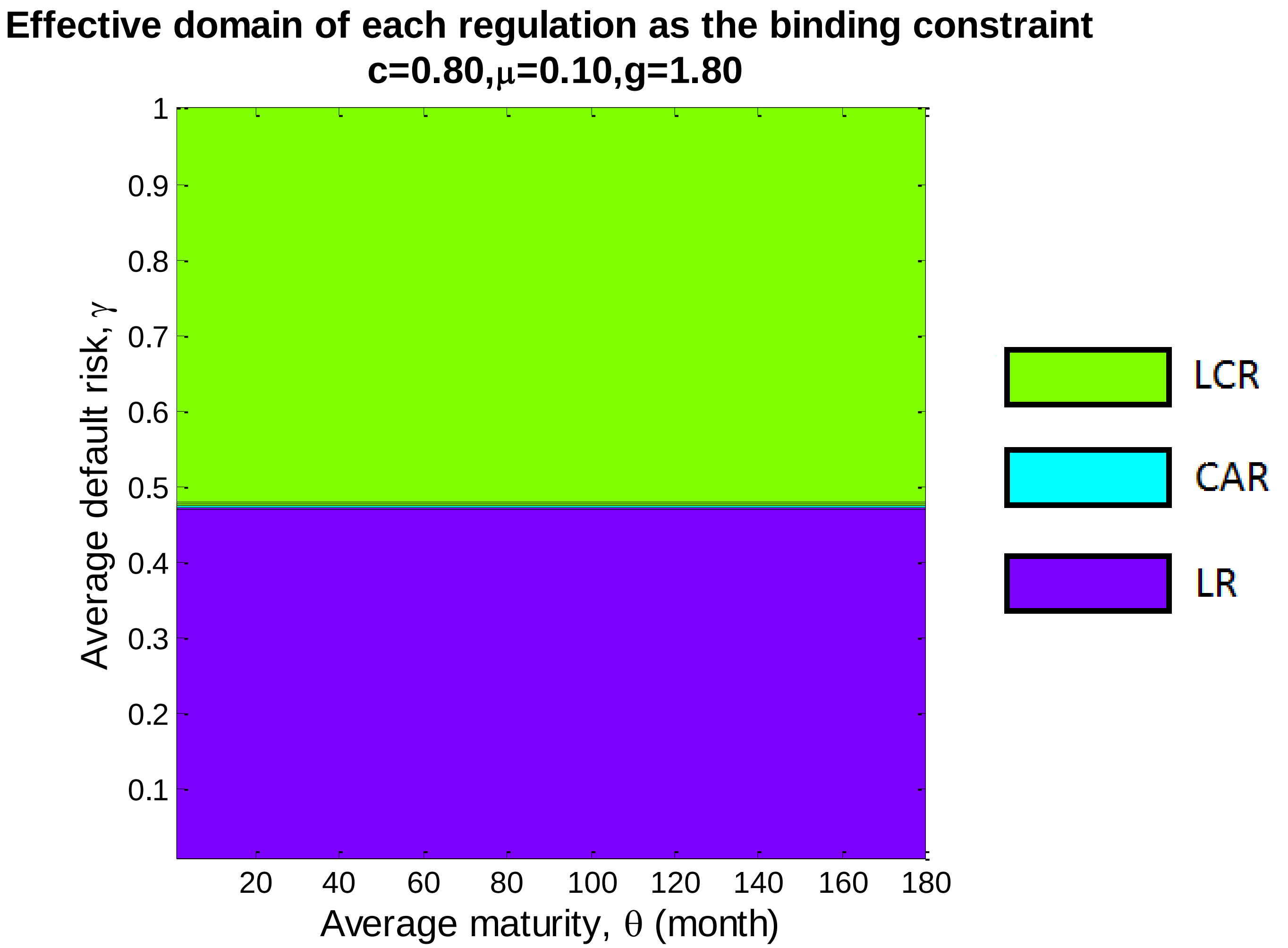
Average default risk, γ
Average maturity, θ (month)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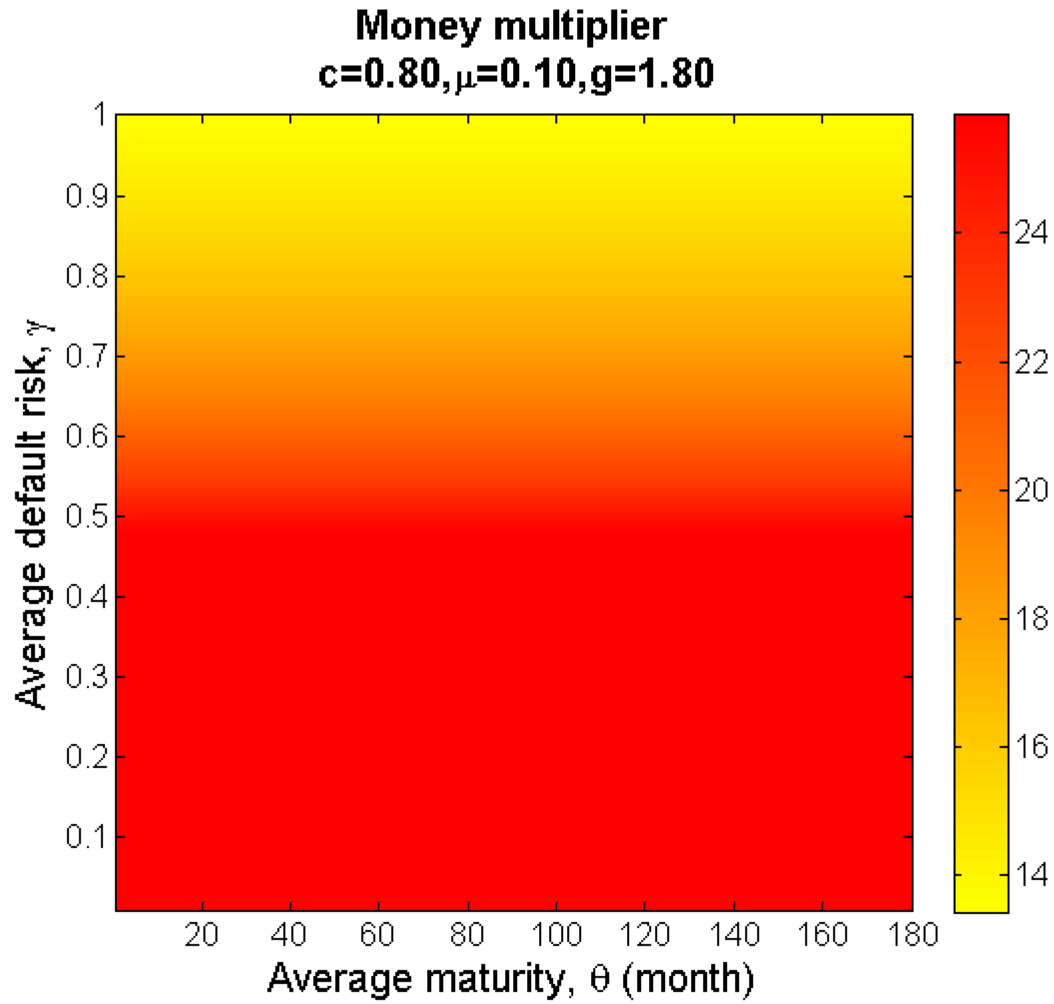
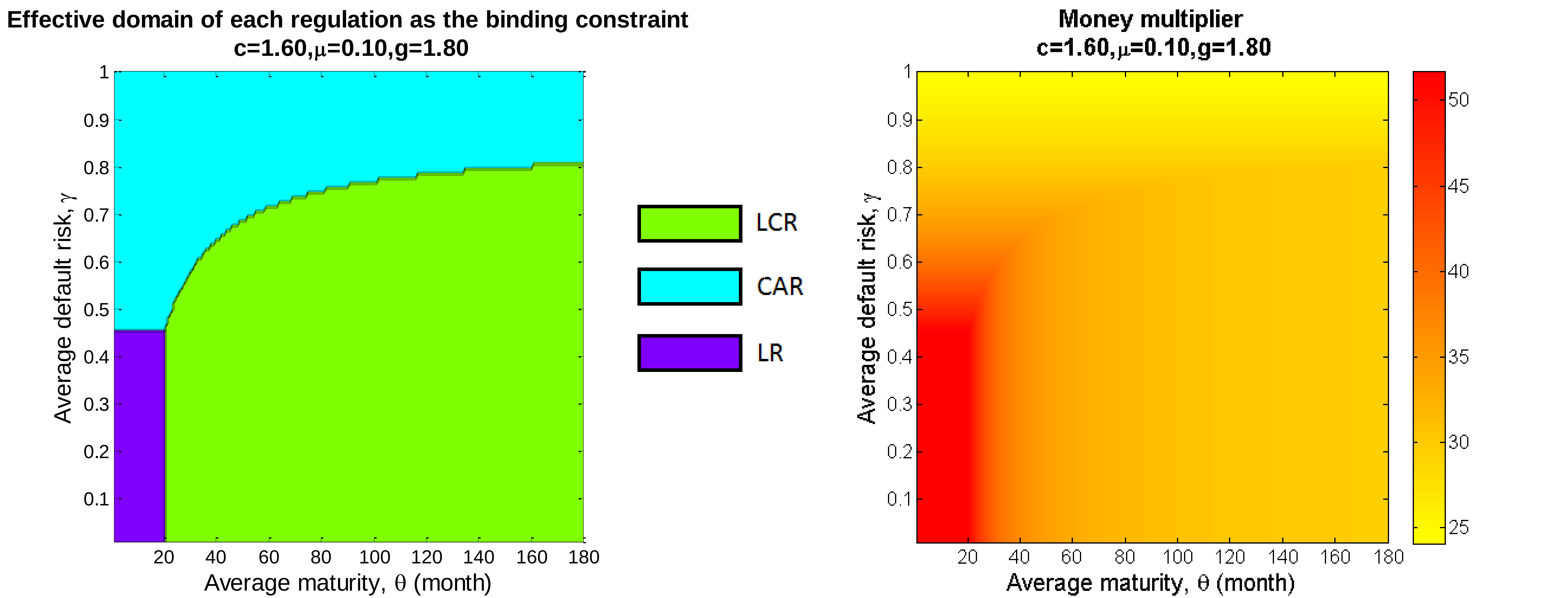
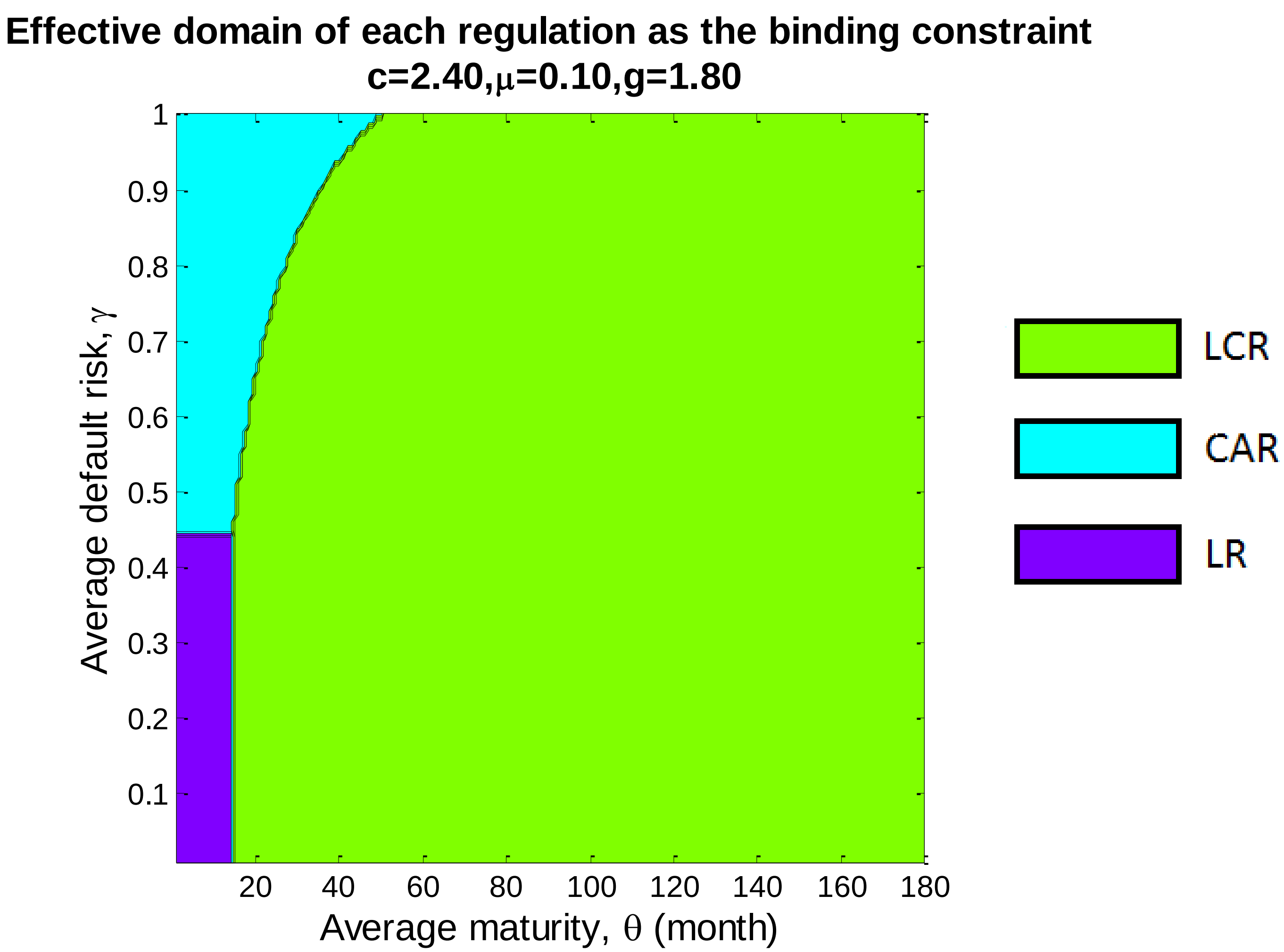
Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR

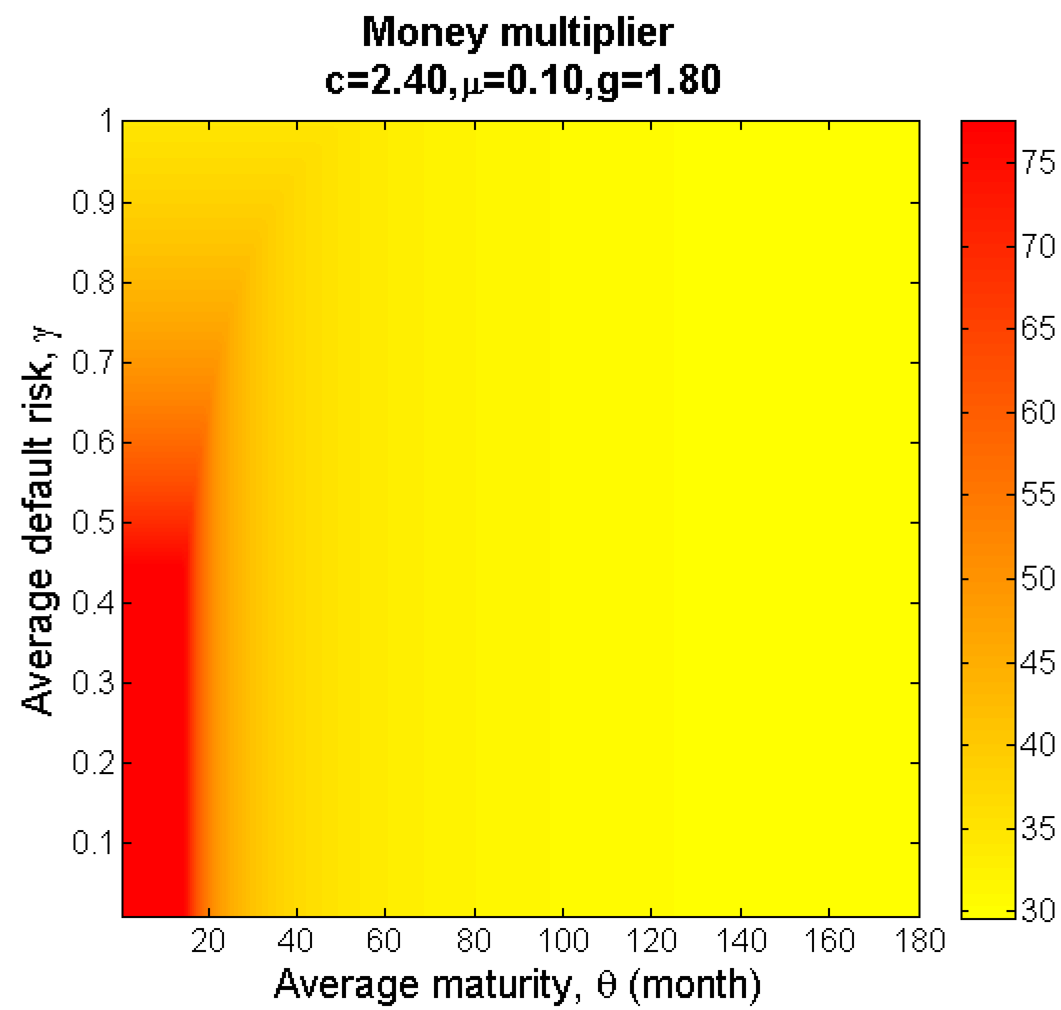

Money multiplier
c=0.80,μ=0.10,g=1.80
Average default risk, γ
Average maturity, θ (month)

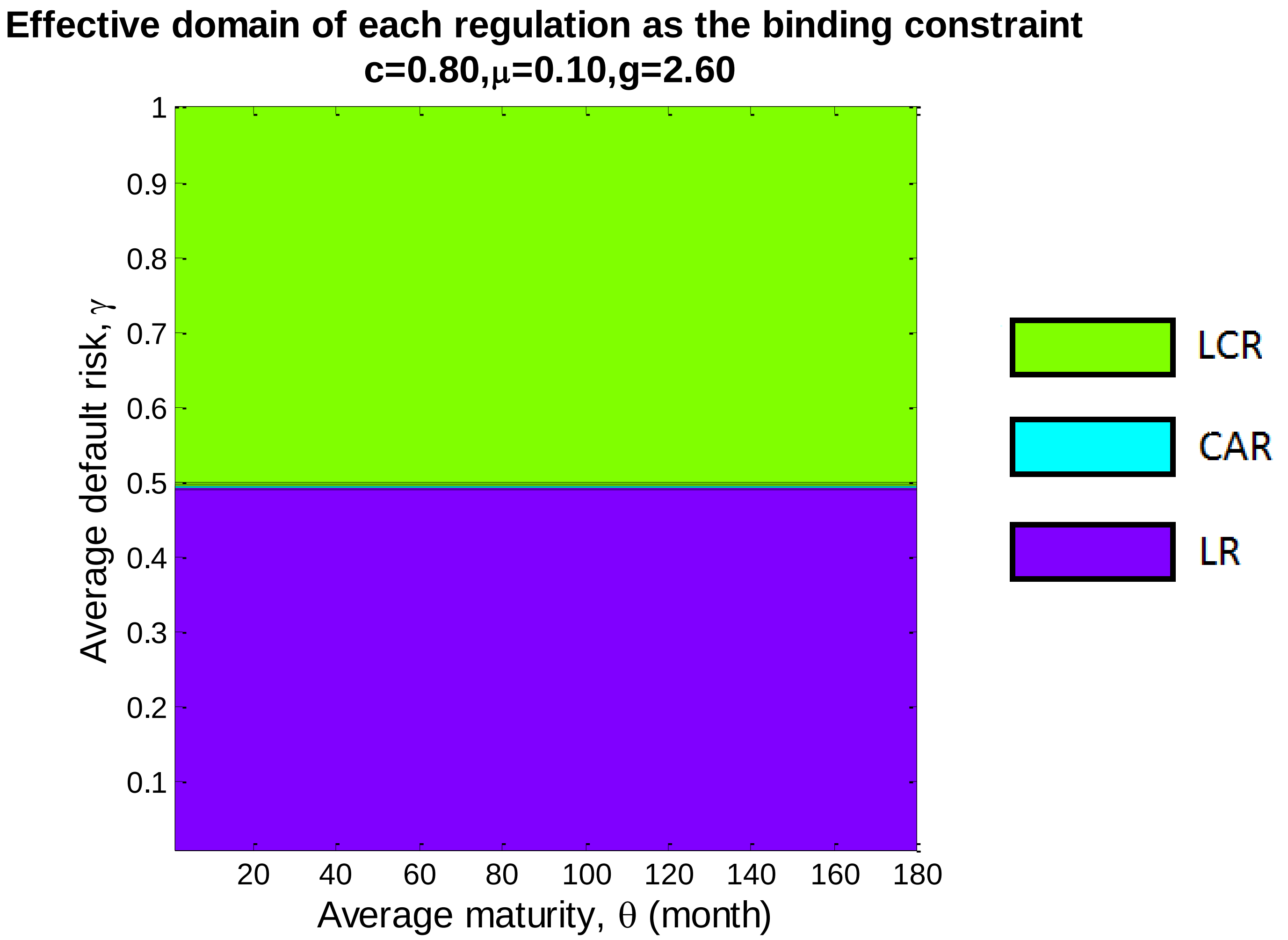
Robustness test

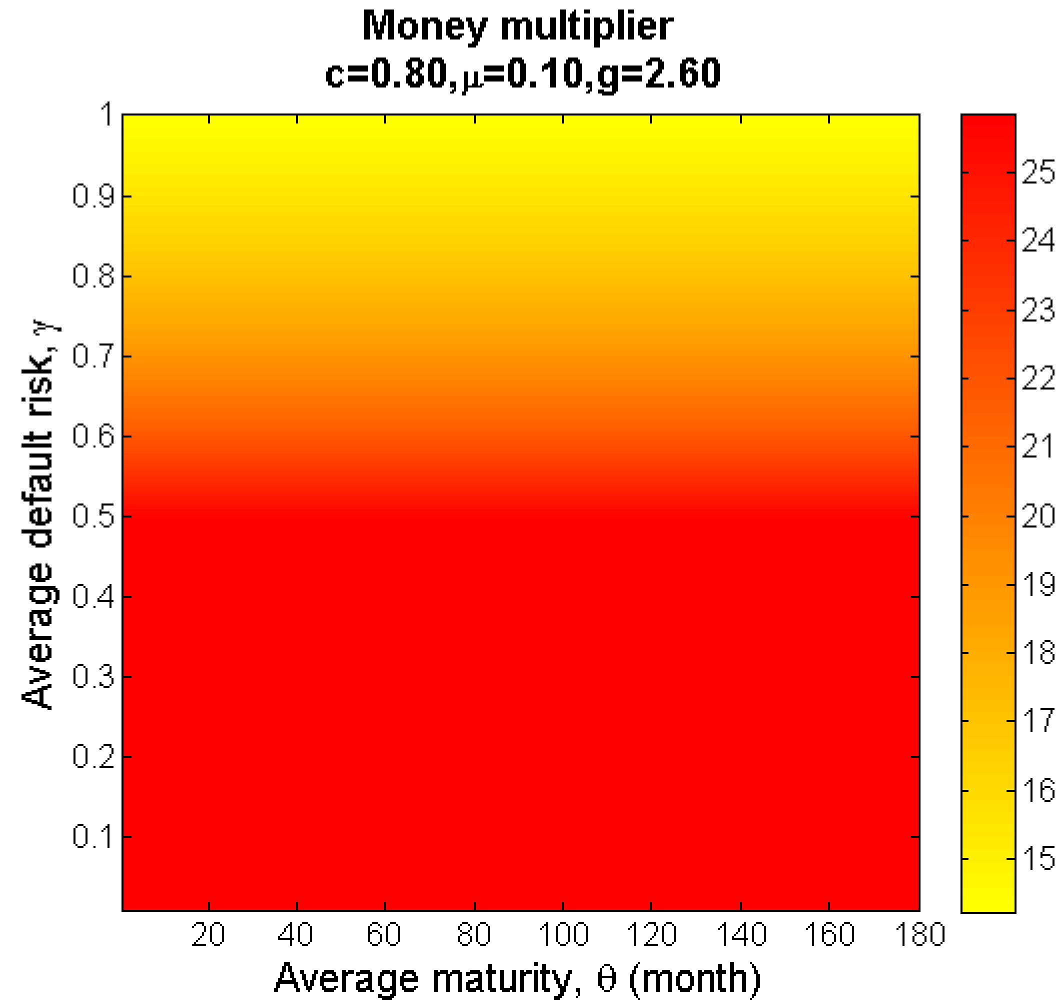


Robustness test






Effective domain of each regulation as the binding constraint
c=0.80,μ=0.10,g=2.60
Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR


Money multiplier
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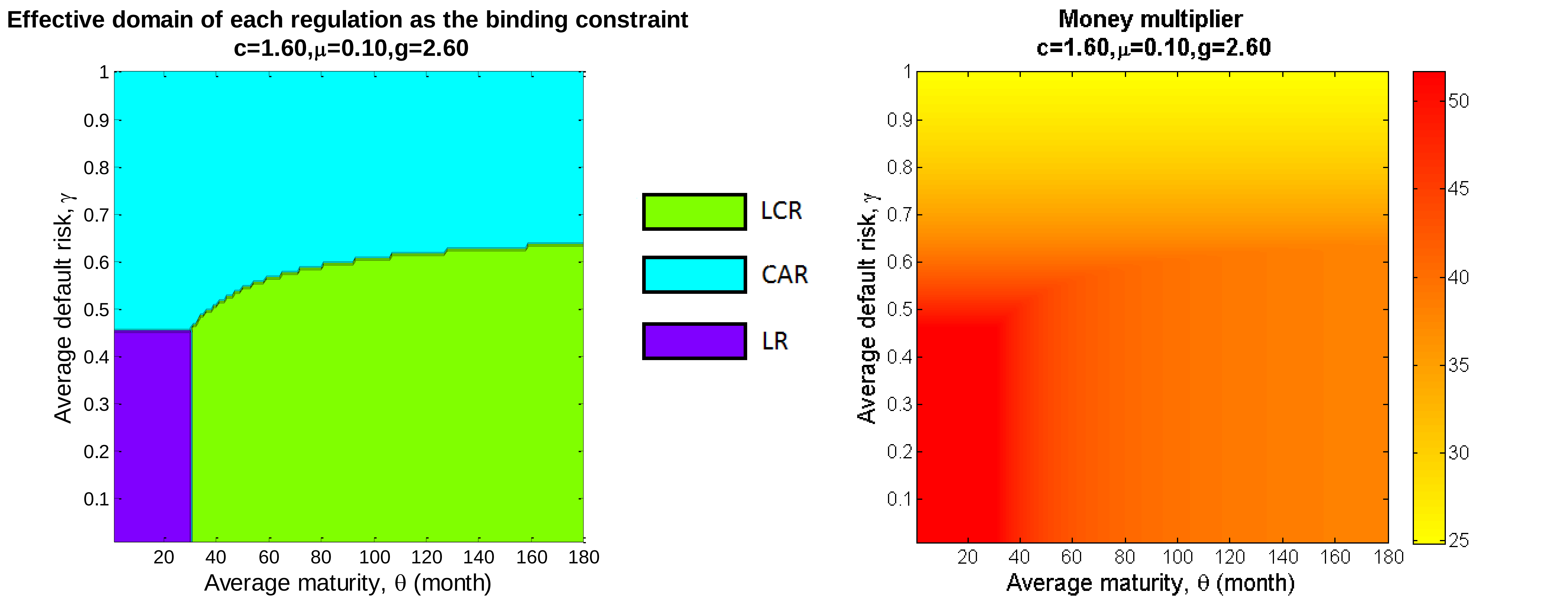
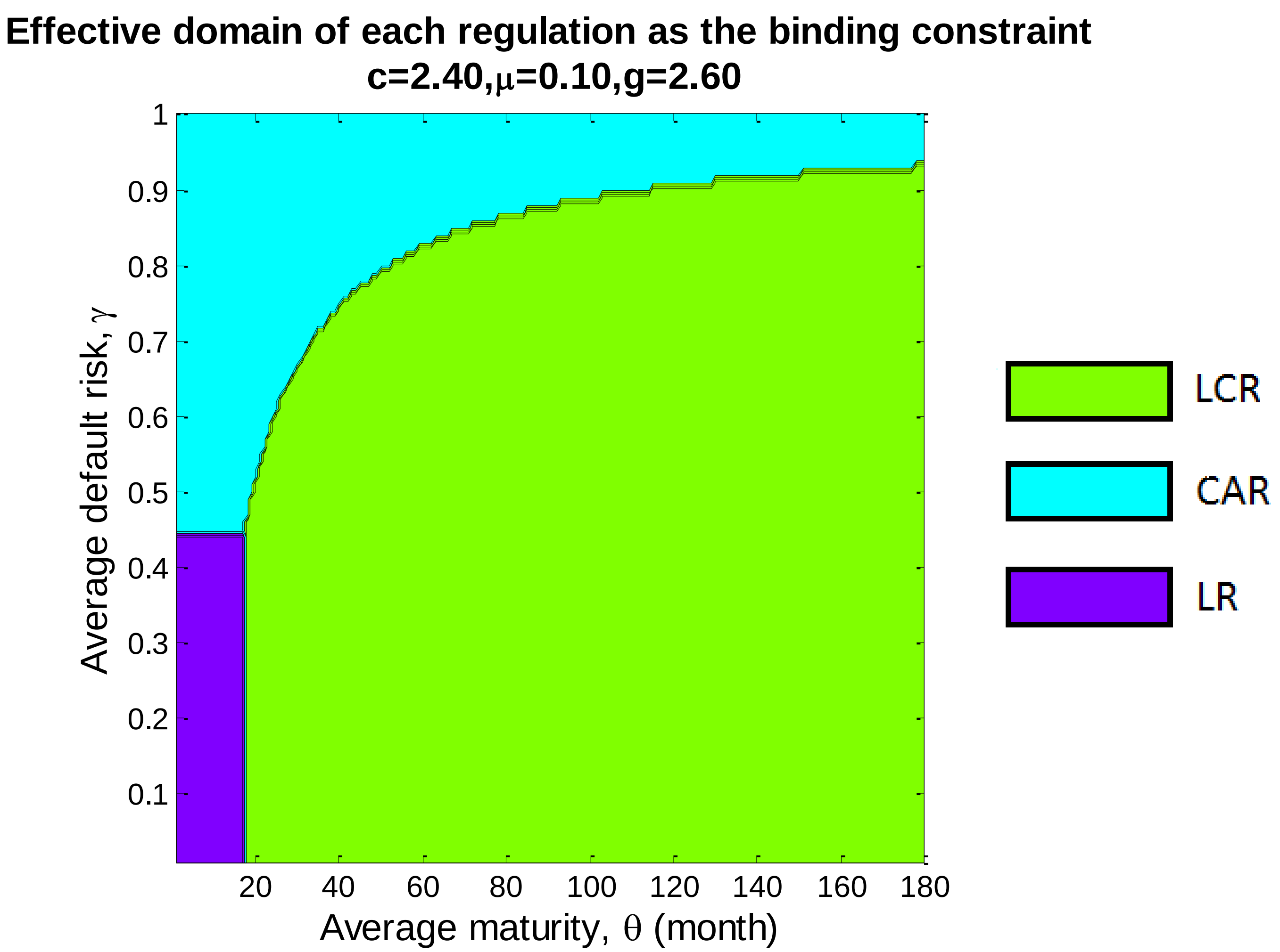
Average default risk, γ
Average maturity, θ (month)


Effective domain of each regulation as the binding constraint
c=1.60,μ=0.10,g=2.60
Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR
Money multiplier
c=1.60,μ=0.10,g=2.60
Average default risk, γ
Average maturity, θ (month)


Effective domain of each regulation as the binding constraint
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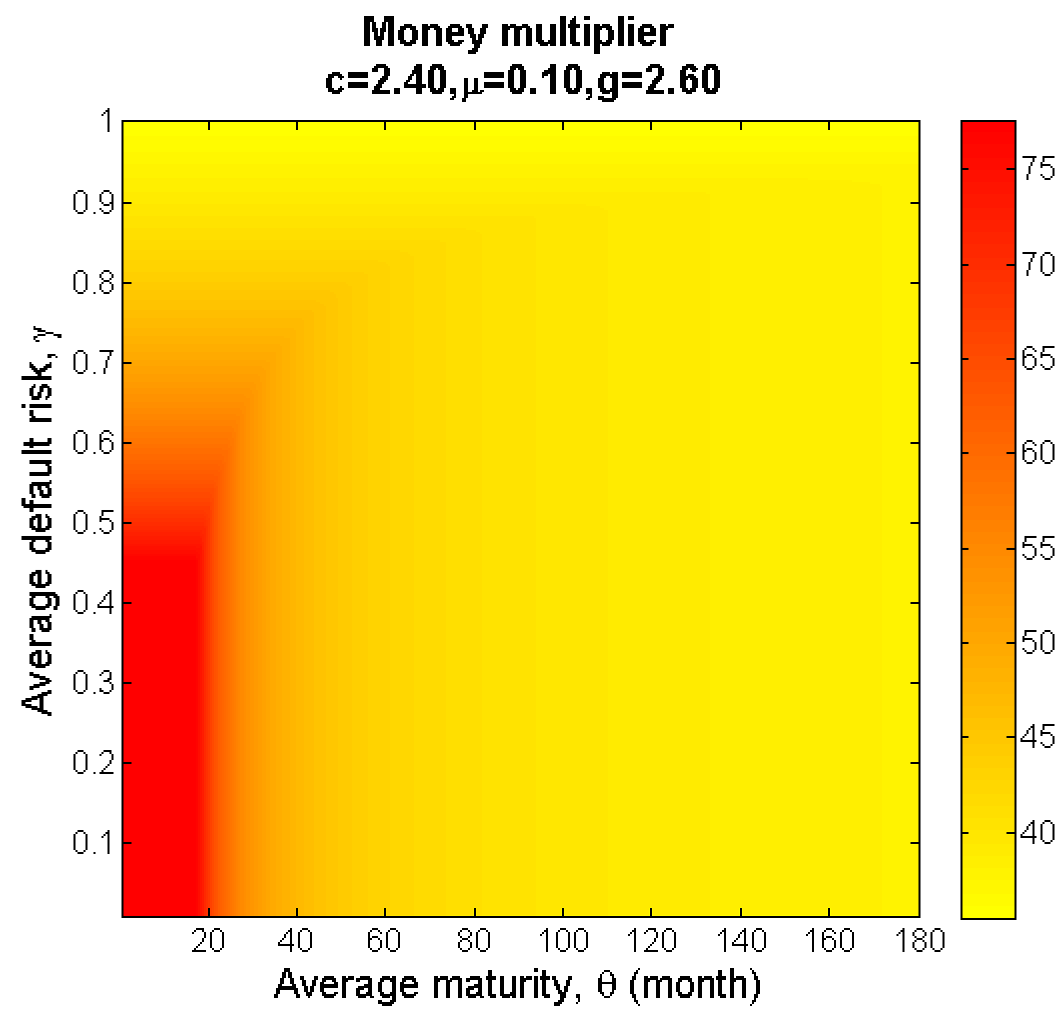
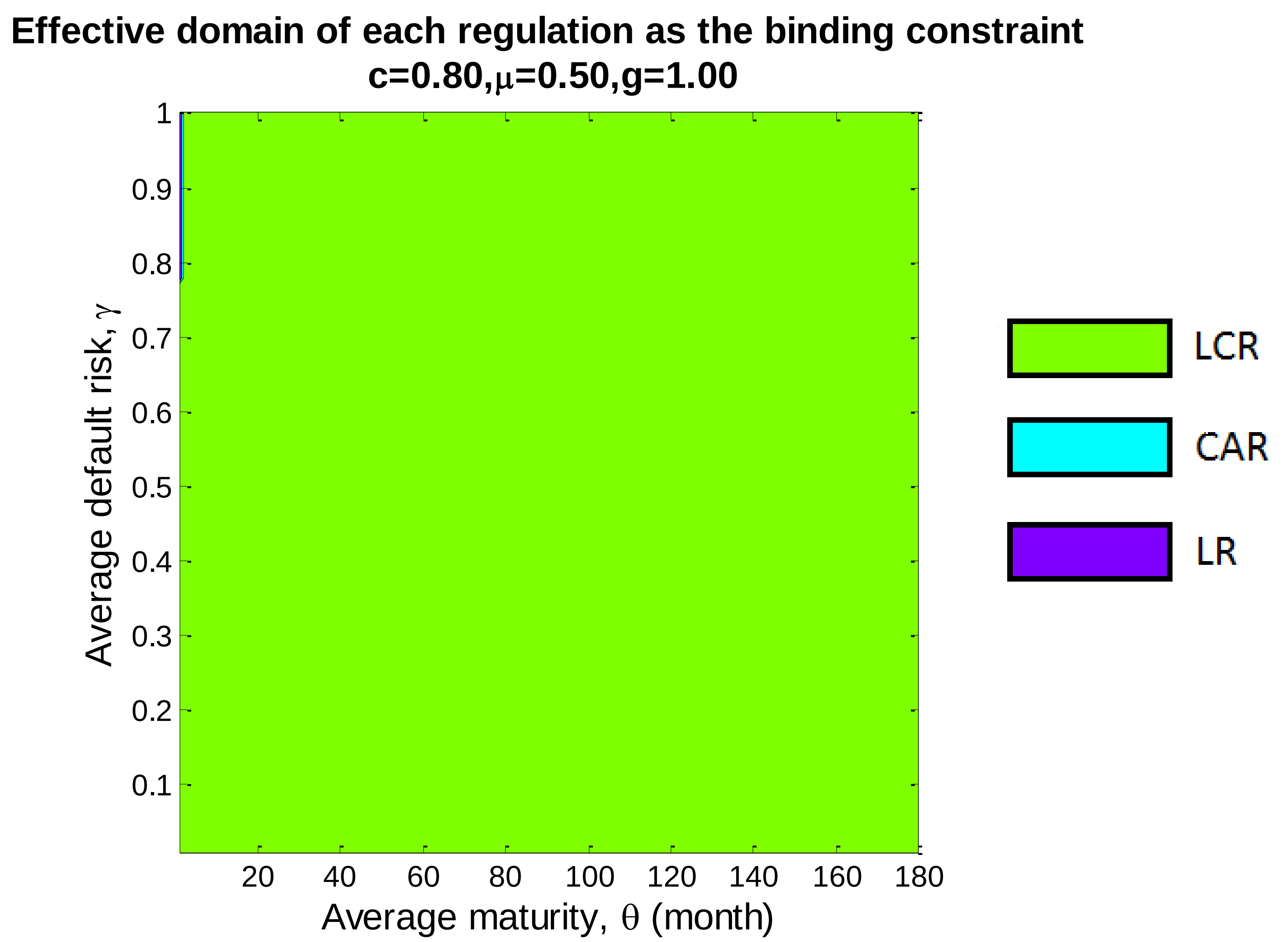
Average default risk, γ
Average maturity, θ (month)
LCR
CAR
LR


Money multiplier
c=2.40,μ=0.10,g=2.60
Average default risk, γ
Average maturity, θ (month)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Average default risk, γ
Average maturity, θ (month)
LCR
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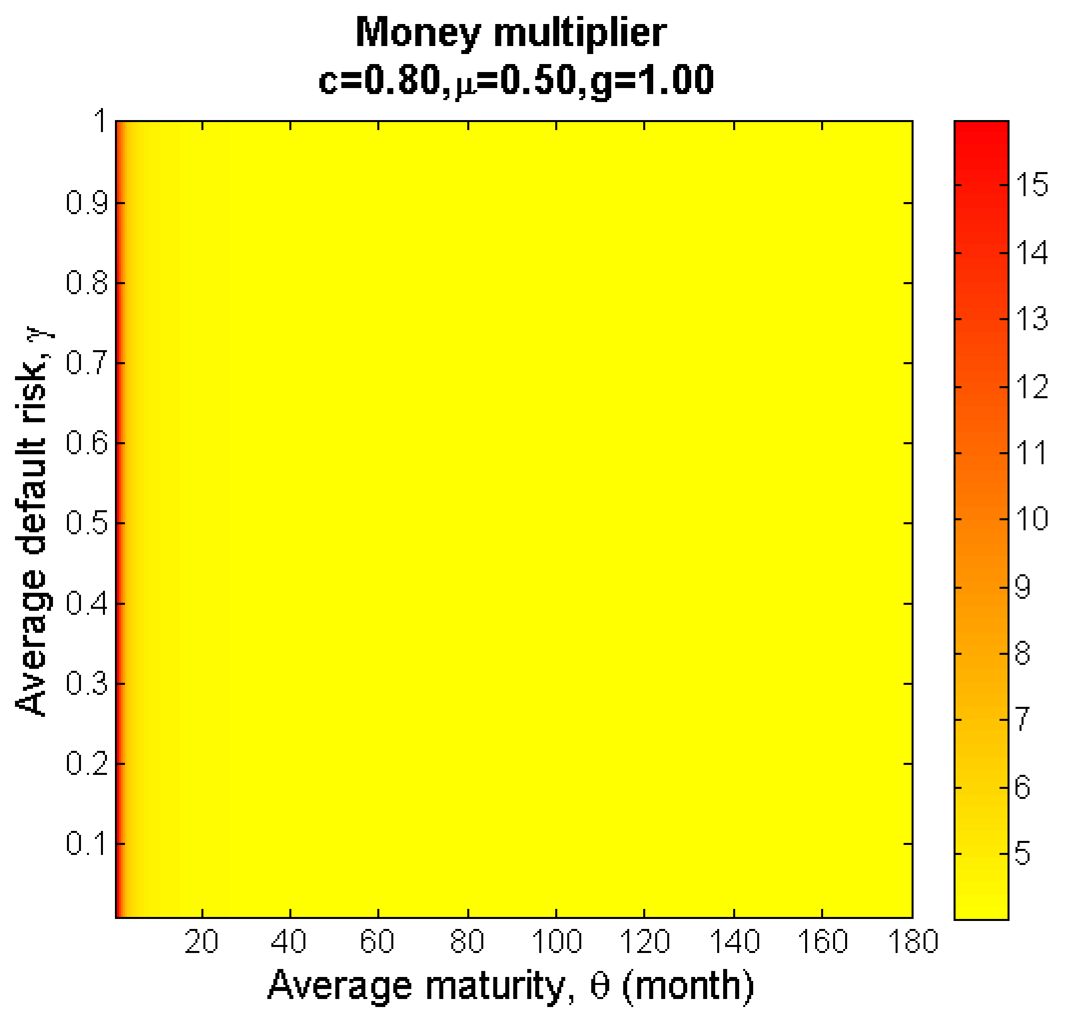
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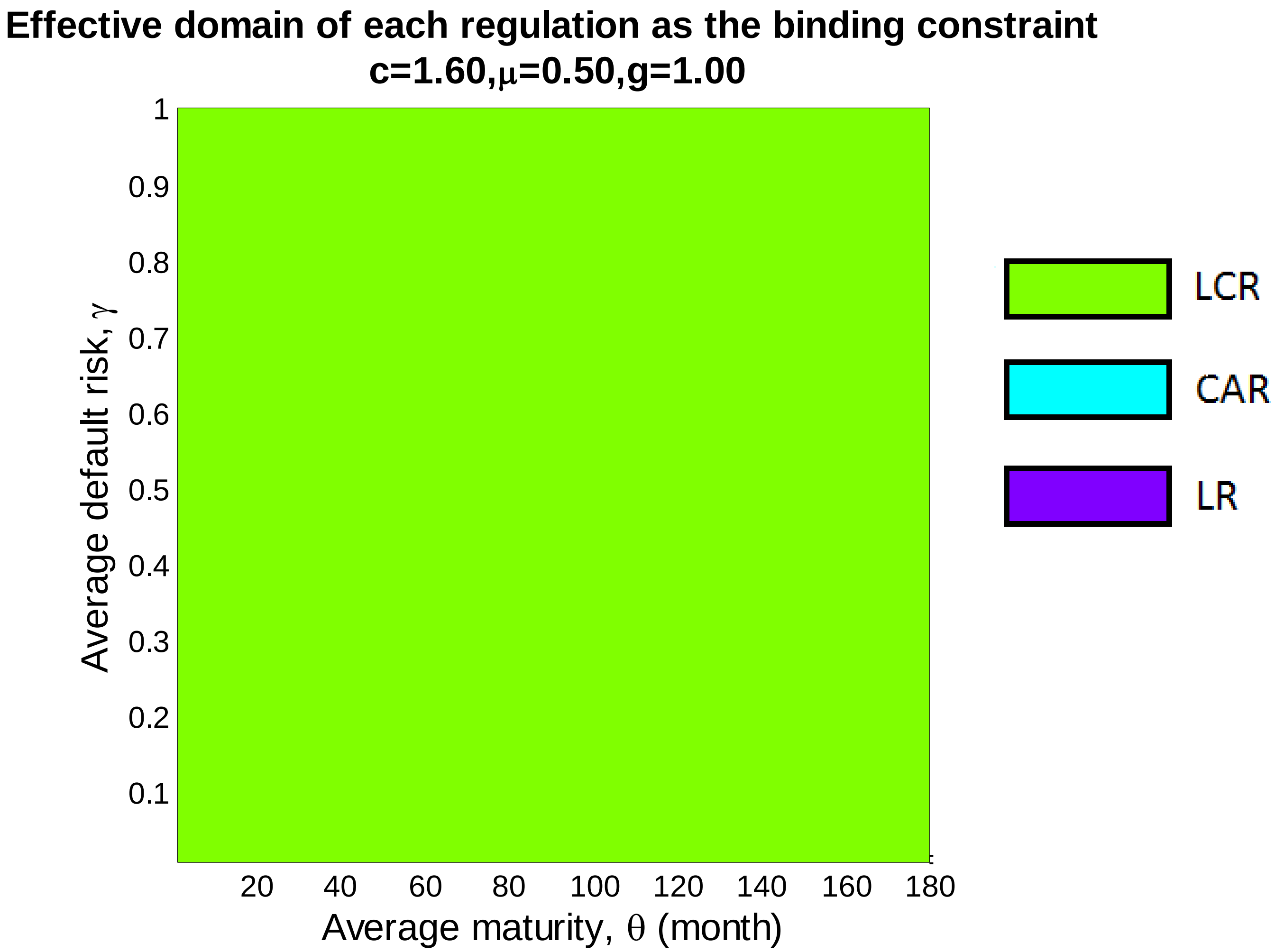
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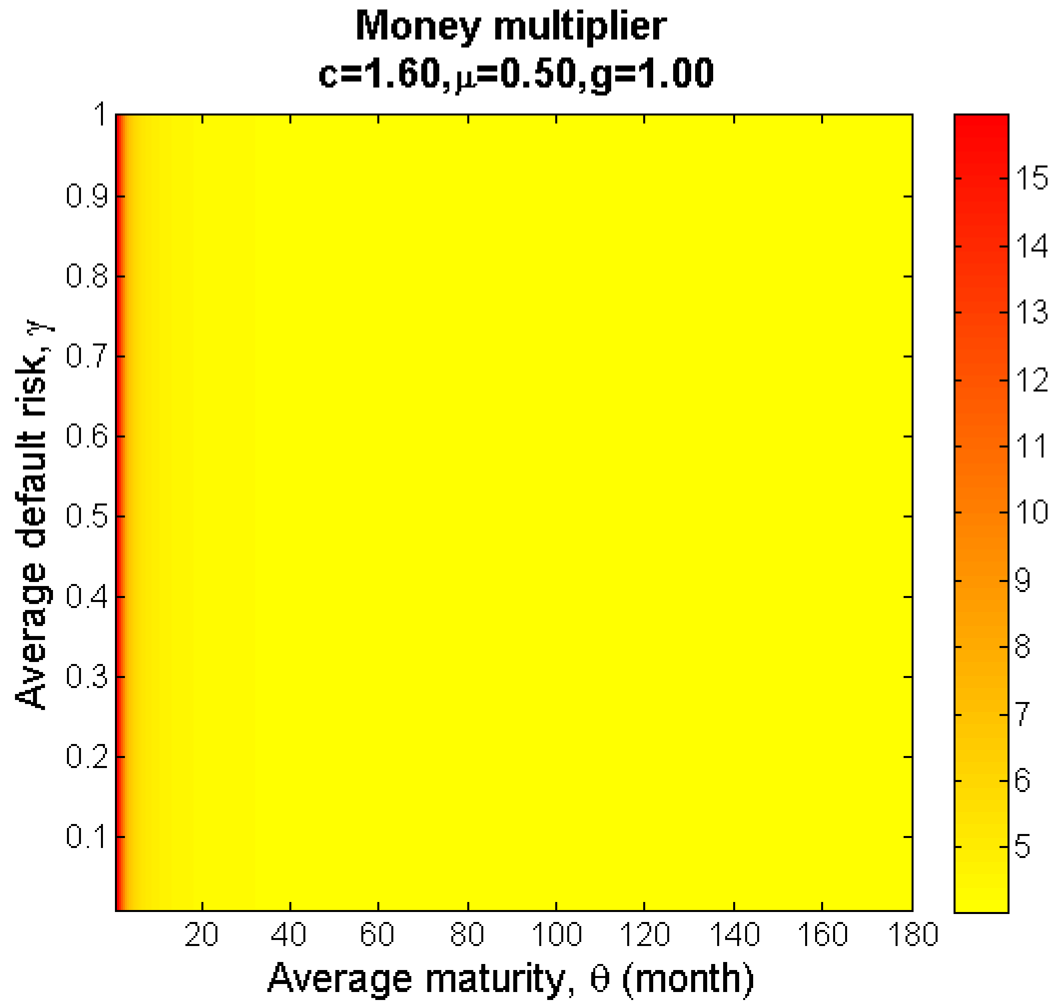
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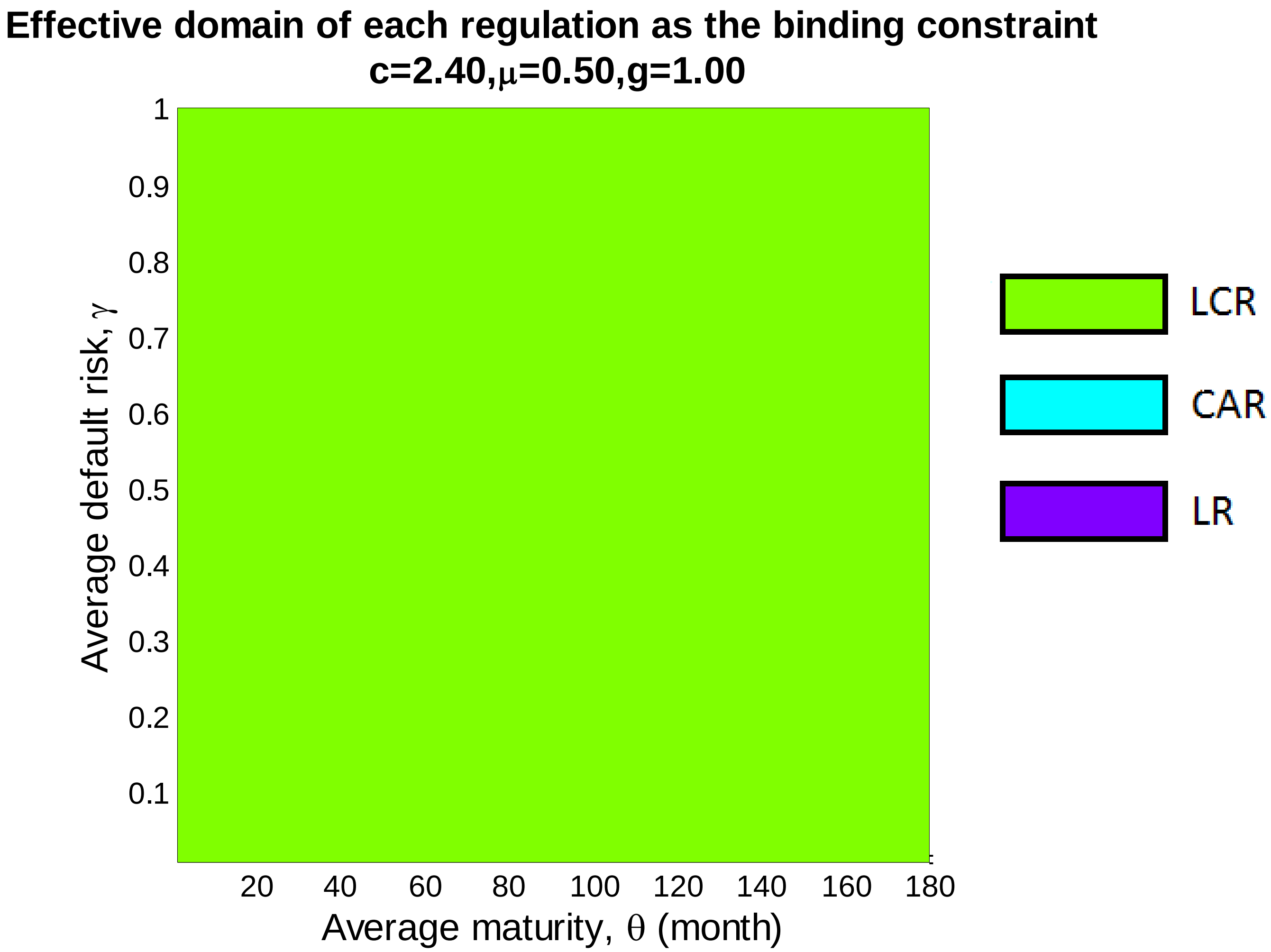
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20 40 60 80 100 120 140 160 180
Average maturity, θ (month)
LCR
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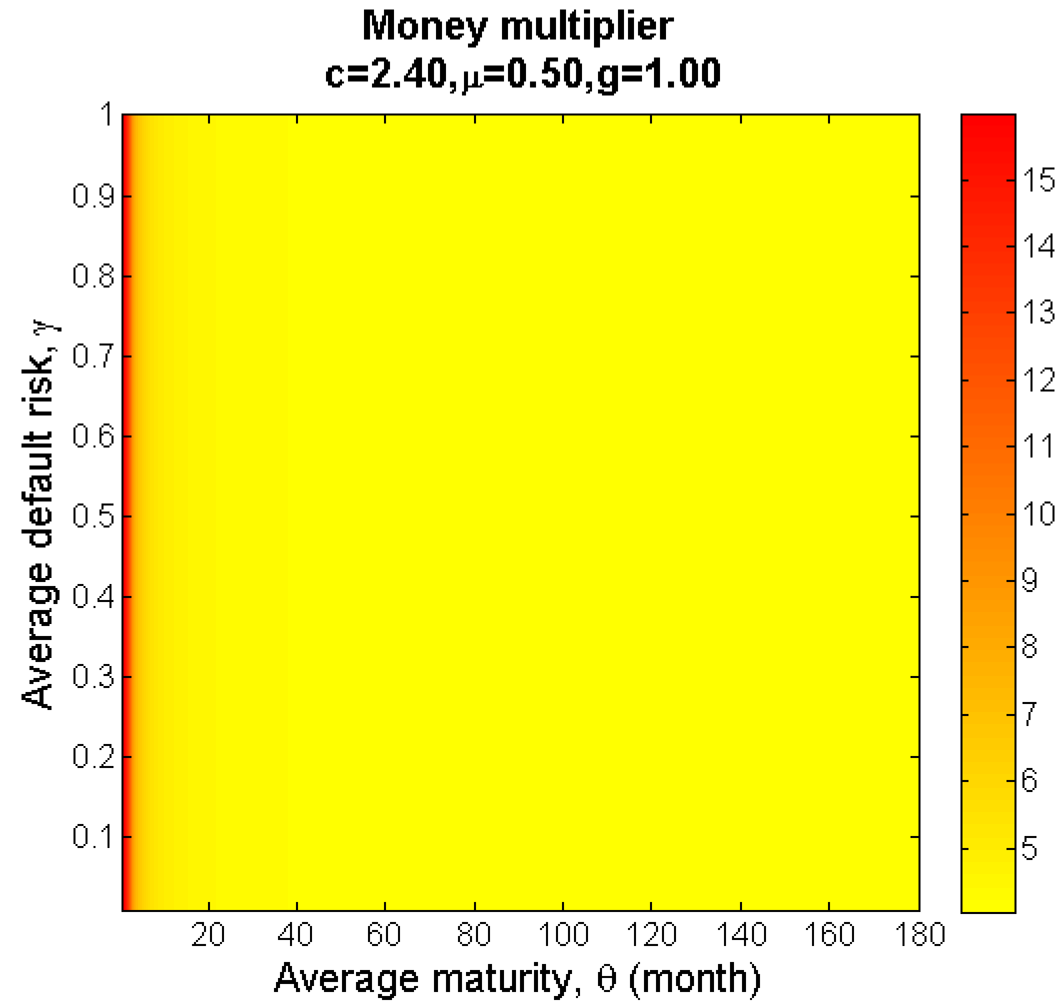
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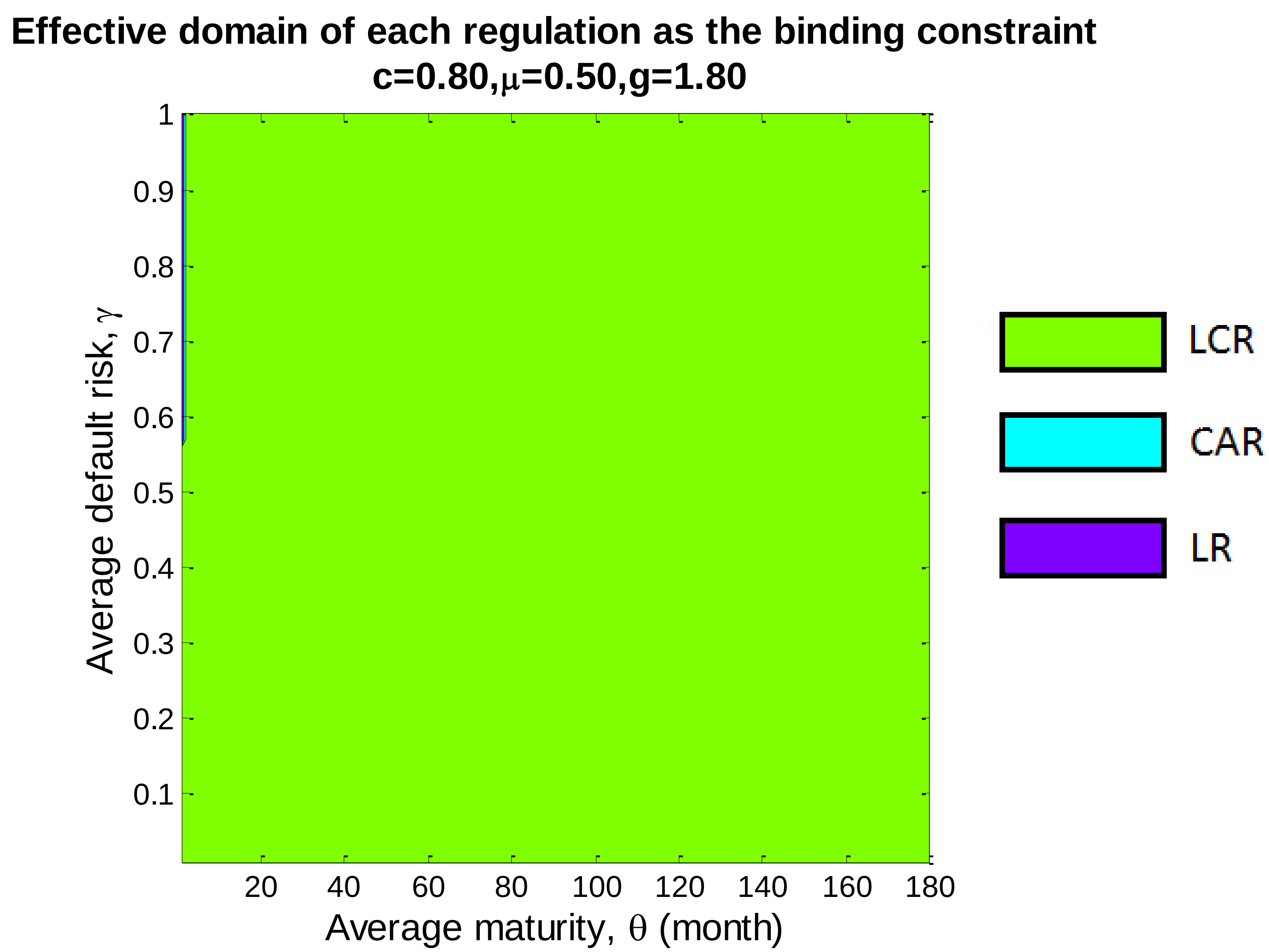
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LCR
CAR
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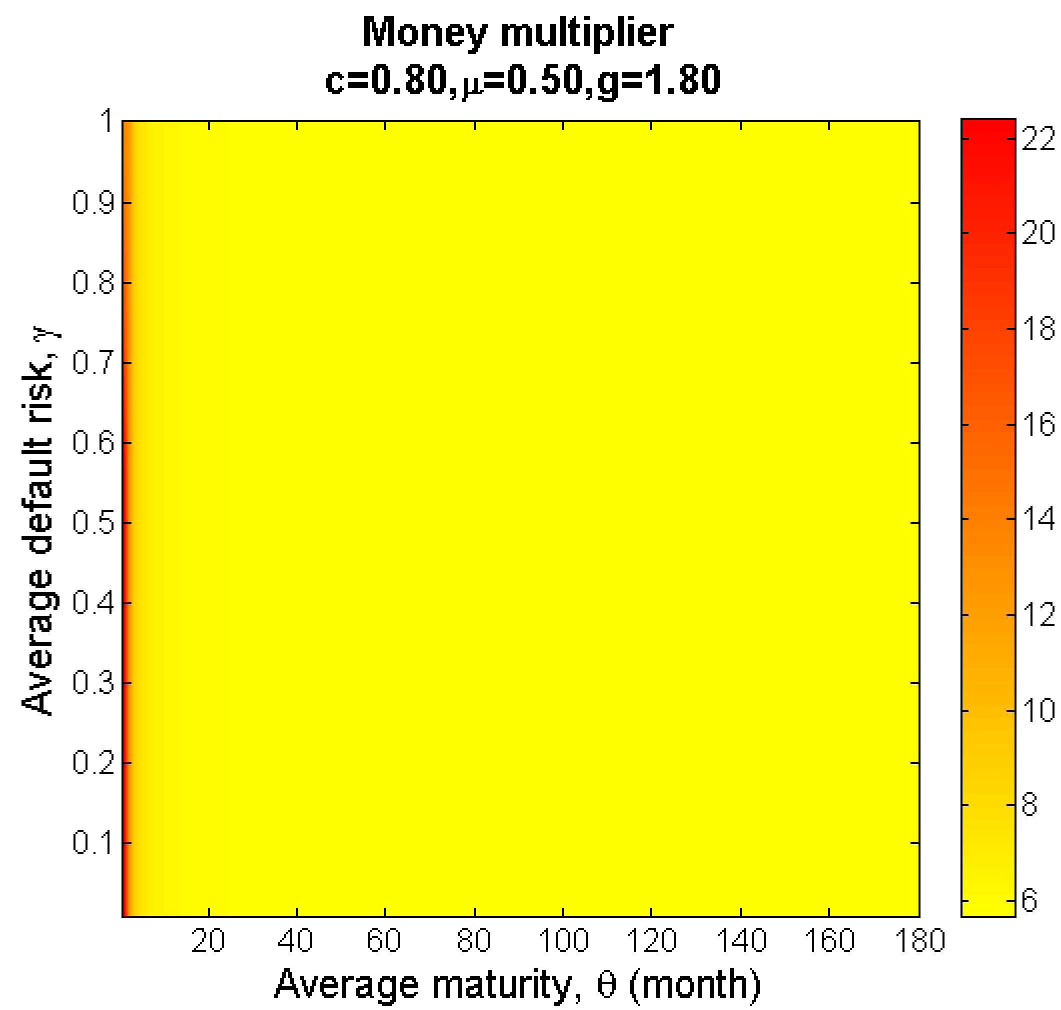
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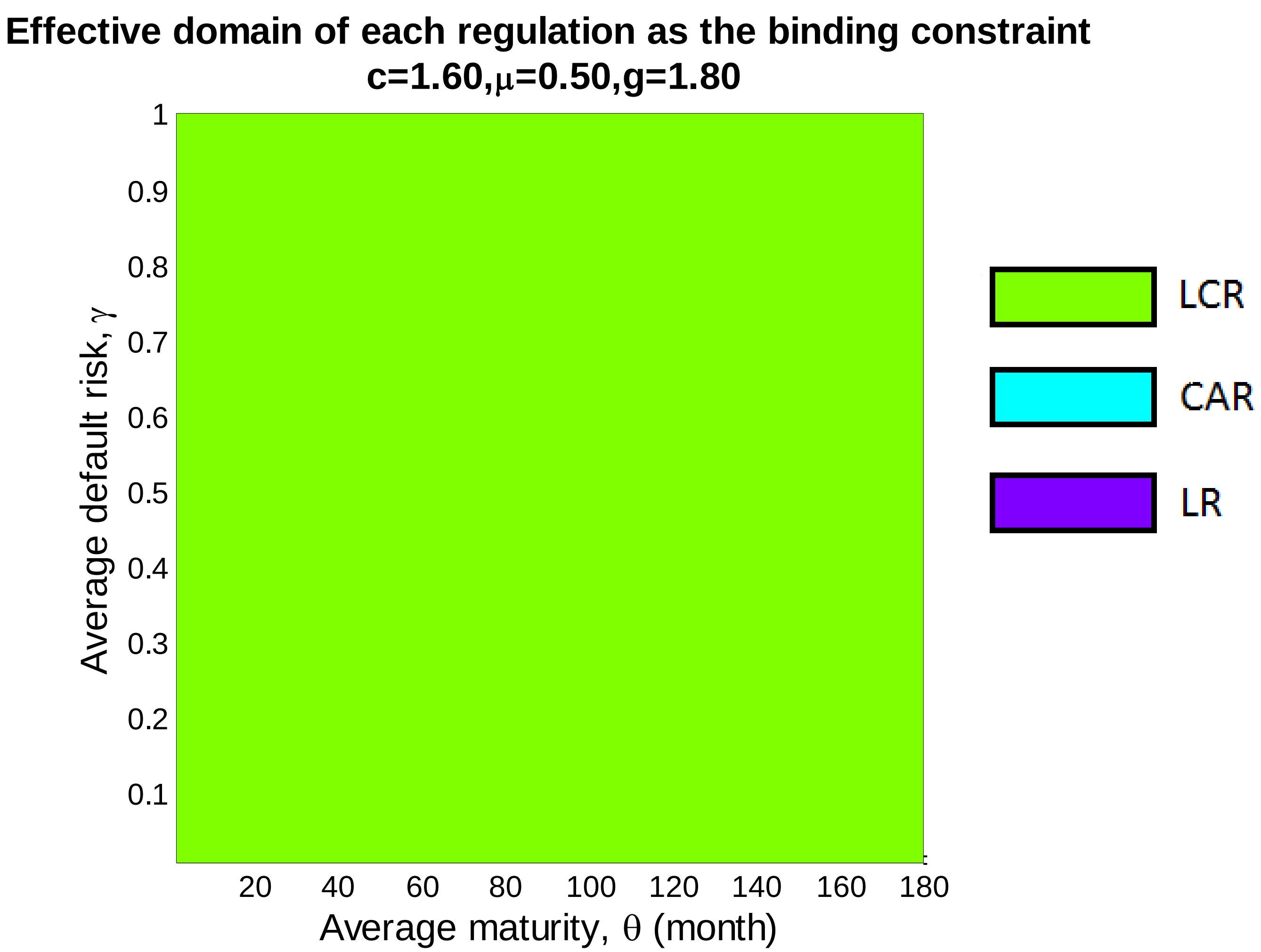
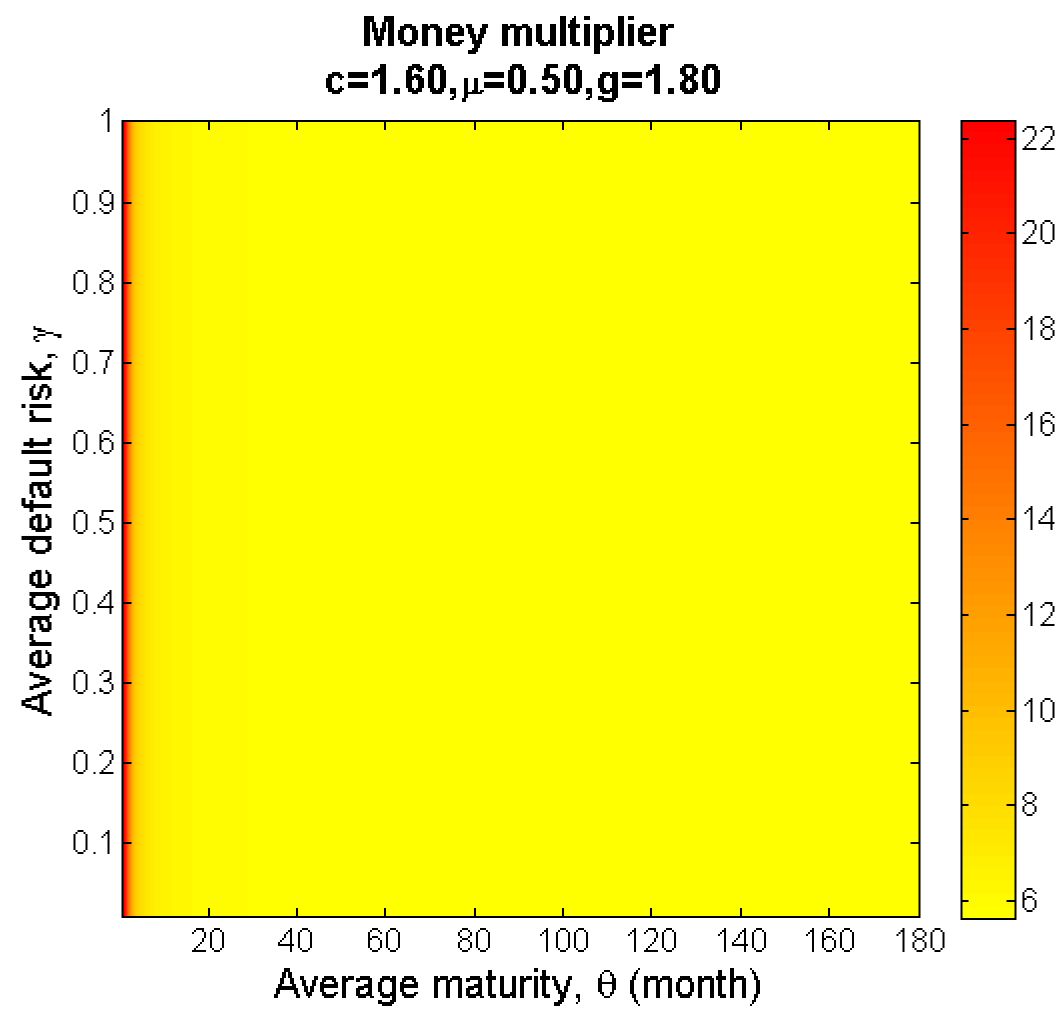
Robustness test





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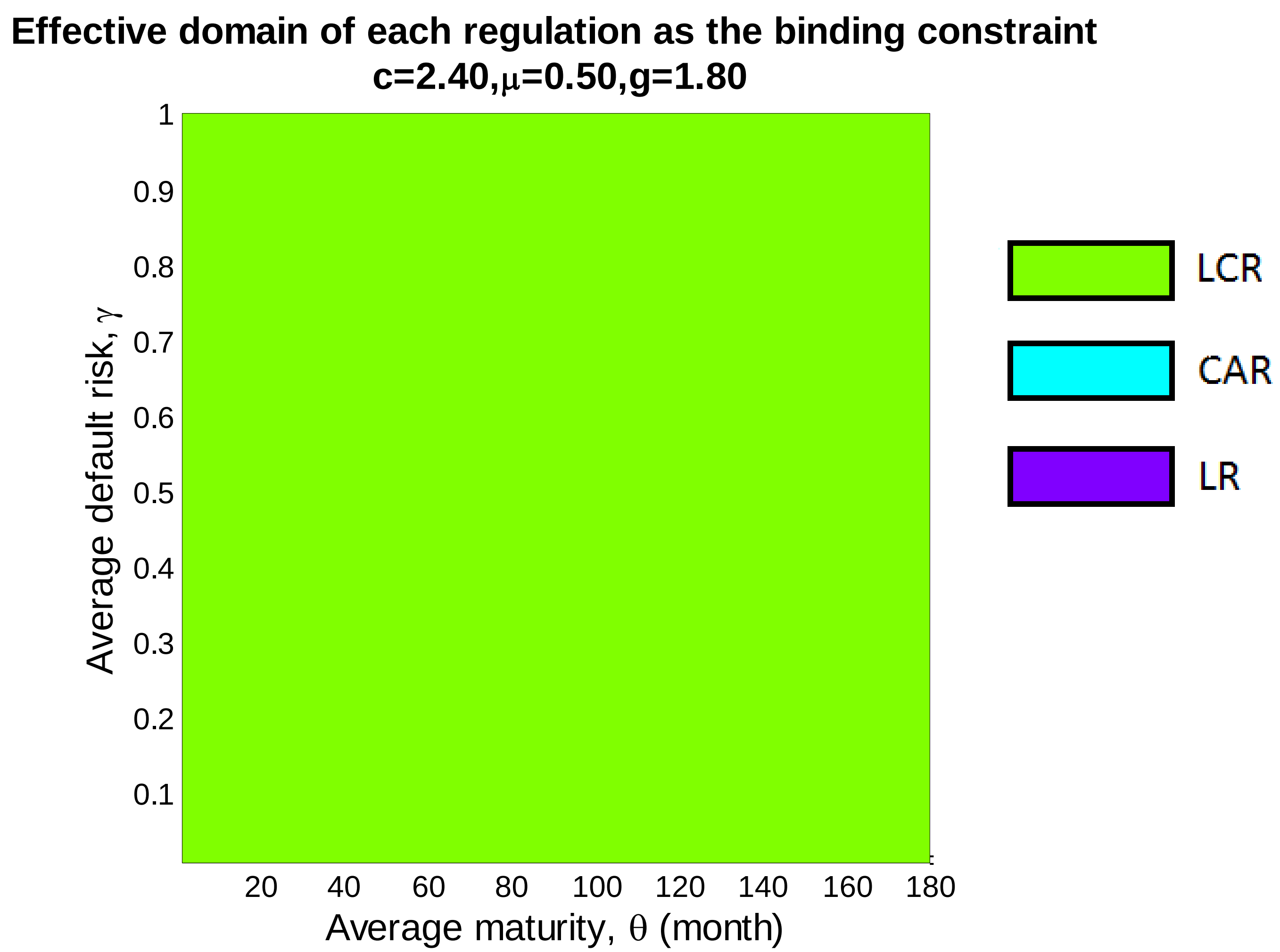

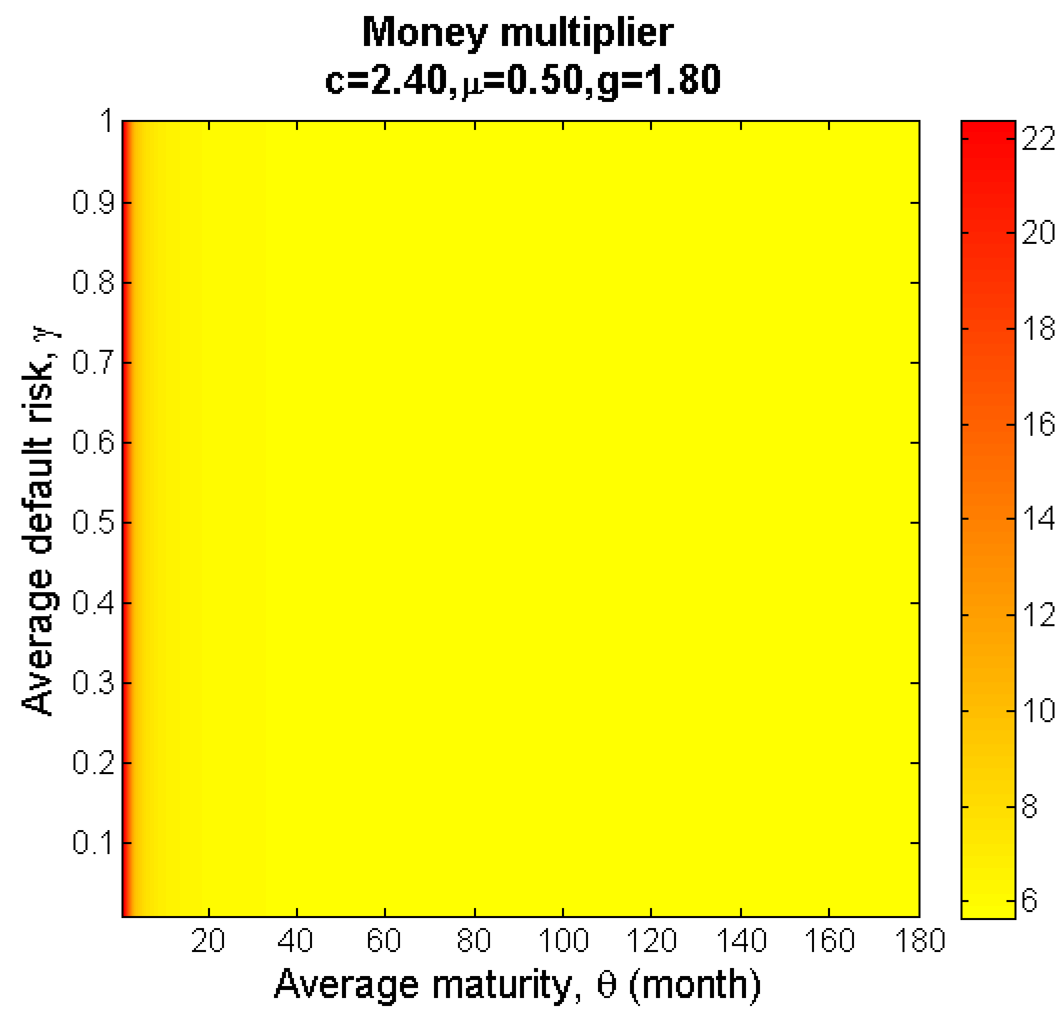

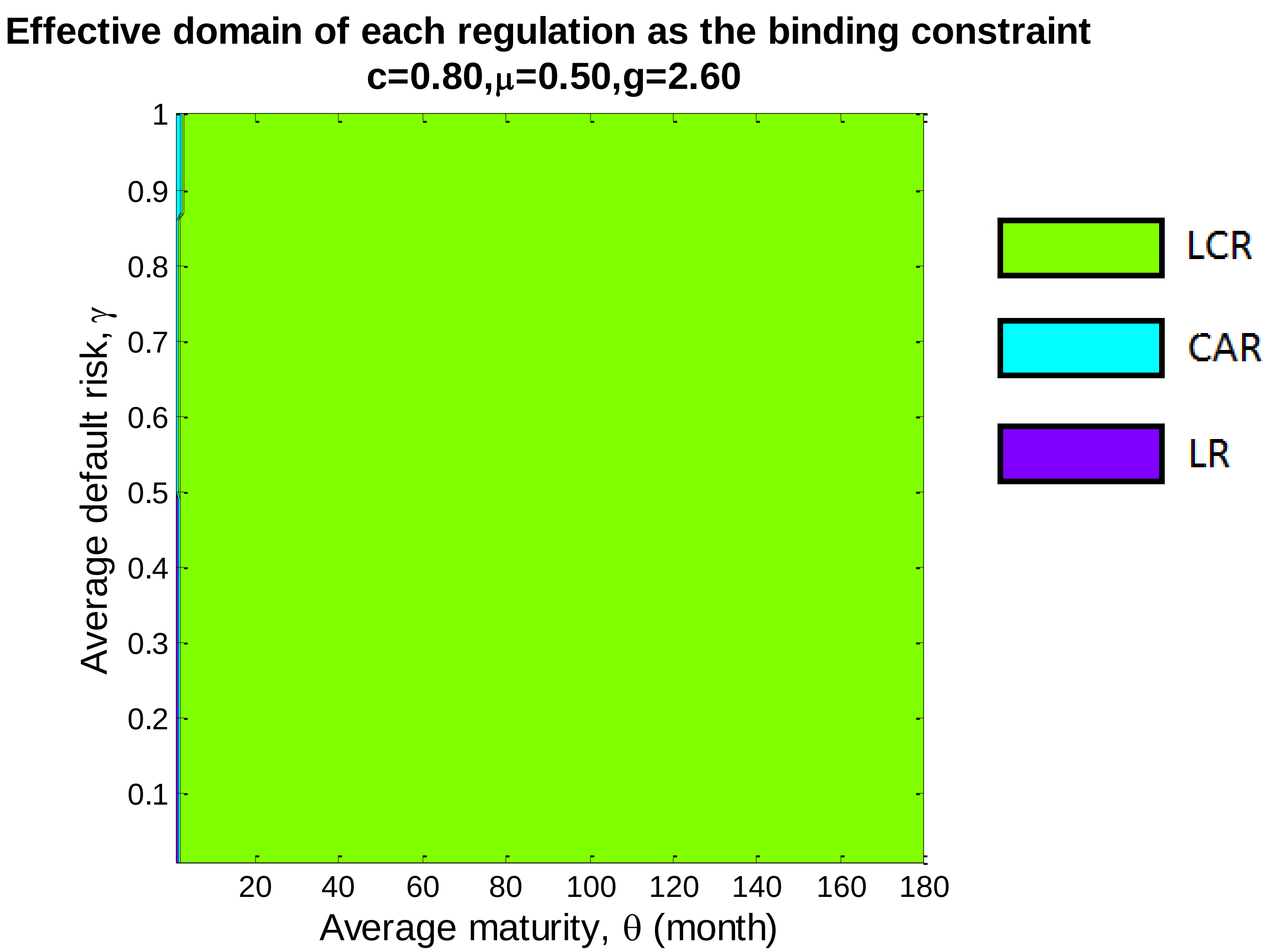
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LCR
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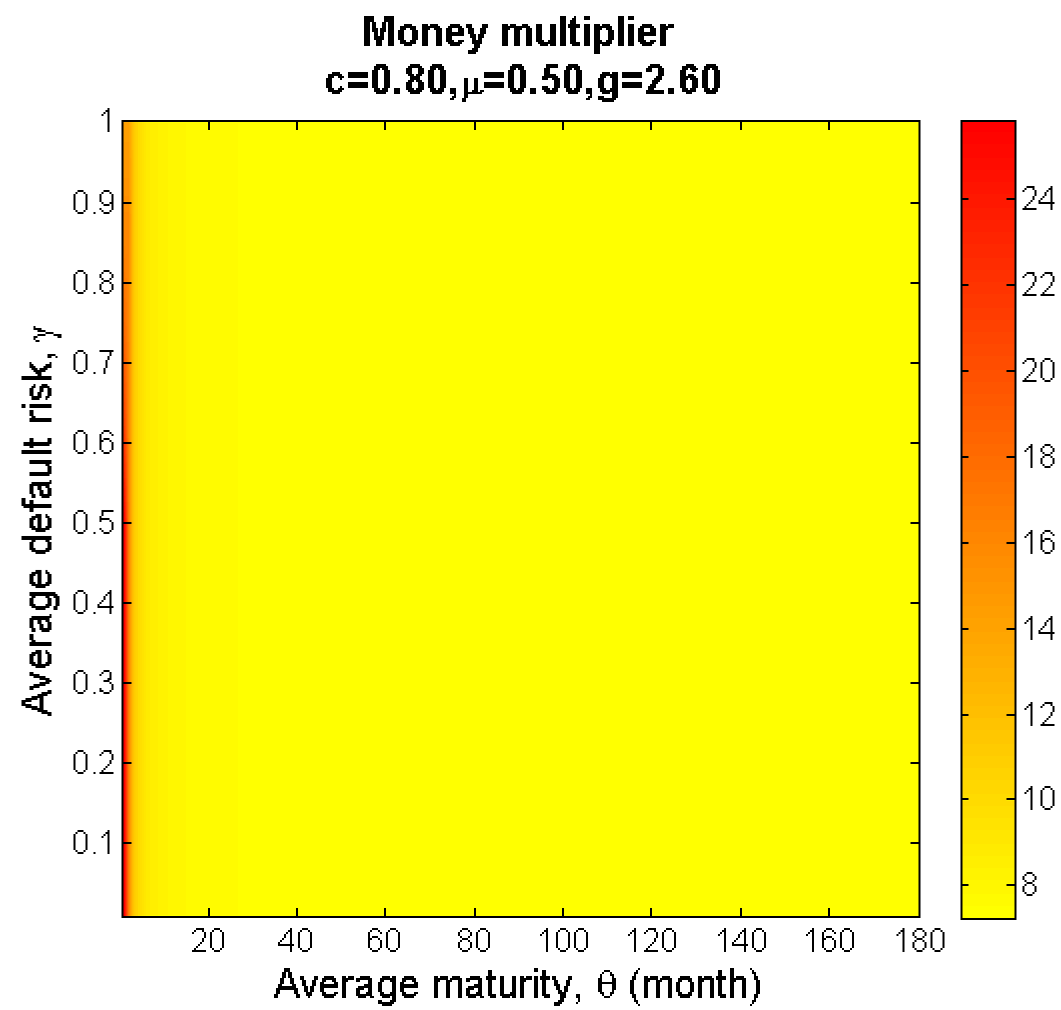
LR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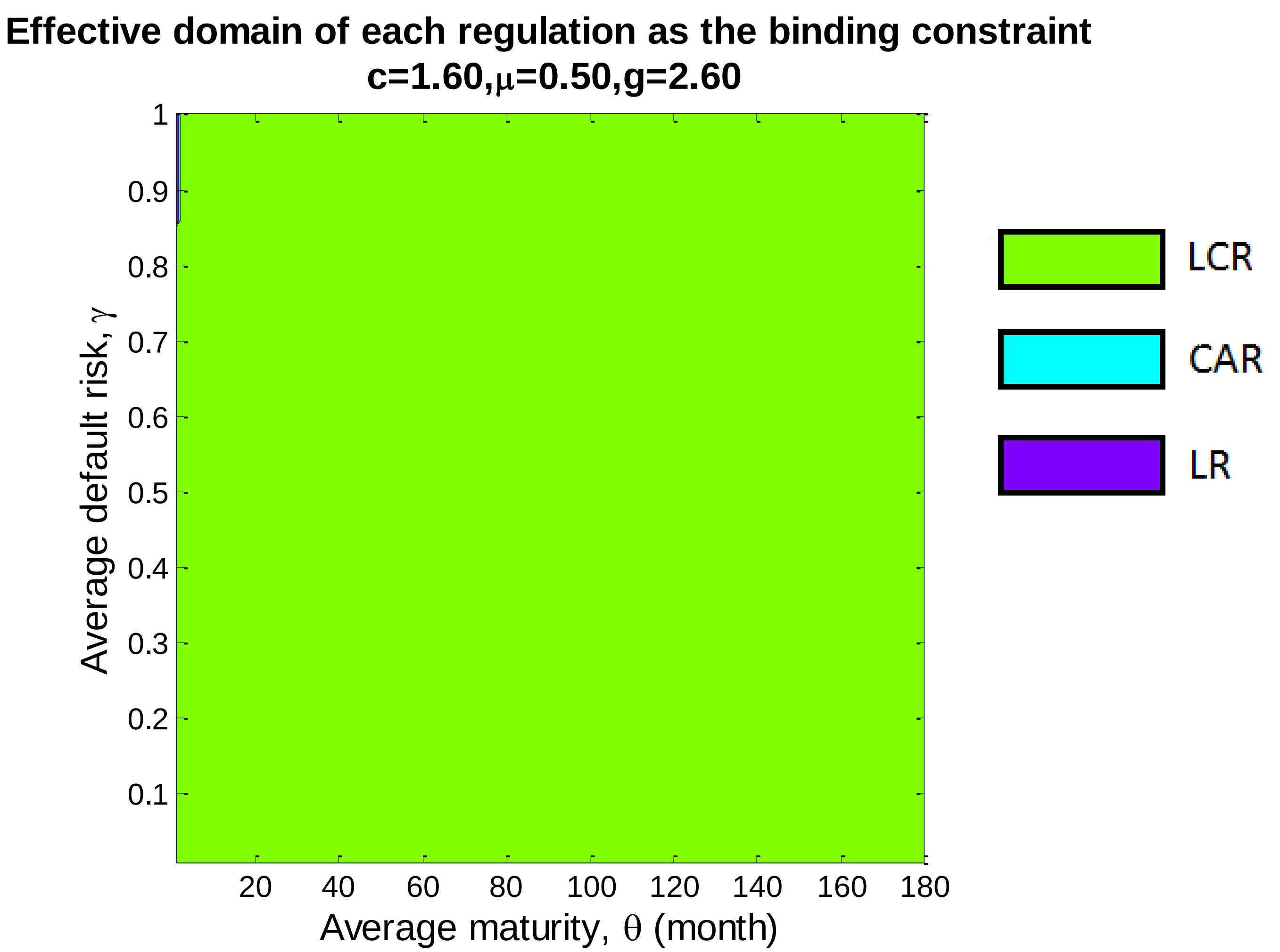
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LCR
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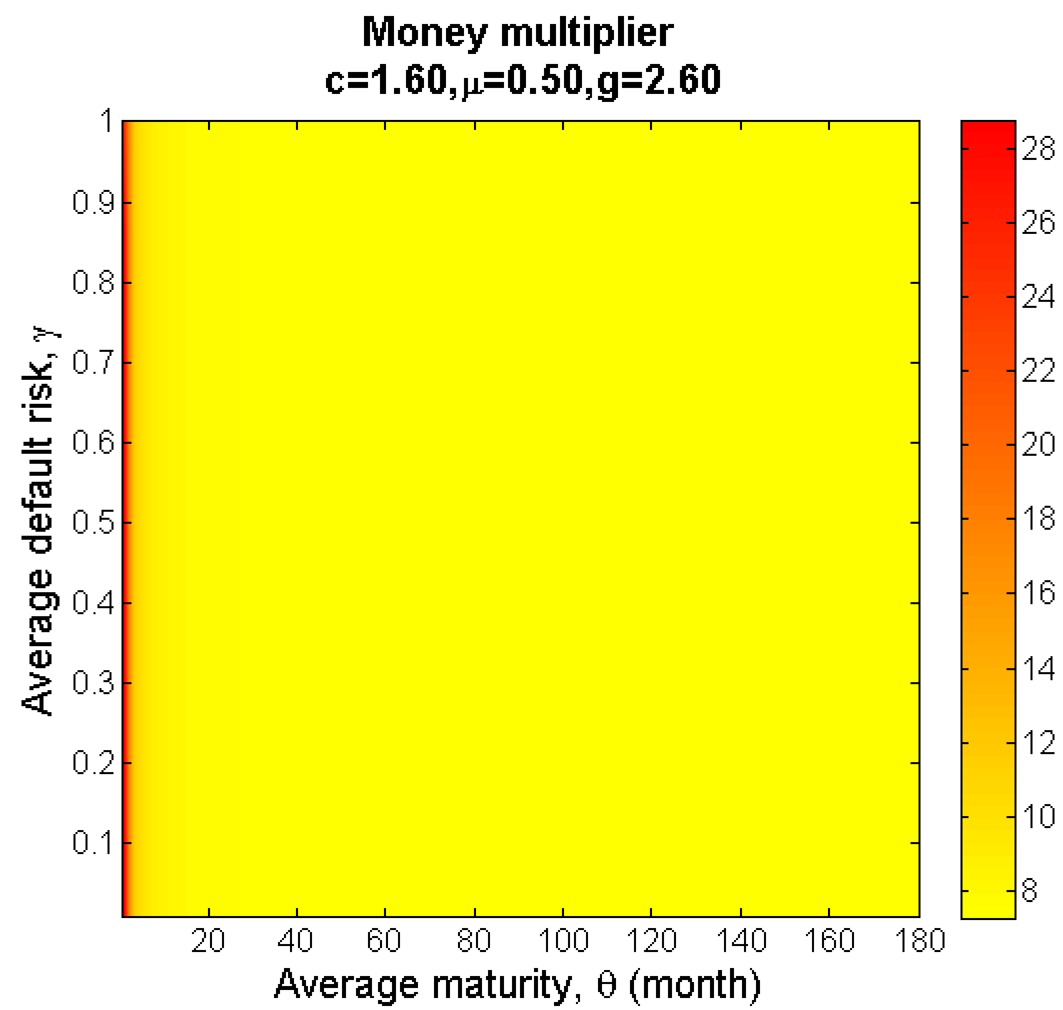
LR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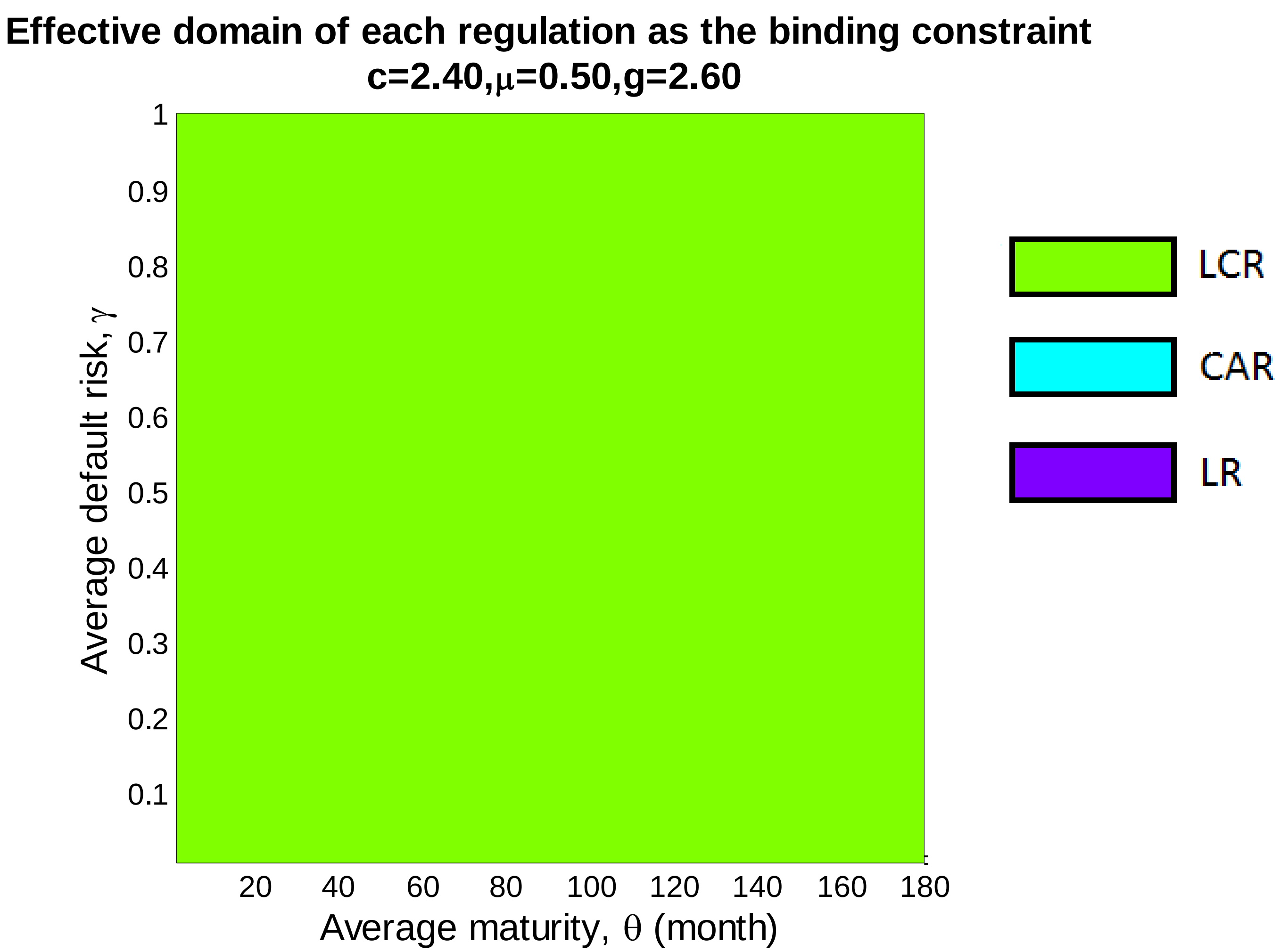
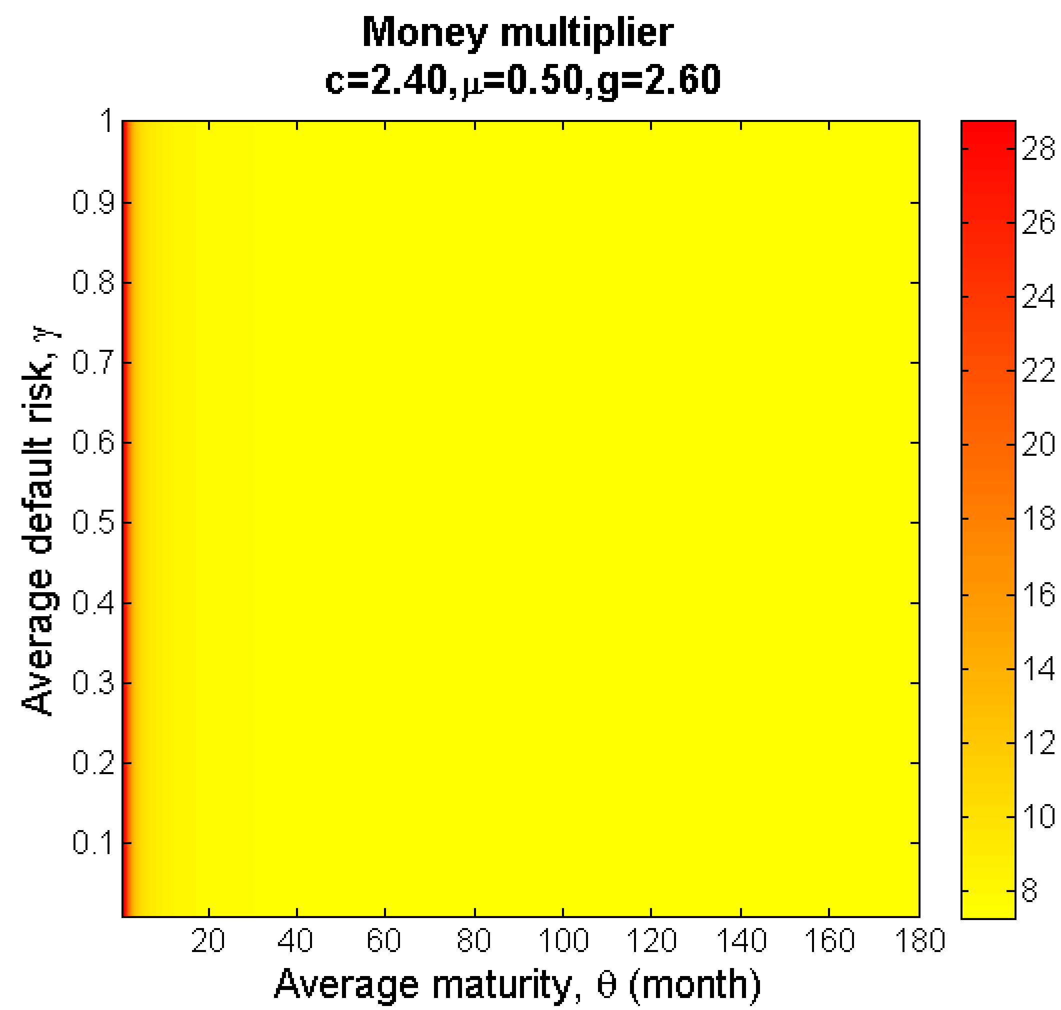
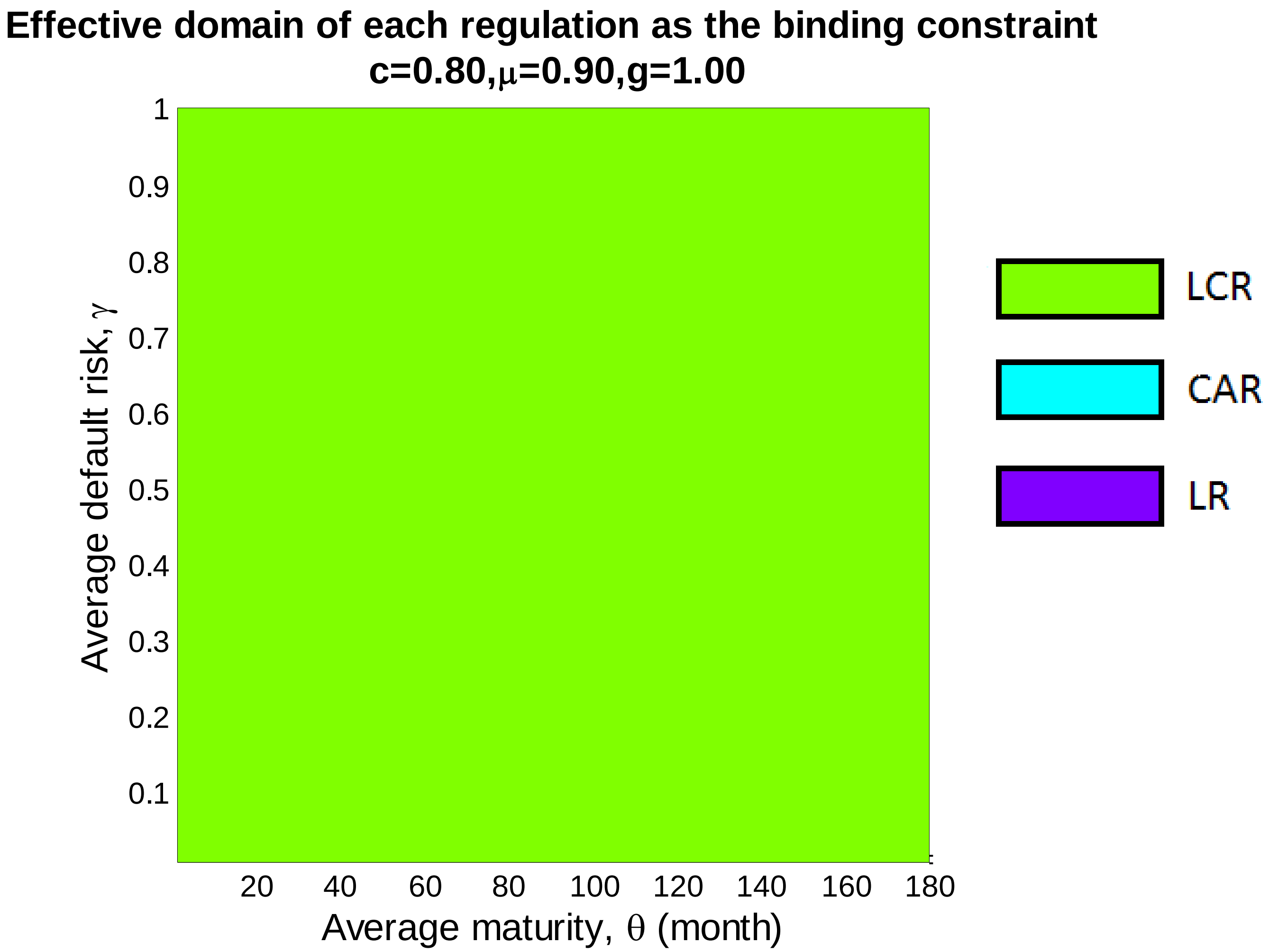
Average maturity, θ (month)

Robustness test






Effective domain of each regulation as the binding constraint
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Average maturity, θ (month)
LCR
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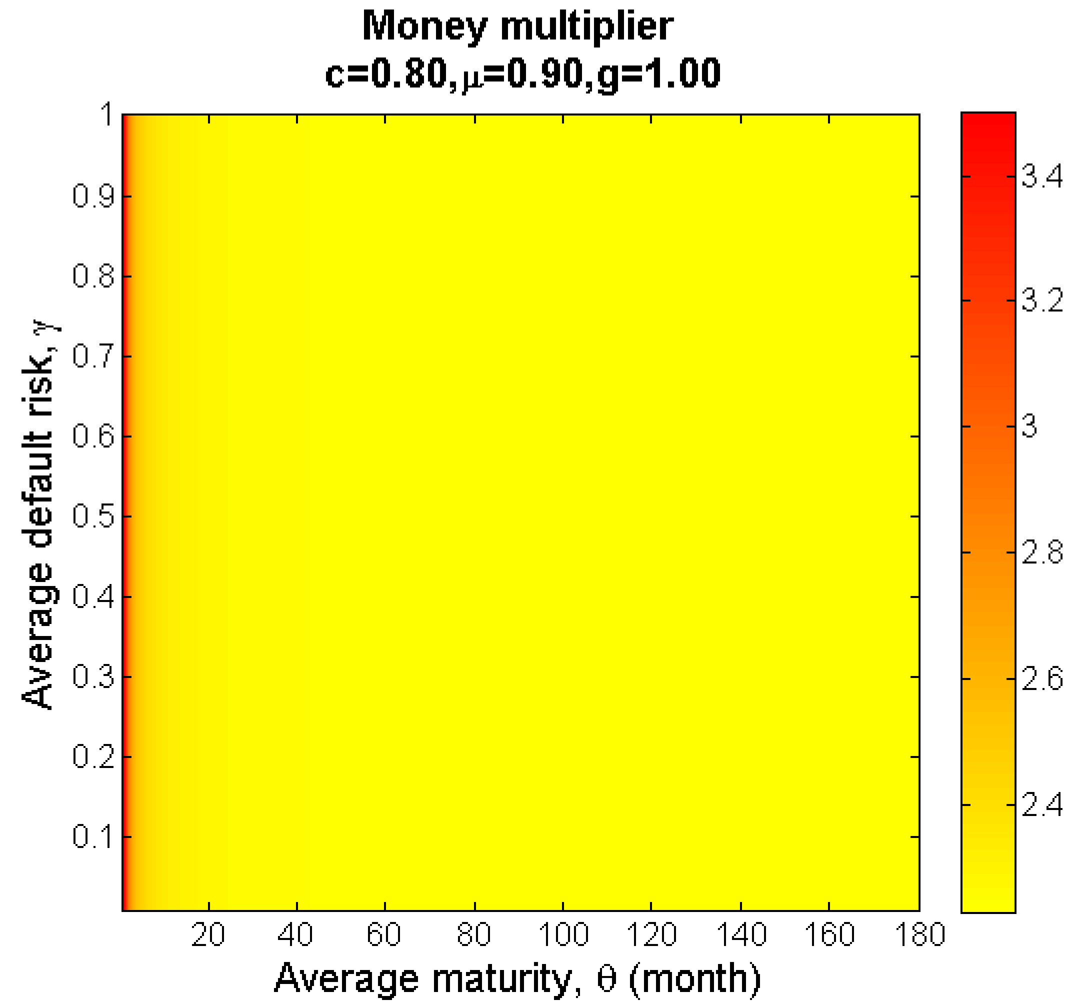
LR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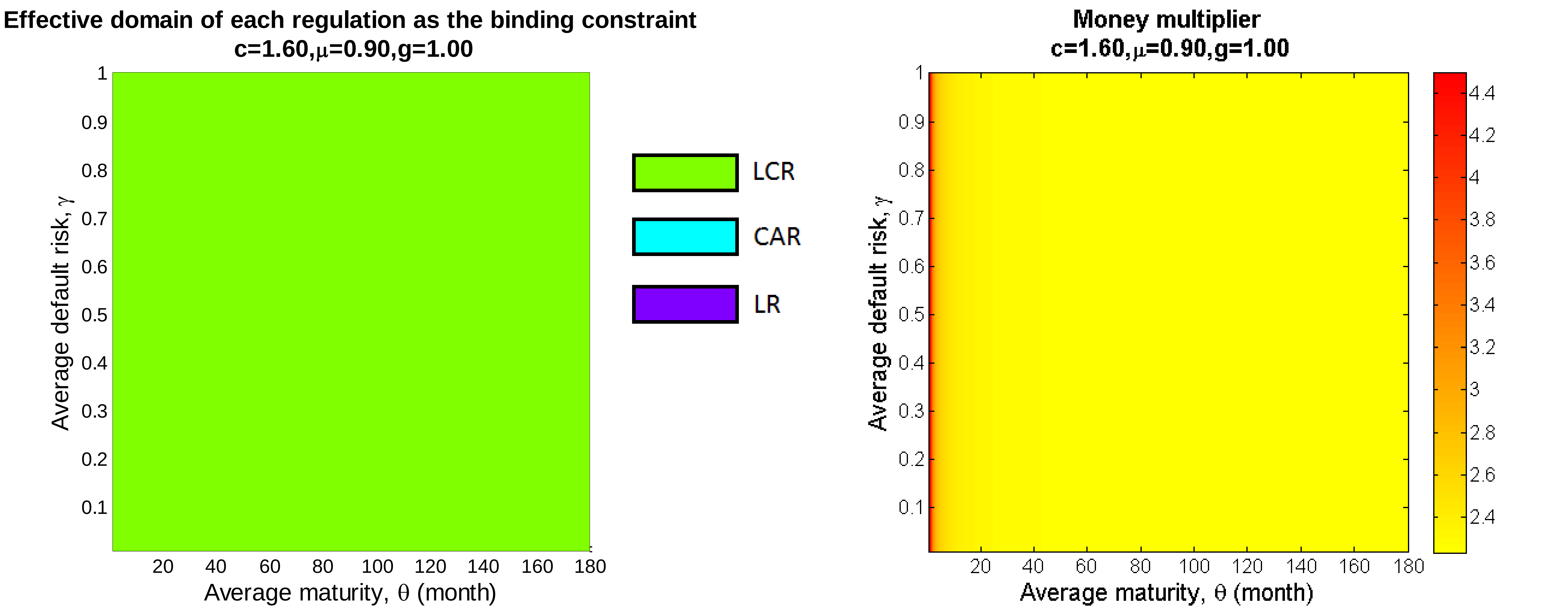
Average maturity, θ (month)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Average default risk, γ
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20 40 60 80 100 120 140 160 180
Average maturity, θ (month)
LCR
CAR
LR
Money multiplier
c=1.60,μ=0.90,g=1.00
Average default risk, γ
Average maturity, θ (month)
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3
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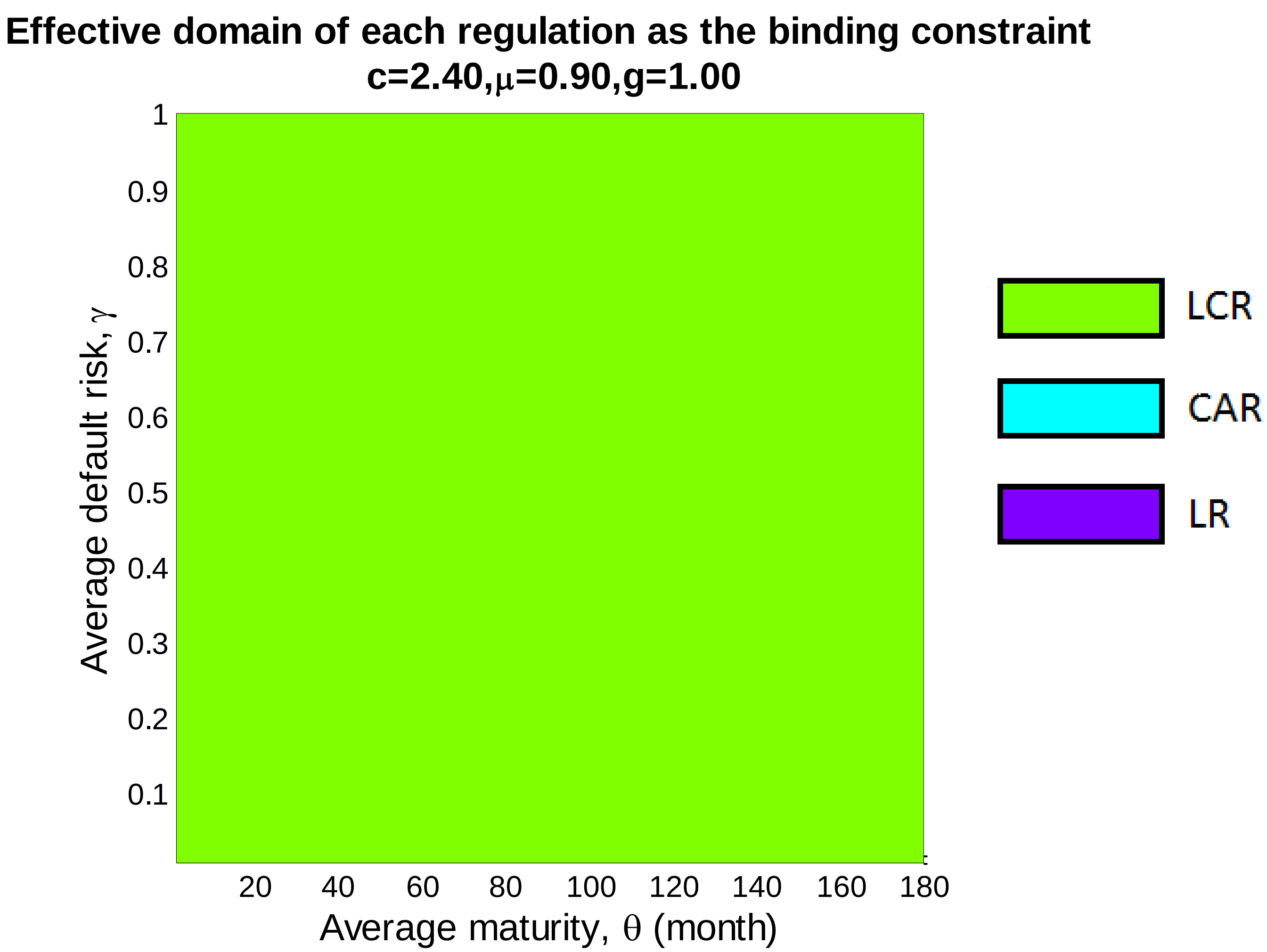
2.4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Average maturity, θ (month)
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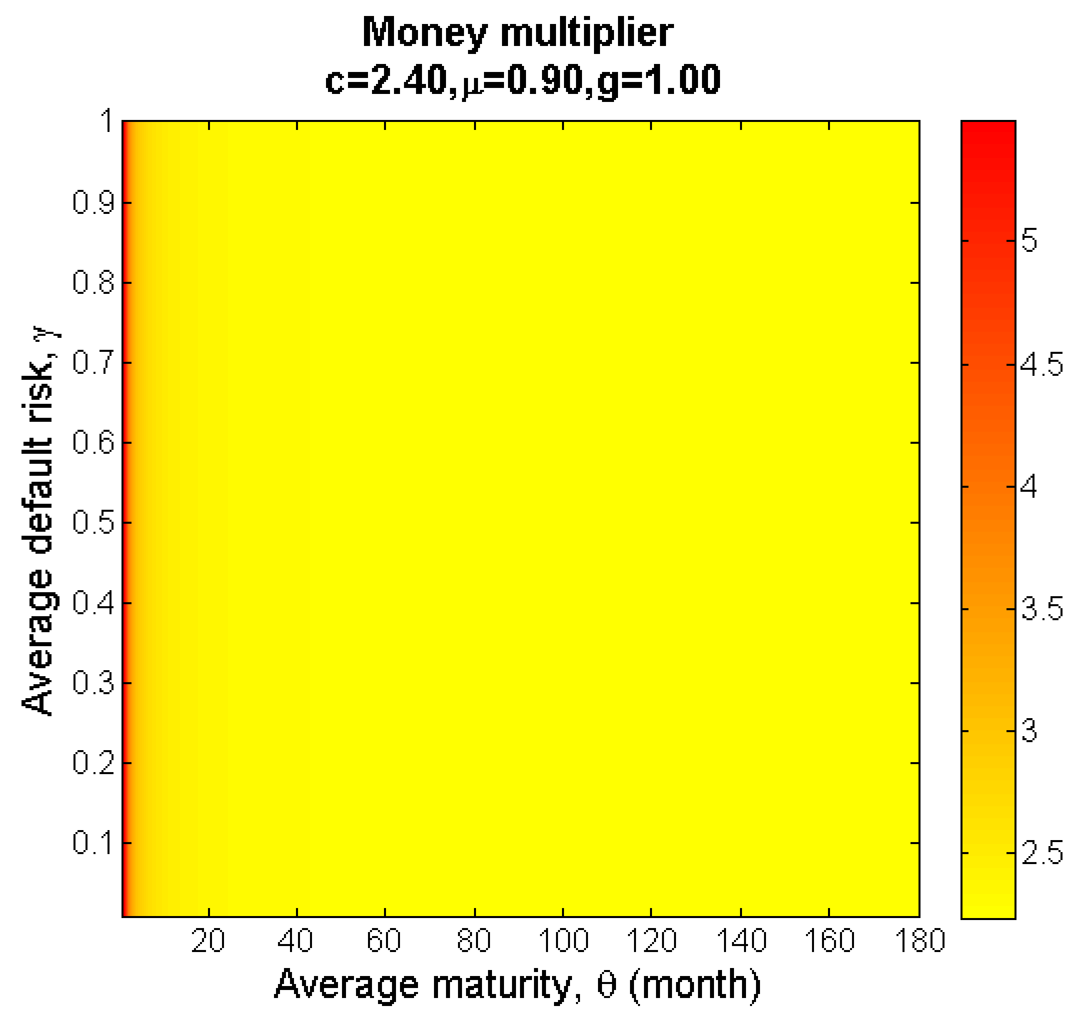
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Average maturity, θ (month)
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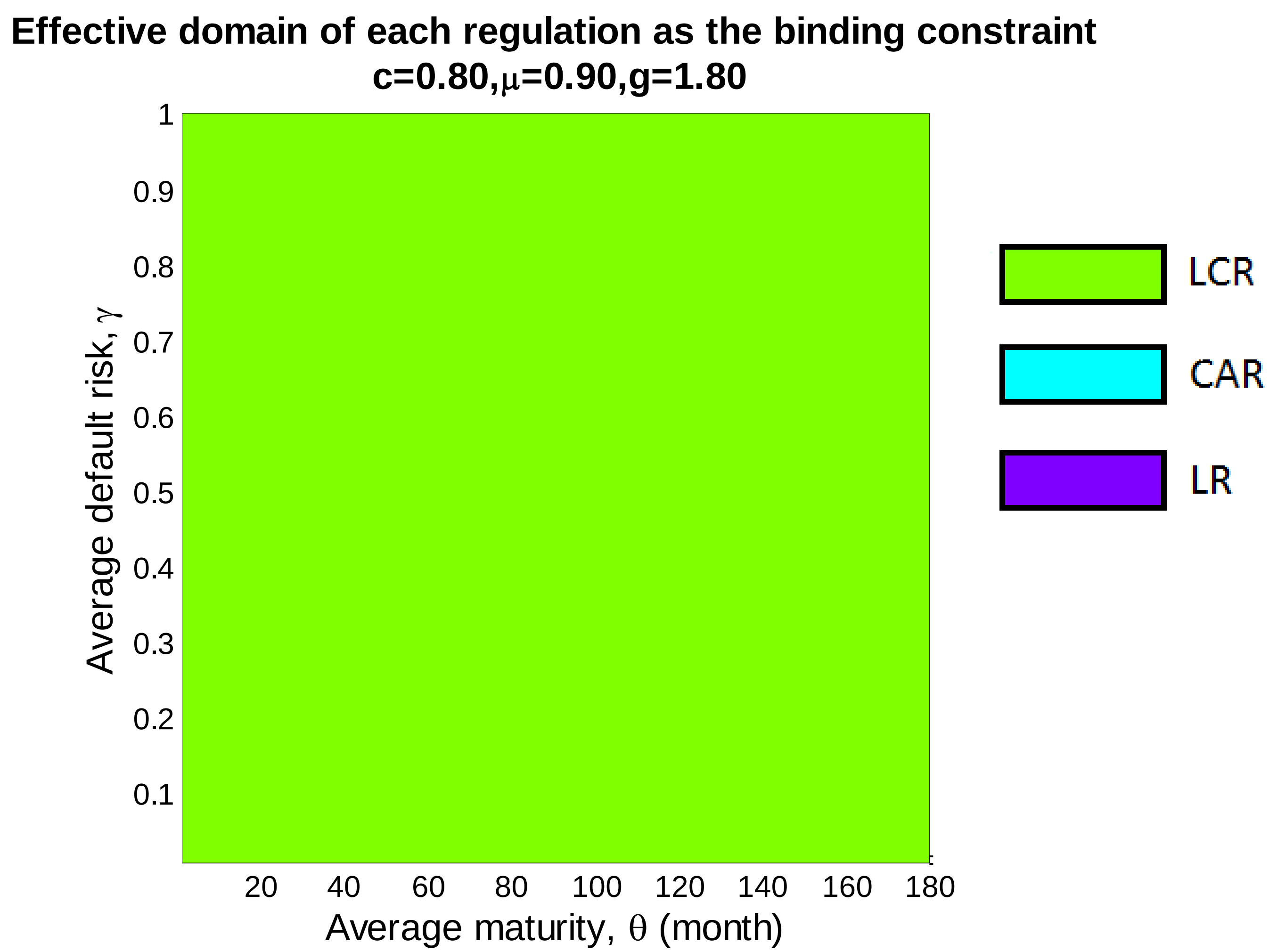
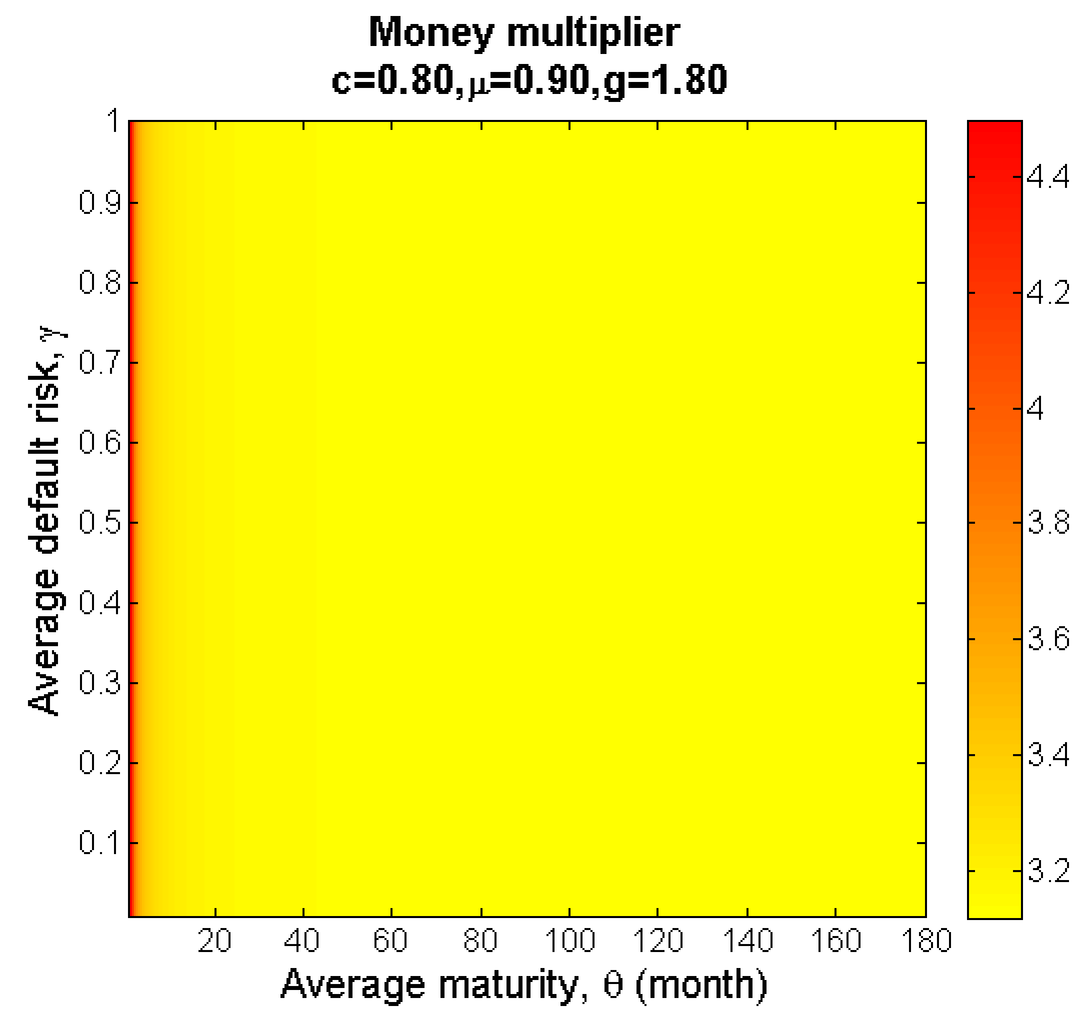
Robustness test





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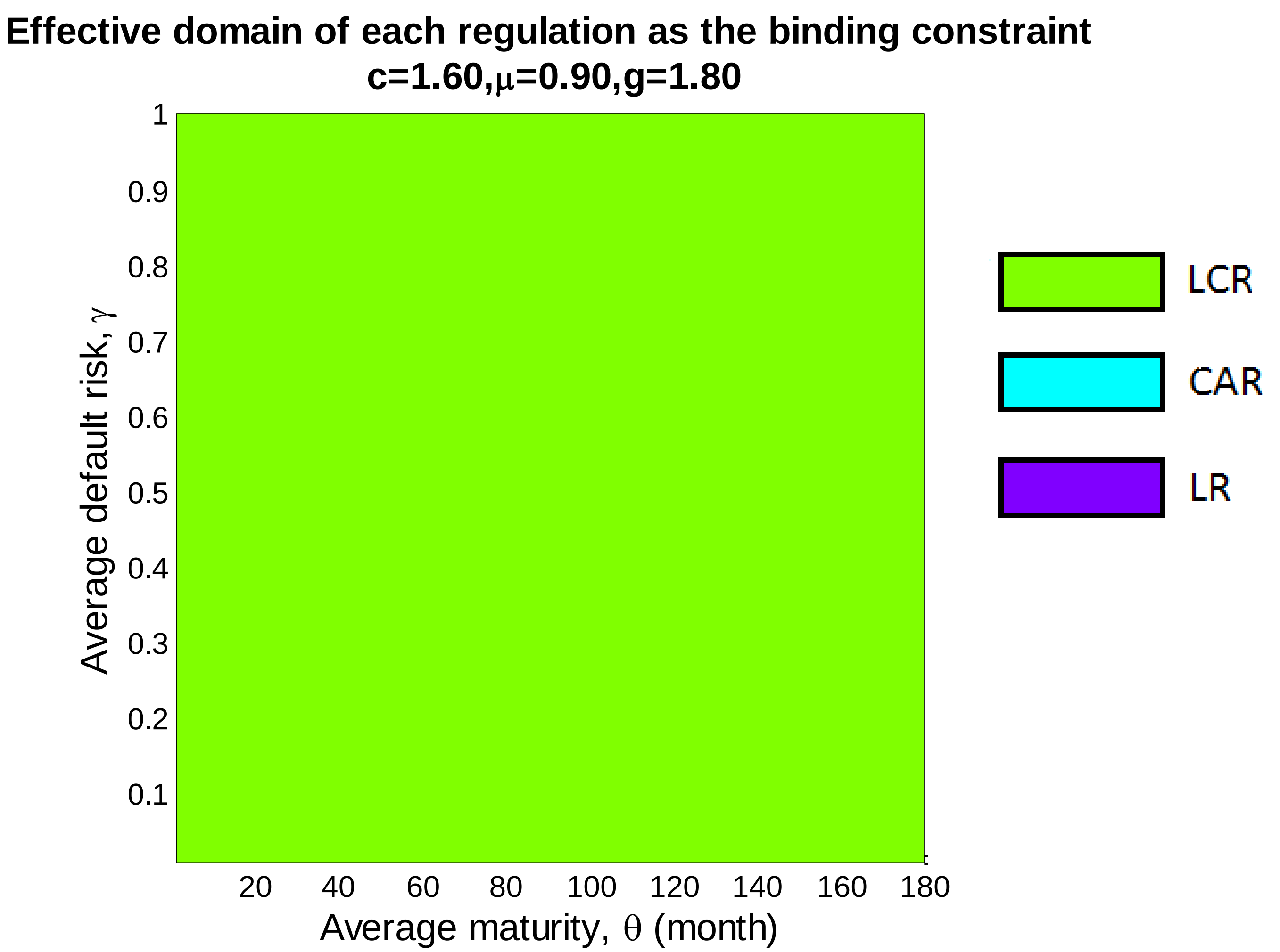

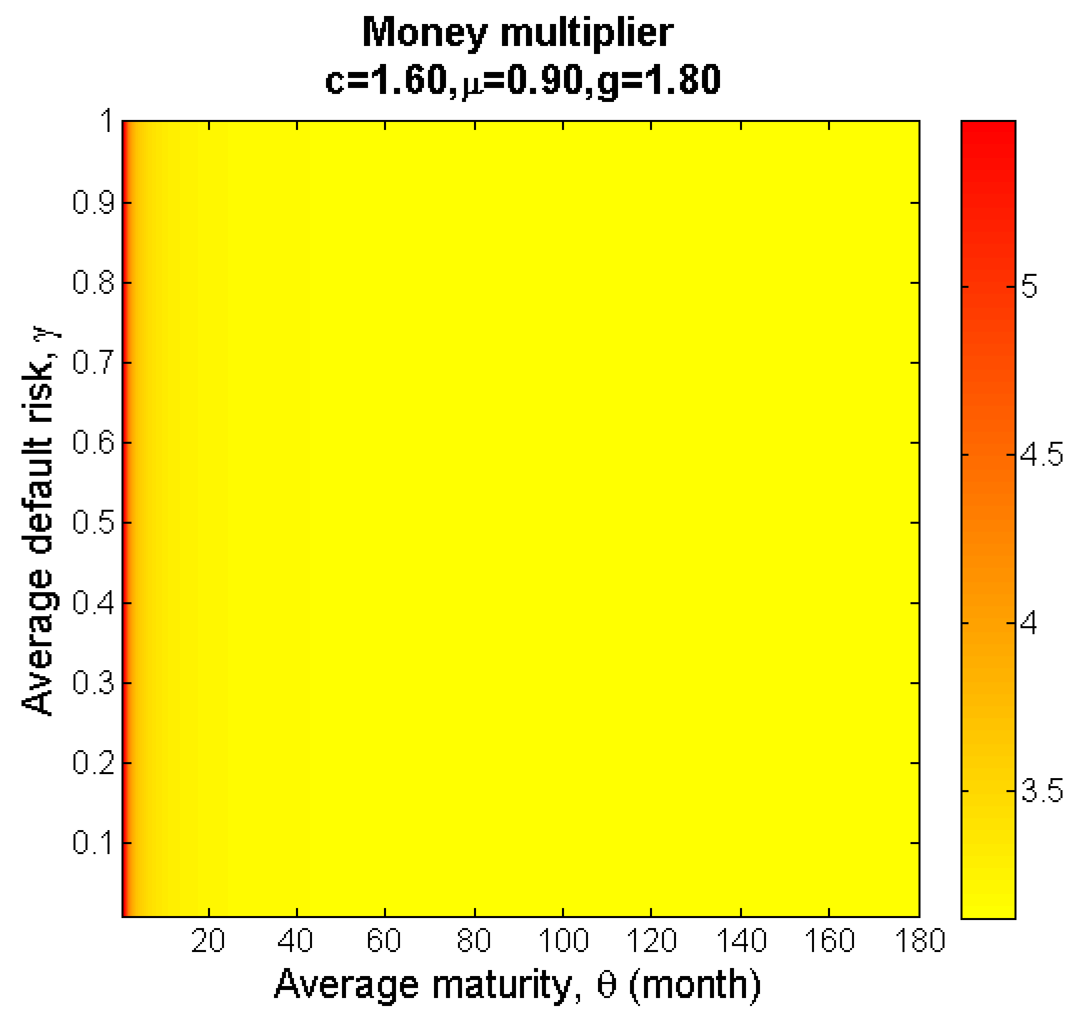

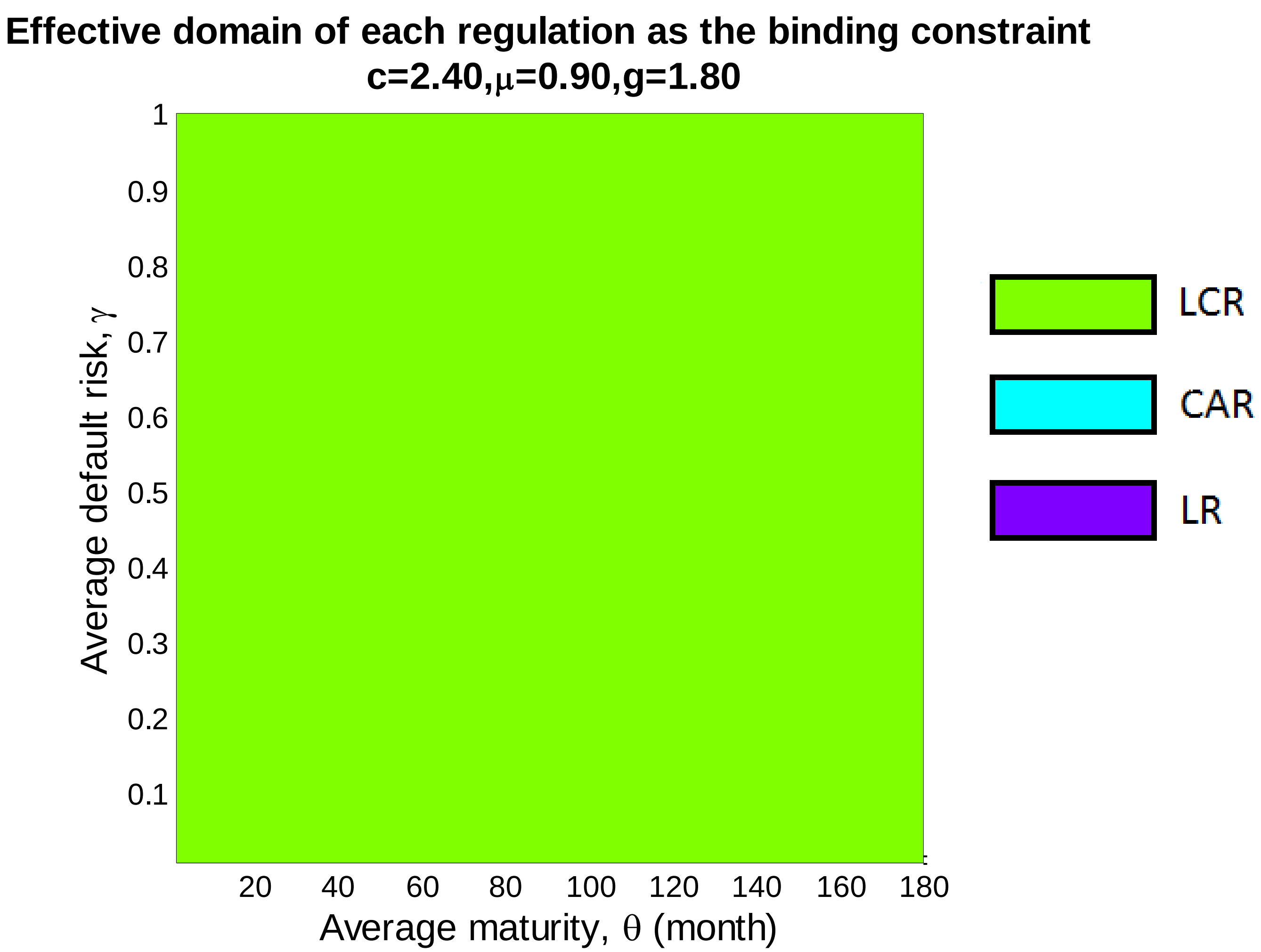
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Average maturity, θ (month)
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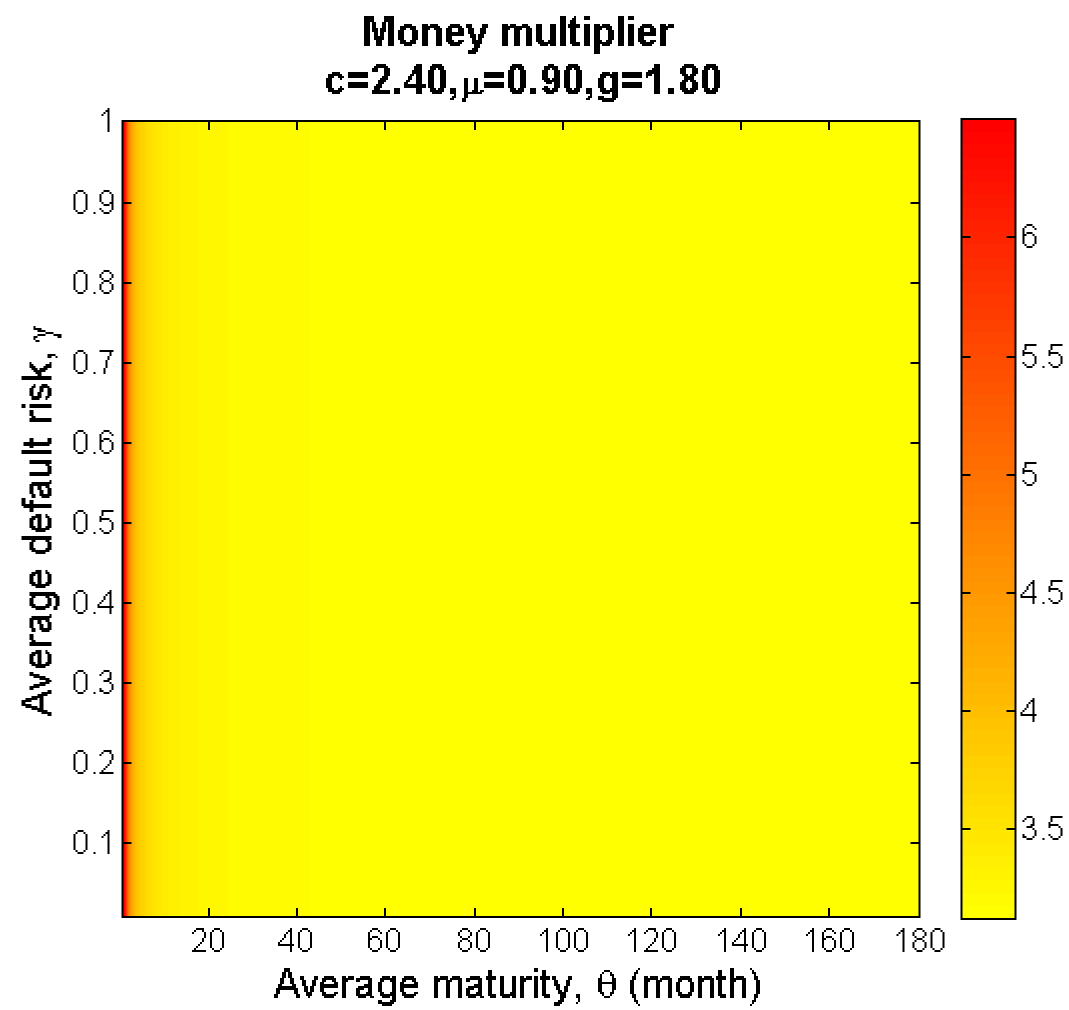
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Average maturity, θ (month)
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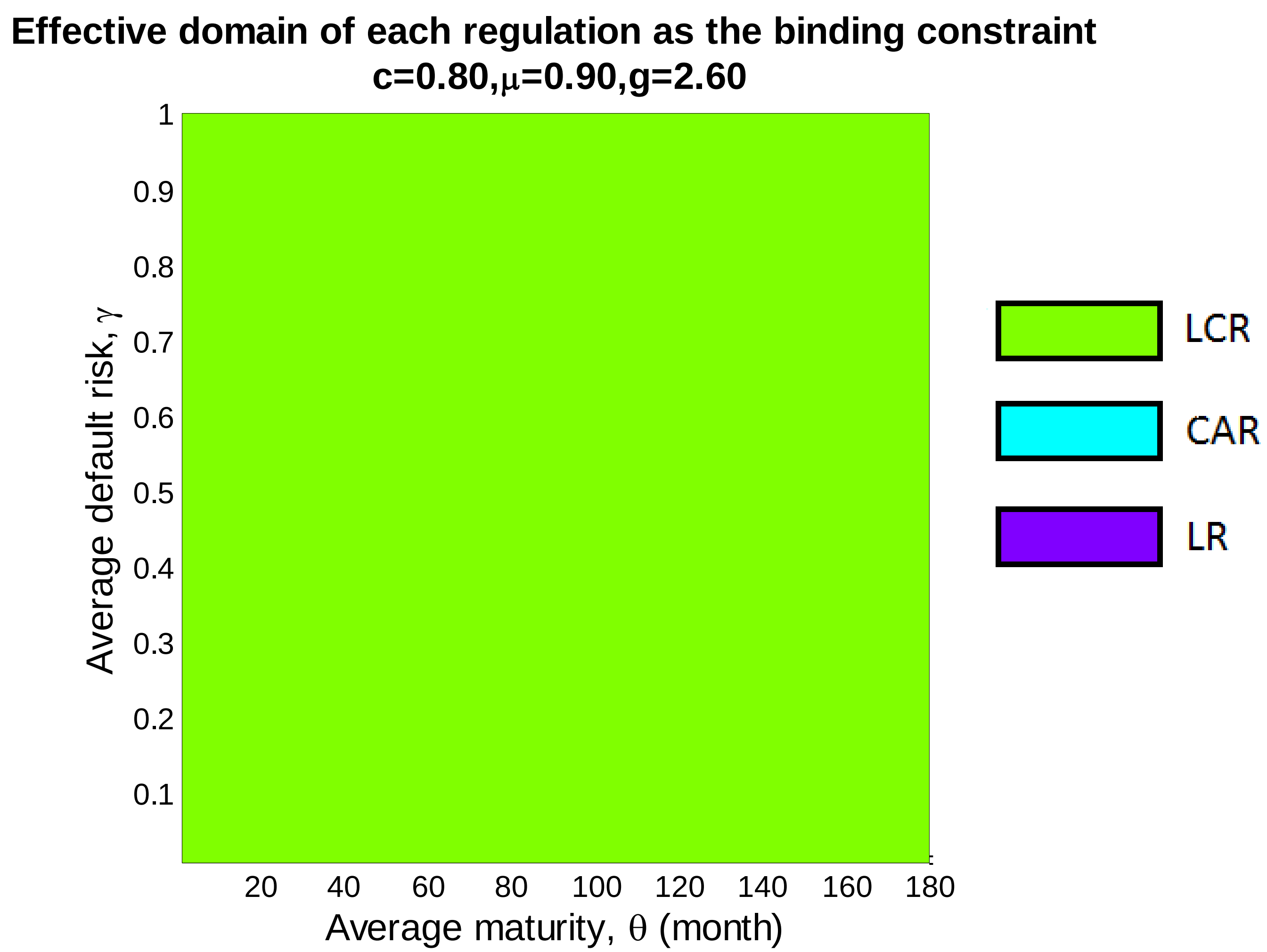
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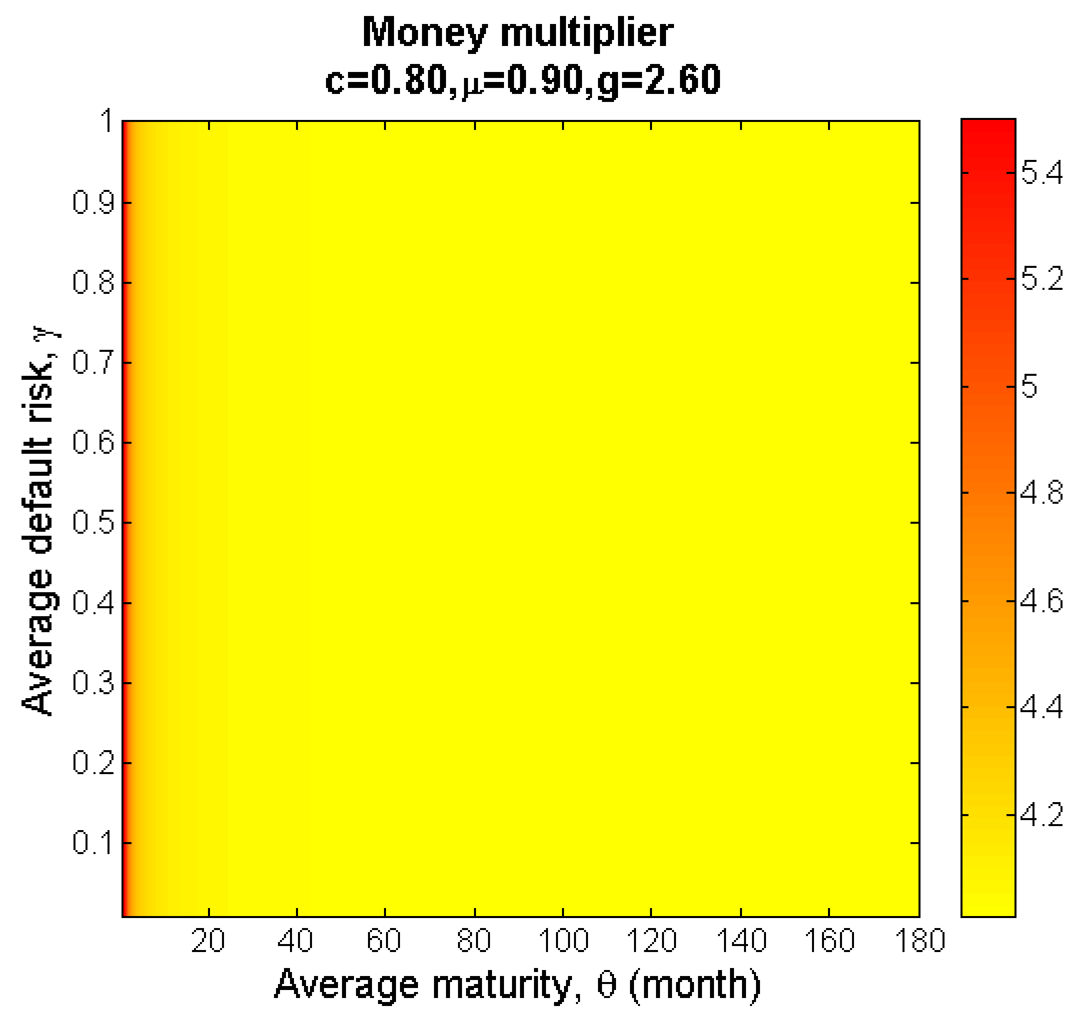
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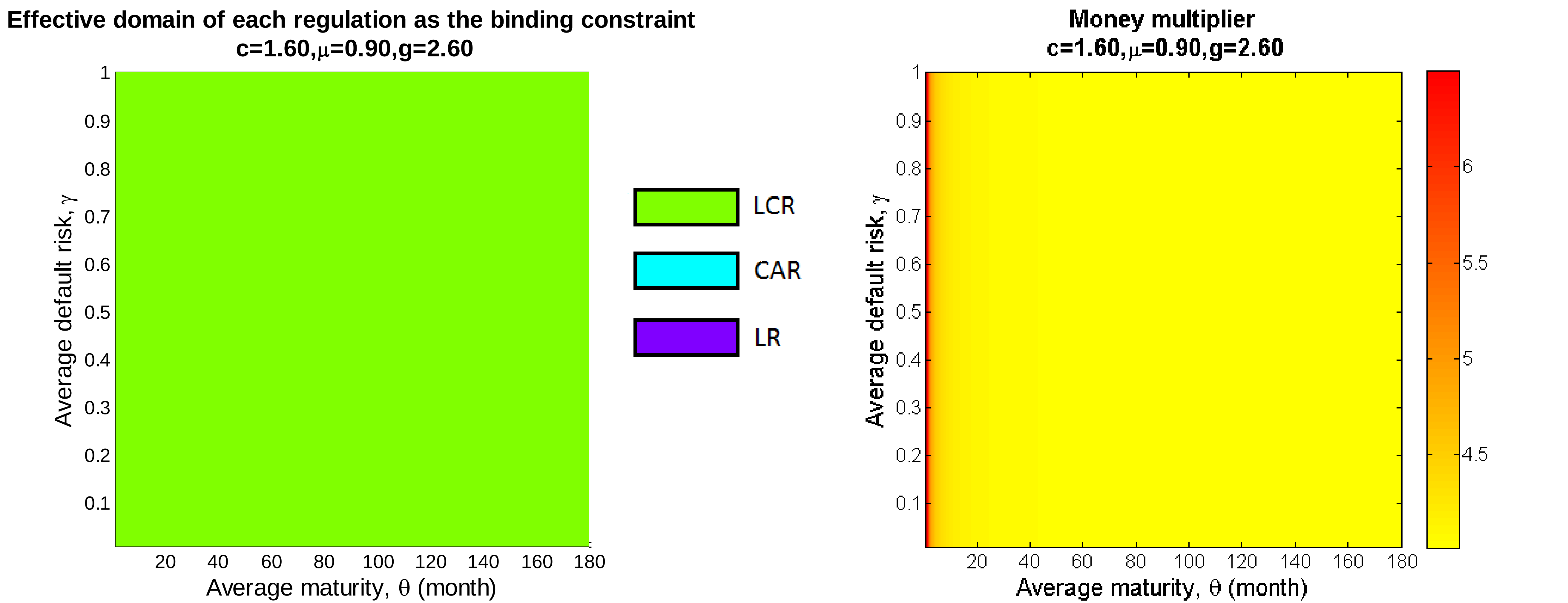
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Average maturity, θ (month)
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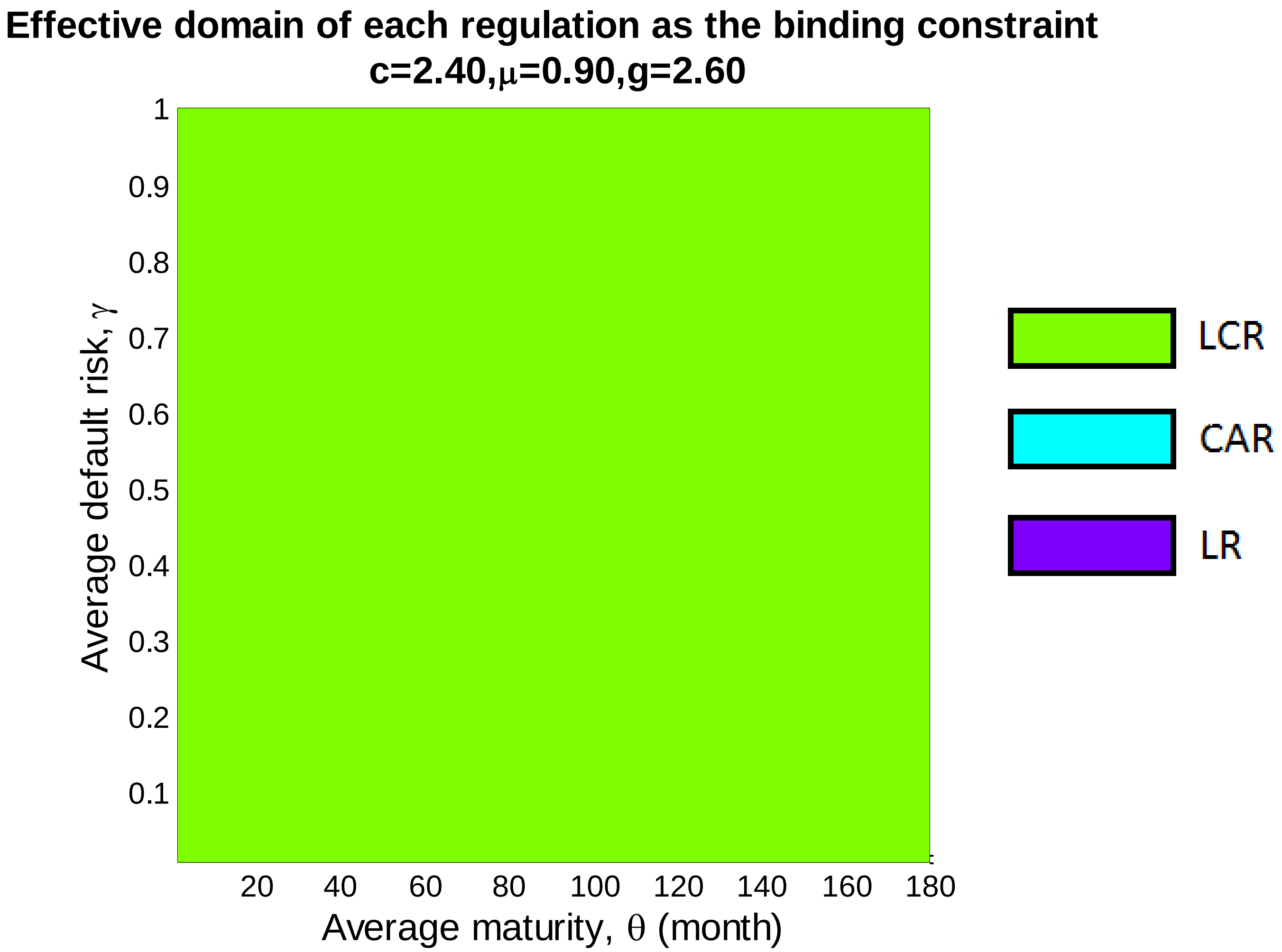
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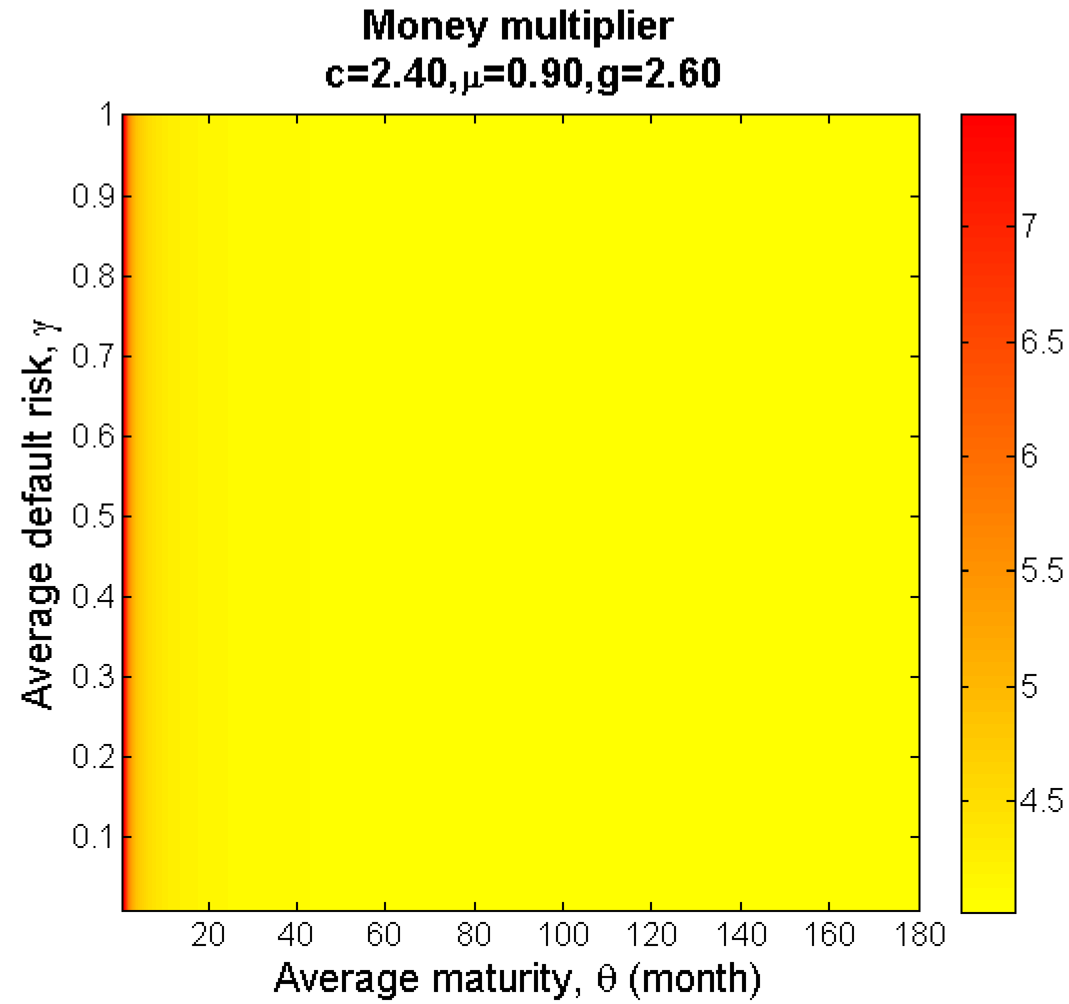
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Average default risk, γ
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Average maturity, θ (month)
7
6.5
6
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4.5

The impact of Basel III on money creation: a theoretical analysis

Wanting Xiong, Yougui Wang*

This version: November, 2017

Abstract

Recent evidences provoke broad rethinking of the role of banks in money creation. We argue that apart from the reserve requirement, prudential regulations also play important roles in constraining the money supply. Specifically, we study three Basel III regulations and theoretically analyze their standalone and collective impacts. We find that 1) the money multiplier under Basel III is not constant but a decreasing function of the monetary base; 2) the determinants of the bank's money creation capacity are regulation-specific; 3) the effective binding regulation and the corresponding money multiplier vary across different economic states and bank balance sheet conditions.

Keywords: money creation, Basel III, liquidity coverage ratio, capital adequacy ratio, leverage ratio, money multiplier
Journal of Economic Literature Classification: E51, G28, G18, E60

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1 Introduction

Since the crisis struck in September 2008, central banks have greatly expanded the scope of its tools to stimulate the economy by cutting interest rates to the zero lower bound and taking on unconventional measures such as “quantitative easing” (QE). In consequence, there has been commensurate increase in the monetary base together with a tripling or quadrupling of the size of central bank balance sheets. However, these actions have had much less impact on bank lending and the broad money aggregate. In particular, the money multiplier, which used to be reasonably stable in normal times, experienced unprecedented plumbing to less than half of its pre-crisis level (See Figure 1 for the empirical movements of the M0 stock, the M2 stock and the money multiplier in the U.S. [1]).

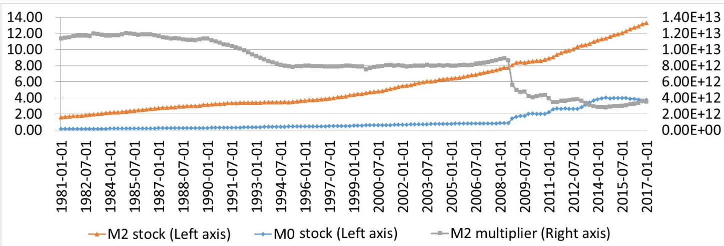

Figure 1: The M0 stock (US dollar) , the M2 stock (US dollar) and the money multiplier in the U.S. from 1981-01-01 to 2017-01-31. Data source: https://fred.stlouisfed.org.

Such collapse of the money multiplier and sluggish response of bank lending to expansionary monetary policy stand in stark contrast to the descriptions of the traditional fractional reserve theory of banking (FRT) and the related bank lending channel of monetary transmission. According to the FRT, the lending behavior of an individual commercial bank is constrained by the amount of deposits and the reserve requirement to which it is subject. Since the amount of required reserves is a fraction of the total deposits, the broad money supply by the banking system as whole is a multiplier of the monetary base. This money multiplier is expressed as the inverse of the required reserve ratio in its simplest form and is often considered to be constant. Therefore, a bank lending channel exists wherein monetary shocks to the level of bank reserves are “multiplied up” to greater changes in deposits and deposits, insofar as they constitute the supply of loanable funds, affect bank lending.

The wide gap between the reality and the FRT suggests a serious need to reassess the role of banks in money creation (Werner, 2014; McLeay et al., 2014; Ábel et al., 2016; Botos, 2016). Inherent in the traditional view of banking are two

[1] Relevant discussions and more data illustrations for other countries can be found in Goodhart (2015); Honda (2004); Disyatat (2011).

assumptions: 1) the central bank controls the money supply by varying the supply of reserves and the required reserve ratio, and 2) the availability of reservable deposits is a binding constraint on commercial bank lending. Regarding the first point, it is argued by many (Ryan-Collins et al., 2012; Goodhart, 2010; Komáromi, 2007) that most central banks have shifted their policy target from the quantity control of reserves to the price control of short-term interest rate. In order to achieve the target interest rate and facilitate the smooth functioning of the interbank payment system, reserves are supplied by the central bank non-discretionarily to meet the commercial bank's demand in normal times. Thus, the amount of reserves are mainly determined by the structural characteristics of the payment system. This renders the reserve requirement policy a less important aspect in the central bank governing framework (Bernanke, 2007; McLeay et al., 2014). In fact, several countries, including Canada, Great Britain, Australia, and New Zealand, have no reserve requirement at all. For countries that do retain this policy, it is often exercised with a time lag (e.g. at least 17 days in the U.S.) (Fullwiler, 2012).

Turning to the second point, there are a number of reasons to be skeptical about the causal relationship from reservable deposits to bank lending. For one, with increasingly ease access to non-deposit or nonreservable-deposit fundings, for example, due to the development of wholesale market (Carpenter and Demiralp, 2012), the growth in loan securitization (Loutskina and Strahan, 2009), and the globalization of banking (Puri et al., 2011), it is very much unlikely that banks will cut lending because they cannot replace the shortfall of reservable deposits. More importantly, the implicit assumption that banks are simply a financial intermediary who lends out the deposits saved with them is essentially misplaced. Instead, banks are different from other financial institutions in that they create deposits, which is used as the common method of payments, out of nothing through lending (Moore, 1988; Palley, 1994; Disyatat, 2011; Keen, 2011; McLeay et al., 2014; Werner, 2014). In this sense, loans drive deposits rather than the other way around.

Building on these rethinkings, we argue that in contrast to the attenuation of the reserve requirement as a constraint on bank lending, prudential regulations have played an increasingly important role in affecting bank behaviors in the money creation process. On the one hand, prudential regulations have become much more stringent after the recent financial crisis. As the most influential international framework of prudential regulations, the third Basel accord on banking supervision (or Basel III) (Basel Committee on Banking Supervision, 2011) strengthens the capital requirement on banks' equity position against default risk by narrowing the definition of eligible capital and requesting a significant rise of the Capital Adequacy Ratio (CAR). On the other hand, prudential regulations have moved to a multi-polar regime with the additional imposition of the Liquidity Coverage Ratio (LCR) requirement which aims to improve banks' liquidity risk profile in stressful times and the Leverage Ratio (LR) requirement which serves as a non-discretionary limit on the expansion of bank balance sheet. Although it has been widely acknowledged that banks respond to changes in the tightening of capital requirements by cutting lending or rising loan rates in the short term (see VanHoose (2007); Peek and Rosengren (2010); Martynova (2015) for reviews of related literature), existing literatures provide no clear explanations for how the broad money supply is influenced by prudential regulations, especially non-capital based requirements. More importantly, few works[2] have sufficiently addressed the research challenge in examining the collective consequences of multiple prudential regulations which take effects through different mechanisms and have interdependent interactions with each other.

Therefore, in response to the call of Haldane (2015) for more efforts in addressing the complexity of multi-polar regulations, this paper considers three prudential regulations in the Basel III framework, including the CAR, LCR and LR regulations. We focus on the immediate impact of these regulations in constraining the commercial banks' ability to lend and create money. Compared with other works on the macroeconomic impact of Basel III (e.g. Slovik and Cournède (2011); Allen et al. (2012); Angelini et al. (2015); Miles et al. (2013); Yan et al. (2012); Quinaz and Curto (2016)), we study a shorter logic chain and make less assumptions about the intertwined macroeconomic causalities, so as to focus on the cumulative impact of multiple regulations that are imposed simultaneously. In addition, our emphasis on the unintended effect of the Basel III accord on downsizing credit supply complements the more extensive literature on its performance in improving financial stability (e.g. Krug et al. (2015); Hartlage (2012); Van Den End and Kruidhof (2013)), and thus lays the foundation for a more comprehensive evaluation of the Basel III accord.

To provide a thorough analysis of the money creation process under Basel III regulations, three questions have to be answered. The first question is what determines the broad money supply and the corresponding money multiplier when the bank is constrained by only one regulation. Second, when multiple regulations take effect at the same time, which of them is the binding constraint that dictates the bank's ability to create money. Last but not least, since most prudential regulations are ratio controls of the items on bank balance sheets, it is also vital to know how the effective binding regulation and corresponding money multiplier depend on the condition of bank balance sheet in different economic scenarios. With the answers to these questions, we will be able to understand why the money multiplier collapses after the massive expansion of the monetary base and advise policy makers on how to boost the banking system's credit creation capacity under multiple prudential regulations in different conditions.

[2] Exceptions can be found in Goodhart et al. (2013); Haldane (2015); Krug et al. (2015); Xiong et al. (2017) .

To achieve our goals, we re-examine the money creation process by employing a dynamic model that complies with both accounting and stock-flow consistencies. For each individual regulation, we present the corresponding expressions for the money supply and money multiplier and examine their dependence on related parameters. We find that 1) under all three regulations, the money multiplier responds negatively to the increase of the monetary base; and 2) the broad money supply cannot be boosted by rising the monetary base when the banking system is constrained by the LR regulation; and 3) the determinants of the money supply and the money multiplier vary for different prudential regulations. In the case where multiple regulations take effect simultaneously, we find that the binding regulation that casts the most rigid constraint on the bank lending and money creation can be different when the conditions of the economy and the bank balance sheet structure vary. Consequently, the levels of the corresponding money multiplier and its determinants will also change. We argue that this result calls for special attention from the policy makers because the same policy may have distinct consequences in different scenarios.

The following of the paper is structured as follows. Section 2 elaborates the role of the commercial banks in money creation and the mechanism through which Basel III regulations affect bank lending behaviors and consequently the broad money supply. Section 3 presents the model and the corresponding equilibrium conditions. Section 4 first presents the standalone impact of each individual regulation on money creation in Section 4.1 and further demonstrates the collective influence when all three regulations are simultaneously imposed in Section 4.2. Section 5 draws our conclusions.

2 Money creation, commercial bank balance sheet and prudential regulations

> "In the modern economy, most money takes the form of bank deposits. But how those bank deposits are created is often misunderstood: Whenever a bank makes a loan, it simultaneously creates a matching deposit in the borrower's bank account, thereby creating new money."
>
> —McLeay et al. (2014),Bank of England,Quarterly Bulletin 2014 Q1

Commercial banks play a central role in money creation. When a bank makes a loan, the most common way is to directly credit the borrower's deposit account, which thereby expands both sides of the bank's balance sheet. When loans are repaid, the amount of deposits decreases. In this sense, bank lending can never be constrained by the lack of debt financing source because deposits are its own product. Instead, the limit on credit creation comes from the portfolio management of banks to maintain liquid, solvent and profitable, for both voluntary and mandatory reasons. To understand this, let us take a detailed look at the bank's business model and the mechanism through which the reserve requirement and prudential regulations take effect.

The most fundamental way for a bank to profit is to earn the interest spread between its assets (e.g. loans) and liabilities (e.g. deposits), which gives the bank a natural motivation to make more loans and expand the balance sheet. On the other hand, such business model also entails the bank's taking on various risks, which is rooted in the asymmetric properties of its assets and liabilities. Deposits should be paid on demand while loans become due only on specific dates, thereby the bank faces potential maturity mismatch that leads to liquidity risk. Also, banks face solvency risk when loans get defaulted or massive asset depreciation happens in economic downturns. Usually, the liquidity risk is managed by banks through a buffer of liquid assets and the access to stable funding sources during stressed market conditions, while the solvency risk is coped with by holding sufficient amount of capital and careful risk management of their assets (see Fig. 2 for illustration).

From this perspective, one function of the reserve requirement is to serve as a liquidity regulation that guarantees banks' holding of enough liquid reserves rather than illiquid loans to meet their payment needs because of deposit withdrawal or transfer. However, with the central bank's policy target shifted to short-term interest rate, the commercial bank's increasing access to funds that bears no reserve constraint and the facilitation of a well-functioning interbank market for reserves, this constraint has ceased to be an influential concern when banks make loans.

In addition, driven by the desire for profit, banks are often prone to underestimate the liquidity and solvency risks which gradually build up during economic booms when the expectations for profitability are collectively good and the short-term fundings are stable and easy to obtain. Also, the explicit or implicit government guarantees in stressed conditions including deposit insurance, bailing-out and last-resort lending, also give rise to the problem of "moral hazard" whereby banks take on excessive risks and maintain lower levels of capital and liquid assets they would otherwise. This sort of development is argued to be the reason for the expansion of bank lending and the deterioration of financial stability in the lead up to the financial crisis (McLeay et al., 2014; Farag et al., 2013; Fullwiler, 2012).

Therefore, in order to guard against this intrinsic destabilizing nature of the financial sector, prudential regulations are indispensable in constraining bank behaviors in a more targeted fashion (Horváth et al., 2014; Jakab and Kumhof, 2015; Li et al., 2017; Farag et al., 2013; Dermine, 2013). Consequently, since the introduction of capital requirements in the Basel I accord, the impact of bank capital and capital regulations on bank lending has been a heated topic for researchers. In

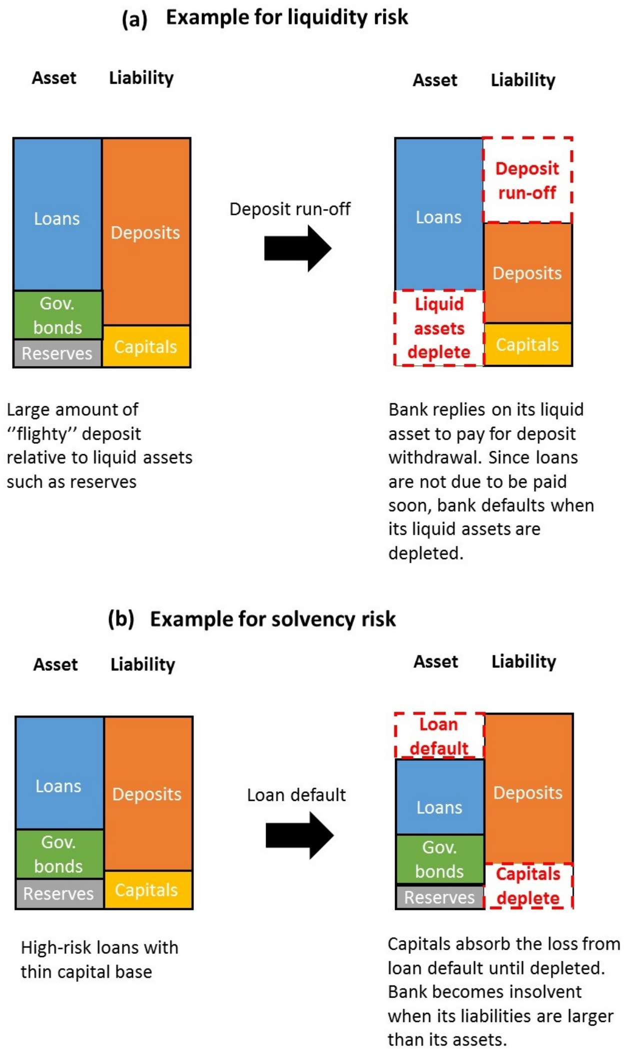

Figure 2: Illustration for liquidity risk (a) and solvency risk (b). Figure adapted from Farag et al. (2013).

the aspect of theory, several mechanisms are proposed to explain how bank capital and capital requirement affect bank lending: 1) the threshold effect of binding capital constraint, where capital-constrained banks become more responsive to contractionary monetary policy and less motivated by expansionary policy (Van den Heuvel, 2002b; Furfine, 2001; Honda, 2004); 2) the bank profit effect, where monetary policy tightening results in reduced bank profit that constitutes lower bank equity and thus leads to a persistent decline in bank lending (Van den Heuvel, 2002a; Chami and Cosimano, 2010); 3) the risk premium effect, where the level of bank capital acts as the signal of the bank's health for its creditors and thereby affects the bank's risk premium in raising external funds (Disyatat, 2011). As for empirical evidences, the important roles of bank capital and capital regulations in bank lending have been generally confirmed. On the one hand, it is well documented by researches across different countries and time periods[3] that individual banks' capital position is an important factor in determining their response to monetary shocks. On the other hand, more recent works (Francis and Osborne, 2009, 2012; Bridges et al., 2014; Aiyar et al., 2016; Mésonnier and Monks, 2014; Noss and Toffano, 2014) focus on the impact of varying capital requirement and estimate a short-term reduction of bank lending ranging from 1.2% to 4.5% due to a 1% increase in capital requirement.

Notwithstanding the extensive discussions on the impact of capital requirement on the bank lending channel, few investigations have been made regarding the constraining effect of other prudential regulations on the money creation process such as the newly proposed LCR regulation, not to mention the more complicated case where multiple prudential regulations are simultaneously imposed[4].

In the Basel III accord framework, the liquidity risk is addressed by the LCR regulation while the solvency risk is attended by the CAR and LR regulations. Next, we will explain the meanings of these regulations and how they limit bank lending and the money supply.

Liquidity Coverage Ratio Basel III accord requires a bank to hold sufficient high-quality liquid assets ($HQLA$) to cover its total net cash outflow ($NCOF$) over 30 days in stressed conditions. Mathematically, the liquidity coverage ratio is defined as

$$LCR = \frac{HQLA}{NCOF}. \tag{1}$$

The minimum liquidity coverage ratio was initially set to be 60% in 2015 and should rise in equal annual steps to reach 100% on 1 January 2019.

According to the Basel III regulations, high quality liquid assets are assets that have low default risk and easy and immediate convertibility into cash at little or no loss of value. Meanwhile, the total net cash outflows is defined as the total expected cash outflows (OF) minus the total expected cash inflows (IF) up to an aggregate cap of 75% of the total expected cash outflows in the specified stress

[3] For the U.S., see Peek and Rosengren (1995a,b); Kishan and Opiela (2000, 2006); for EU countries, see Gambacorta and Mistrulli (2004); Altunbaş et al. (2002); Gambacorta and Marques-Ibanez (2011); Puri et al. (2011); for India, see Nachane et al. (2006); Albertazzi and Marchetti (2010); for Japan, see Peek and Rosengren (1997); for Spain, see Jiménez and Ongena (2012); for Malaysia, see Abdul Karim et al. (2011).

[4] See Li et al. (2017); Xiong et al. (2017) for exception.

scenario for the subsequent 30 calendar days, i.e.

$$NCOF = OF - min\{IF, 0.75OF\}. \tag{2}$$

The 75% cap of total expected cash outflows is introduced to prevent banks from relying solely on anticipated inflows to meet their liquidity requirement so that they must maintain a minimum amount of stock of $HQLA$ equal to 25% of the total cash outflows(Basel Committee on Banking Supervision, 2013).

Risk-based capital adequacy ratio To strength the capital framework of the banking sector, the Basel III accord raises the minimum requirement of bank capital in relation to the risk-weighted assets (RWA) and introduces two additional capital buffers: a mandatory "capital conservation buffer" and a "discretionary counter-cyclical buffer", allowing national regulators to require additional capital buffer during periods of high credit growth. The risk-based capital adequacy ratio is usually defined based on the Tier-1 core capital ($CET1$), which is bank capital with the highest quality classification, over the risk-weighted assets, i.e.

$$CAR = \frac{CET1}{RWA}. \tag{3}$$

Compared to Basel II, the minimum requirement of $CET1$ over RWA is raised from 2% to 4.5%, while the mandatory "capital conservation buffer" requires 2.5% and the "discretionary counter-cyclical buffer" ranges from 0% to 2.5%. Therefore, the actual minimum requirement of CAR facing by banks is 7% in all periods and even up to 9.5% in certain conditions.

Leverage Ratio The leverage ratio regulation is a non-risk-based capital requirement. It is calculated by dividing the amount of Tier 1 capital by the bank's average total consolidated assets(TA), which includes the exposures of all assets and non-balance sheet items. In other words, the leverage ratio is defined as

$$LR = \frac{CET1}{TA}. \tag{4}$$

The leverage ratio is introduced as a backstop to the risk-based capital adequacy ratio with the aim of constraining excess leverage in the banking system and providing an extra layer of protection against model risk and measurement error. Basel III requires the banks to maintain a leverage ratio in excess of 3%. A higher minimum leverage ratio is requested by the U.S. Federal Reserve for 8 Systemically important financial institution (SIFI) banks and their insured bank holding companies. It is argued by some that the simple leverage ratio is a much more reliable guide and predictor of actual bank default than the risk-based ratio (Alessandri and Haldane, 2011; Blundell-Wignall and Roulet, 2013).

In essence, the Basel III accord sets a minimum limit on the banks' holdings of high liquid assets and core capital, which serve as the credit base to guard against

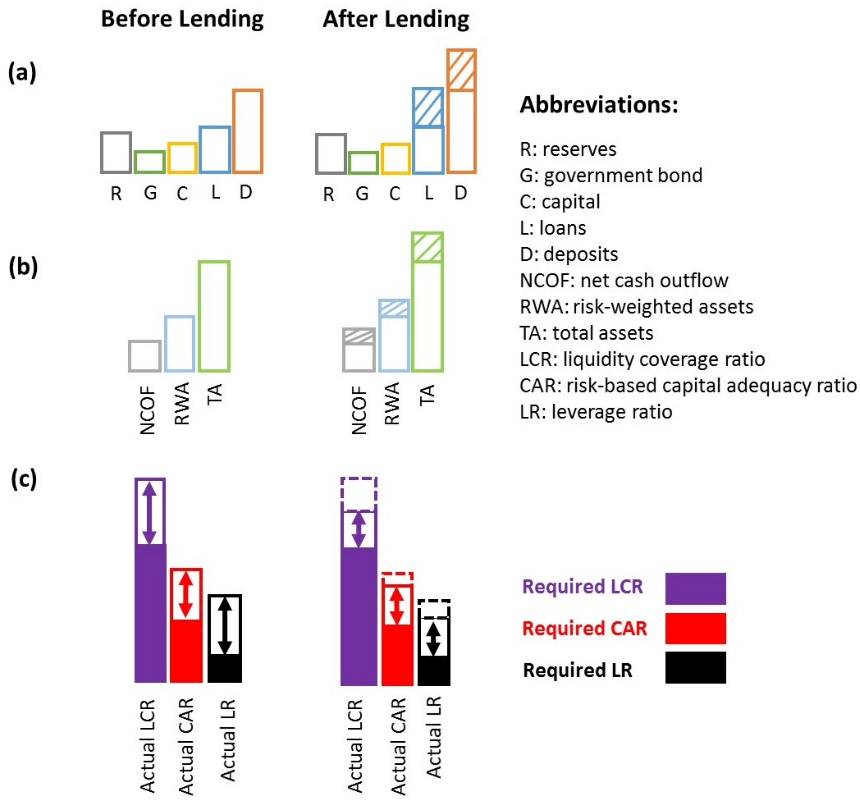

Figure 3: Changes in the components of bank balance sheet and monitor instruments under Basel III regulations after increasing the loan stock. (a) After making new loans in excess of due loan repayments, the stocks of loans and deposits increase while the stocks of reserves, government bonds and bank capital remain unchanged. (b) Along with the increase of the loan stock, banks are exposed to higher liquidity and solvency risks. As a result, the net cash outflow, risk-weighted assets and total assets rise accordingly. However, the amount of high quality liquid assets (including reserves and zero-risk-weight government bonds) and bank capital, which serve as the credit base for banks to guard against liquidity and solvency risks, do not change. (c) Because of the increasing denominators and the constant nominators, the actual liquidity coverage ratio, risk-based capital adequacy ratio and the leverage ratio drop and approach to their corresponding minimum requirements set by the Basel III regulations. Therefore, given no improvement of the bank's credit base, the implementation of prudential regulations casts a maximum limit for the amount of loans and deposits that can be created by the bank.

the liquidity and solvency risks for banks to conduct the business of borrowing short and lending long. However, it is often difficult for banks to improve their credit base in the short-term or without the help of external forces. While individual banks can adjust their holdings of the stock of high liquid assets, the available stock of high liquid asset for the banking system as a whole is fundamentally dependent on central bank policies. For the capital stock to grow, a bank has to issue additional common shares or accumulate retained earnings, which will impair the bank's profitability performance in terms of reduced return to equity or lower dividend payout ratio. Therefore, given the current level of the credit base, the credit creation ability of banks is constrained by the prudential regulations. Specifically, as illustrated in Fig. 3(a), when the lending flow exceeds the repayment flow, the stock of loans and deposits simultaneously increase. As a result, the amount of total assets rises. Meanwhile, the increase of the loan stock is accompanied by rising exposure to default risk, which results in higher quantity of risk-weighted assets. Similarly, higher liquidity risk comes with the increase of the deposit stock or other liabilities, which brings about larger expected net cash outflow. On the other hand, the amount of bank capital and that of high quality liquid assets such as reserves and government bonds with zero risk-weight are not directly affected by the behaviors of bank lending and loan repayment. In other words, compared to the fast easy expansion of the stocks of loans and deposits, changes in the banking system's liquidity and equity positions are much slower and more dependent on external forces. In consequence, as shown in Fig. 3(c), the actual liquidity coverage ratio, risk-based capital adequacy ratio and leverage ratio usually decrease along with the increase of loans and deposits. When these ratios reach or come close to the Basel III's minimum requirements, banks will be more cautious or stop the expansion of loans due to the high cost of breaching the regulation[5]. In other words, if there is no regulation, there is no theoretical limit for the credit supply of banks before massive defaults or funding flights kick in. But if given the minimum requirement of concerned prudential regulation and the current level of the bank's credit base and the risk conditions of its asset and liability, we can derive at a maximum limit for the loans and deposits that can be created by the bank.

3 The model

To demonstrate the impacts of Basel III regulations on the credit creation process, we employ a stock-flow consistent dynamical model modified based on the work of Li et al. (2017)[6]. We consider a representative commercial bank with a simplified

[5] In order to increase the actual LCR,CAR and LR, banks may also increase the share of safe or short-term loans and raising more stable funds. However, the effects of these actions are marginal compared with the overall quantity control of loans and deposits.

[6] Compared with the model in Li et al. (2017), we make a more realistic assumption about the commercial bank's balance sheet structure by considering bank capital and government bonds in addition to reserves, deposits and loans. Such extension allows us to explore the constraining effects of different prudential regulation including the LCR, CAR and LR regulations.

balance sheet shown in Table. 1. On the asset side, there are three items: reserves (R), government bonds with zero risk-weight (B) and loans (L) with an average risk-weight of γ. On the liability side, we only consider deposits (D) and bank capital (C). Following Krug et al. (2015), we do not make distinction between core capital Tier 1 and other capital.

To focus our analyses on the impacts of prudential regulations on commercial bank behaviors, we assume that the demand for loans is always larger than the supply of loans and that the interest rate is constant and profitable for the bank. In addition, due to the reasons mentioned in the last section, we suppose there is no change in bank's liquidity and equity positions in the short-run, i.e. the stocks of reserves, government bonds and bank capital are constant and exogenously given. Also, banks are assumed to hold no voluntary buffer above the minimum capital or liquidity requirements. With these assumptions, we abstract from the real economy, loan demand and the price effect of varying interest rate while keeping only the minimum elements necessary in the study of the constraining effect of Basel III on money creation. These simplifications allow us to focus on the complexity of the multi-polar prudential regulation framework itself, which includes the difference in the standalone impact of individual policy instrument and their complicated interactions when simultaneously imposed. Moreover, the adopted stock-flow consistent framework guarantees the consistency of our analyses with both the accounting principle and the law of stock-flow motion. These properties make it easier to integrate our findings in more complicated stock-flow consistent models such as the inspiring work of Caiani et al. (2016) where the banking sector is considered to be special and not deduced to a mere financial intermediary.

Table 1: A simplified balance sheet for a representative commercial bank

Asset	Liability
Reserves (R)	Deposits (D)
Government bonds (G)	
Loans (L)	Capital(C)

Suppose time is discrete and the unit of each time step is one month. Due to the accounting consistency, the following identity between assets and liabilities should always hold:

$$R(t)+G(t)+L(t)=D(t)+C(t). \tag{5}$$

The stocks of reserves, government bonds and bank capital are assumed to be constant and exogenously given. In other words,

$$R(t)=R, \tag{6}$$

$$G(t) = G = gR, \tag{7}$$

$$C(t) = C = cR, \tag{8}$$

where g is the ratio of government bonds to reserves and c is the ratio of bank capital to reserves.

At each time t, changes in the stock of loans and deposits are both governed by the difference between the new bank lending flow (LF) and the loan repayment flow (RP)[7], i.e.

$$L(t+1) - L(t) = LF(t) - RP(t), \tag{9}$$

$$D(t+1) - D(t) = LF(t) - RP(t). \tag{10}$$

For the initial period, we assume there is no loans ($L(1) = 0$) and $D(1) = L(1) + R(1) + G(1) - C(1) = R + G - C$. Because the amount of deposits cannot be negative, $R + G - C \geq 0$ must hold.

For simplicity, we also assume all loans are amortized with an average maturity of θ. In other words, a new loan made at month t', $LF(t')$, will be paid off at month $t' + \theta$. Thus the amount of repayment for this loan due at month t, denoted as $RP_{t'}(t)$, is

$$RP_{t'}(t) = \begin{cases} 0, t \neq t'+1, t'+2, \ldots, t'+\theta; \\ \frac{LF(t')}{\theta}, t = t'+1, t'+2, \ldots, t'+\theta. \end{cases} \tag{11}$$

Thus, the total repayment flow due at time t, $RP(t)$, can be computed as the sum of repayments due for all loans made in the past θ periods, which is given by

$$RP(t) = \begin{cases} 0, t = 1 \\ \sum_{t'=1}^{t-1} \frac{LF(t')}{\theta}, 1 < t < \theta; \\ \sum_{t'=t-\theta}^{t-1} \frac{LF(t')}{\theta}, t \geq \theta. \end{cases} \tag{12}$$

As articulated in Section 2, the bank's decision of making new loans is constrained by prudential regulations because the credit base cannot be increased in the short

[7] In addition to bank lending and loan repayment, the stock of deposits will also be changed by the flows of cash deposits and withdrawal. For simplicity we assumes no cash and focus on the behaviors of lending and repayment.

term. Let us denote L_{max} as the maximum loan stock for the bank to satisfy the minimum requirement of concerned prudential regulation given the current level of credit base and exposures to risk. Because we do not consider the bank's voluntary holding of additional credit base, the increment of the outstanding loan stock $L(t)$ should be no more than its difference with the maximum loan stock L_{max}, i.e.

$$L(t+1) - L(t) = LF(t) - RP(t) = \rho(L_{max} - L(t)), \tag{13}$$

where ρ ($\rho \in [0,1]$) controls the speed at which $L(t)$ approaches to L_{max}. From Equation 13, we can obtain the expression for the new lending flow as

$$LF(t) = RP(t) + \rho(L_{max} - L(t)). \tag{14}$$

When the dynamical model reaches the stock-flow equilibrium, all stocks and flows should be constant. Thus, supposing the system reaches equilibrium at time t^*, we should have $\forall t \geq t^*$,

$$L(t) = L^*, \tag{15}$$

$$D(t) = D^*, \tag{16}$$

$$LF(t) = RP(t) = LF^* = RP^*, \tag{17}$$

where L^*, D^*, LF^* and RP^* are respectively the equilibrium values of loans, deposits, the flow of new lending and the flow of repayment. Also, from Equations 14 and 17, we find that the equilibrium loan stock is at the maximum value permitted by the concerned prudential regulation, i.e.

$$L^* = L_{max}. \tag{18}$$

In addition, by manipulating Equations 9,12, 15 and 17 (details are shown in A), we can prove that

$$LF^* = RP^* = \frac{2}{1+\theta} L^*, \ t \geq t^*. \tag{19}$$

We assume there is no cash in our model, thus the monetary base MB is then equal to the amount of reserves, and the broad money supply M is hereafter the amount of deposits. Combining Equations 5,18, the broad money supply can be rewritten as a function of the maximum loan stock under the concerned prudential regulation as follows:[8]

$$M = R + G - C + L_{max}. \quad (20)$$

Correspondingly, based on Eqs. 6,7 and 8, the money multiplier m, defined as the ratio of the broad money supply and monetary base, is then given by

$$m = \frac{M}{MB} = 1 + g - c + \frac{L_{max}}{R}. \quad (21)$$

Henceforth, based on this model, we move on to examine the specific impacts of Basel III regulations on money creation.

4 Impacts of Basel III regulations

In this section, we will first analyze in Sec.4.1 the standalone effect of individual regulation on credit creation by deriving at the maximum limit on bank loans when only one regulatory instrument is imposed and solving for the corresponding equilibrium money supply and money multiplier. We will also briefly analyze the determinants of the money supply and the money multiplier in each condition. Then in Sec.4.2, we will inspect the collective impact of the simultaneous imposition of all policy instruments, identify which of them is the binding constraint and analyze how the corresponding money multiplier changes across different economic states and with varying bank balance sheet condition.

4.1 Standalone impact of individual regulations

The liquidity coverage ratio Assume the minimum requirement of LCR is r_{LCR}. The constraint in Equation 1 can be rewritten as

$$r_{LCR} * NCOF \leq HQLA. \quad (22)$$

Since only reserves and government bonds with zero risk-weight are qualified as high quality liquid assets in our model, we have

$$HQLA = R + G. \quad (23)$$

[8] Note that because we do not consider banks' voluntary holdings of excessive reserves and bank equities above the minimum prudential requirement, these expressions reflect the banking system's maximum ability to create money. Since our purpose is to evaluate the policy impact of the Basel III regulation on money creation rather than estimating the real values of the money supply and the money multiplier, we will focus on the relative changes of these values when the regulation of concern is different or when the economic condition varies.

As indicated in Equation 2, the net cash outflow is a function of the expected cash outflow and inflow within 30 days. In real world, the total expected cash outflows are calculated by multiplying the outstanding balances of various categories or types of liabilities and off-balance sheet commitments by the rates at which they are expected to run off or be drawn down, while the total expected cash inflows are calculated by multiplying the outstanding balances of various categories of contractual receivables by the rates at which they are expected to flow in. In our model, we assume the total cash outflow (OF) comes from the potential loss of deposits, which is given by

$$OF(t) = \mu D(t), \tag{24}$$

where μ is the run-off ratio of deposit loss to total deposits. The total cash inflow (IF) is supposed to be constituted by the expected loan repayment due in one month with a discount rate of 50%[9] due to the assumption of stressed condition, i.e.

$$IF(t) = 0.5RP(t). \tag{25}$$

According to the definition of net cash outflow in the LCR regulation (Equation 2), when the total expected inflow is not less than 75% of the total expected outflow, we have $NCOF(t) = OF(t) - 0.75OF(t) = 0.25OF(t)$; otherwise, the net cash outflow is the difference of outflow and inflow, that is, $NCOF(t) = OF(t) - IF(t)$. Putting these two conditions together with Equations 24 and 25, the following expression for the net cash outflow can be obtained:

$$NCOF(t) = \begin{cases} 0.25\mu D(t), IF(t) \geq 0.75OF(t); \\ \mu D(t) - 0.5RP(t), IF(t) < 0.75OF(t). \end{cases} \tag{26}$$

Next, let us consider the first condition, $IF(t) \geq 0.75OF(t)$, where the LCR regulation is equivalent to the following constraint:

$$0.25\mu r_{LCR} D(t) \leq R + G. \tag{27}$$

[9] According to the official document regarding the LCR regulation provided by the Basel committee(Basel Committee on Banking Supervision, 2013), different inflow rate are set by the Basel III accord for different types of bank assets. For instance, the accord requires that a bank should assume that maturing reverse repurchase or securities borrowing agreement secured by Level 1 assets (which corresponds to overnment bonds and bank reserves in our model) will be rolled-over and will not give rise to any cash inflows (0%). On the other hand, the inflow rate for non-HQLA assets varies from 0%-100% for different types of counterparties based on their abilities to fulfill debt obligations in stressed conditions. Here we take 50% as an exemplary inflow discount rate for the repayments received from outstanding bank loans. Discussions for relaxing this assumption are given in Appendix C.

Due to the accounting consistency in Equation 5, we can rewrite the above inequality as a function of $L(t)$:

$$0.25\mu r_{LCR}\left[R+G-C+L(t)\right] \leq R+G, \tag{28}$$

When Equation 28 takes equality, the bank's actual capital adequacy ratio reaches the minimum policy requirement and the loan stock achieves its maximum value, i.e. $L(t) = L_{max}$. With simple manipulations, it is easy to obtain that

$$L_{max} = (\frac{4}{\mu r_{LCR}} - 1)(R+G) + C. \tag{29}$$

Substituting Equation 29 into Equations 20 and 21, we have the equilibrium expressions for the broad money supply and money multiplier respectively as

$$M = \frac{4(R+G)}{\mu r_{LCR}}, \tag{30}$$

$$m = \frac{4}{\mu r_{LCR}}(1+\frac{G}{R}) = \frac{4(1+g)}{\mu r_{LCR}}. \tag{31}$$

From Equations 30 and 31, it is straightforward to show that

$$\frac{\partial M}{\partial R} = \frac{4}{\mu r_{LCR}} > 0, \tag{32}$$

$$\frac{\partial m}{\partial R} = -\frac{4G}{\mu r_{LCR} R^2} < 0. \tag{33}$$

In other words, in this situation, when the central bank raises the monetary base, the broad money supply will also increase, but not by a constant money multiplier. Instead, the money multiplier drops with the increase of reserves.

Additionally, it can be inferred from Equation 30 that $\frac{\partial M}{\partial G} > 0$, which demonstrates the positive dependence of the money supply on the amount of government bonds with zero-risk weight. Also, we find that both the the money supply and the money
on the deposit run-off ratio μ so that $\frac{\partial M}{\partial r_{LCR}} < 0, \frac{\partial m}{\partial r_{LCR}} < 0, \frac{\partial M}{\partial \mu} < 0, \frac{\partial m}{\partial \mu} < 0$.

In the second condition where $IF(t) < 0.75OF(t)$, considering Equations 23 and 26, the LCR regulation in Equation 22 takes the following form:

$$r_{LCR}[\mu D(t) - 0.5RP(t)] \leq R+G. \tag{34}$$

Similarly, when $L(t) = L_{max}$, the above inequality takes equality. Based on Equations 17,19 and 18, we know that $\forall t \geq t^*, RP(t) = \frac{2}{1+\theta} L_{max}$. Also, from Equation 5,16 and 18, we can have $\forall t \geq t^*, D(t) = R + G - C - L_{max}$. By substituting the expressions of $RP(t)$ and $D(t)$ in terms of L_{max} into Equation 34 with a few manipulations, we can obtain the expression for the maximum loan stock as follows:

$$L_{max} = \frac{(1+\theta)\left[(R+G)(1-\mu r_{LCR}) + \mu r_{LCR} C\right]}{r_{LCR}[\mu(1+\theta)-1]}. \tag{35}$$

As a result, the equilibrium money supply and money multiplier are respectively given by

$$M = \frac{(R+G)(1+\theta-r_{LCR}) + r_{LCR} C}{r_{LCR}[\mu(1+\theta)-1]}, \tag{36}$$

$$m = \frac{(1+\frac{G}{R})(1+\theta-r_{LCR}) + r_{LCR}\frac{C}{R}}{r_{LCR}[\mu(1+\theta)-1]} = \frac{(1+\theta)\left[(1+g)(1-\mu r_{LCR}) + \mu r_{LCR} c\right]}{r_{LCR}[\mu(1+\theta)-1]}. \tag{37}$$

Correspondingly,

$$\frac{\partial M}{\partial R} = \frac{1+\theta-r_{LCR}}{r_{LCR}[\mu(1+\theta)-1]} > 0, \tag{38}$$

$$\frac{\partial m}{\partial R} = -\frac{(1+\theta-r_{LCR})G + r_{LCR} C}{r_{LCR}[\mu(1+\theta)-1]R^2} < 0, \tag{39}$$

which indicates that after a positive shock to the monetary base, the broad money supply will increase, but the size of the increment decreases with the scale of reserves. Again the money multiplier is not a constant as in the case where the banking system is only regulated by the reserve requirement. In addition, both the money supply and money multiplier respond negatively to the increase of the minimum requirement of LCR ($\frac{\partial M}{\partial r_{LCR}} < 0, \frac{\partial m}{\partial r_{LCR}} < 0$).

Furthermore, we find that the money supply is not only a increasing function of the bank's holdings of government bonds ($\frac{\partial M}{\partial G} > 0$), but also the amount of capital ($\frac{\partial M}{\partial C} > 0$). Like reserves, government bonds are high quality liquid assets that contribute to the bank's resilience against maturity mismatch. Bank capital, on the other hand, serve as the non-debt financing source that is not exposed to liquidity risk and as the signal of the bank's health for its creditors. Therefore, other things equal, well capitalized banks are able to have more expected cash inflow and less outflow in a liquidity stressed condition than low-capital banks. In other words, the banking system's ability to create money is higher when it holds more capital.

Apart from the amount of high quality liquid assets and bank capital, we can see from $\frac{\partial M}{\partial \mu} < 0, \frac{\partial M}{\partial \theta} < 0, \frac{\partial m}{\partial \mu} < 0, \frac{\partial m}{\partial \theta} < 0$ that the reduction of the bank's exposure to liquidity risk, either due to more stable debt financing source or the shortening of the average maturity of loans, will also lead to increases in both the money supply and the money multiplier.

Because the expressions for the expected cash inflow and IF^* and OF^* in the equilibrium are respectively

$$IF^* = 0.5RP^* = \frac{L^*}{1+\theta}, \tag{40}$$

$$OF^* = \mu D^*, \tag{41}$$

we can rewrite the conditions of $IF^* \geq 0.75OF^*$ and $IF^* < 0.75OF^*$ as a function of μ, θ, g, c following the manipulations shown in B. In specific, the two conditions are respectively equivalent to $\mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}$ and $\mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}$.

In summary, the full expressions for the equilibrium money supply and money multiplier are respectively given by

$$M_{LCR} = \begin{cases} \frac{4(R+G)}{\mu r_{LCR}}, \ \mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}; \\ \frac{(R+G)(1+\theta-r_{LCR})+r_{LCR}C}{r_{LCR}[\mu(1+\theta)-1]}, \ \mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}, \end{cases} \tag{42}$$

$$m_{LCR} = \begin{cases} \frac{4(1+g)}{\mu r_{LCR}}, \ \mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}; \\ \frac{(1+g)(1+\theta-r_{LCR})+r_{LCR}c}{r_{LCR}[\mu(1+\theta)-1]}, \ \mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}. \end{cases} \tag{43}$$

The risk-based capital adequacy ratio For simplicity, our model does not distinguish the quality of bank capital and assumes all capital are qualified in the calculation of the risk-based capital adequacy ratio. Denoting r_{CAR} as the minimum policy requirement, we can have the following expression for the CAR regulation:

$$C(t) \geq r_{CAR} * RWA(t), \tag{44}$$

where $C(t) = C$ and the amount of risk-weighted assets RWA is computed as the product of bank assets and their corresponding risk-weight, as given by

$$RWA(t) = 0 * (R+G) + \gamma L(t) = \gamma L(t). \tag{45}$$

When Equation 44 takes equality, the banking system reaches its maximum credit creation ability, which yields

$$L_{max} = \frac{C}{\gamma r_{CAR}}. \tag{46}$$

Substituting Equation 46 into Equations 20 and 21, we have the equilibrium expressions for the money supply and the money multiplier as follows:

$$M_{CAR} = R + G + (\frac{1}{\gamma r_{CAR}} - 1)C. \tag{47}$$

$$m_{CAR} = 1 + \frac{G}{R} + (\frac{1}{\gamma r_{CAR}} - 1)\frac{C}{R} = 1 + g + (\frac{1}{\gamma r_{CAR}} - 1)c. \tag{48}$$

Furthermore, it can be demonstrated that

$$\frac{\partial M_{CAR}}{\partial R} = 1 > 0, \tag{49}$$

$$\frac{\partial m_{CAR}}{\partial R} = -\frac{G + (\frac{1}{\gamma r_{CAR}} - 1)C}{R^2} < 0. \tag{50}$$

Similar as in the case of LCR regulation, the broad money supply is an increasing function of the monetary base whereas the money multiplier is a decreasing function of the monetary base. As indicated by $\frac{\partial M_{CAR}}{\partial R} = 1$, the increase of reserves will not have any multiplier effect on the broad money supply.

In addition, the broad money supply is positively dependent on the amount of government bonds and bank capital ($\frac{\partial M}{\partial G} > 0$, $\frac{\partial M}{\partial C} > 0$). Moreover, we can see that the values of money supply and money multiplier also depend on the average default risk of bank loans (γ) and the minium policy requirement of CAR (r_{CAR}) in that $\frac{\partial M}{\partial \gamma} < 0$, $\frac{\partial m}{\partial \gamma} < 0$, $\frac{\partial M}{\partial r_{CAR}} < 0$, $\frac{\partial m}{\partial r_{CAR}} < 0$.

The leverage ratio With the minimum requirement of leverage ratio being r_{LR}, the bank faces the following constraint:

$$C(t) \geq r_{LR} * TA(t), \tag{51}$$

where $C(t) = C$ and $TA(t) = R + G + L(t) = D(t) + C$. When the equality is taken, the loan stock reaches its maximum limit, which is given by

$$L_{max} = \frac{C}{r_{LR}} - R - G. \tag{52}$$

Correspondingly, the equilibrium money supply and money multiplier are

$$M_{LR} = (\frac{1}{r_{LR}} - 1)C, \tag{53}$$

$$m_{LR} = (\frac{1}{r_{LR}} - 1)\frac{C}{R} = (\frac{1}{r_{LR}} - 1)c. \tag{54}$$

The responses of money supply and money multiplier to reserve shocks are respectively given by

$$\frac{\partial M_{LR}}{\partial R} = 0, \tag{55}$$

$$\frac{\partial m_{LR}}{\partial R} = -(\frac{1}{r_{LR}} - 1)\frac{C}{R^2} < 0. \tag{56}$$

As shown by Equation 53, the determinants of the broad money supply only include the minimum policy requirement of LR and the amount of bank capital. Thus, the only way to increase the money supply under the given LR regulation is to increase the amount of bank capital ($\frac{\partial M_{LR}}{\partial C} > 0$). In other words, rising the monetary base will have no impact on the banking system's broad money supply and the only consequence of this action is the reduction of the money multiplier.

Heretofore, we have examined the standalone impact of each individual regulation on the bank's ability to lend and create money. To conclude, we summarize these results in Table 2. We find that 1) the tightening of both the prudential requirements and the reserve requirement will have a negative impact on the banking system's ability to create money; and 2) in contrast to the constant money multiplier based on the reserve requirement, the money multiplier under the Basel III accord is a decreasing function of the monetary base and the broad money supply may or may not expand when there is a positive shock to the monetary base; and 3) due to the different constraining effects of different regulations to which the bank is subject, the money creation process are sensitive to different types of economic changes. For instance, the variation of the level of bank capitals can affect the money supply and the money multiplier only when the banking system is constrained by capital-based requirements of the CAR and the LR regulations. On the other hand, the stability of the bank's debt-based financing source and the maturity structure of loans only matter when the LCR regulation is taking effect.

Table 2: Comparison of the standalone impact of Basel III regulations with the reserve requirement on money creation

	Reserve requirement	LCR regulation	CAR regulation	LR regulation
Purpose	monetary control and prudential purpose[10]	prevent the liquidity risk due to maturity mismatch	prevent the insolvency risk due to loan default	encourage deleverage and limit balance sheet expansion
Means	$\frac{D}{R} \geq r_{RR}$[11]	$\frac{HQLA}{NCOF} \geq r_{LCR}$	$\frac{C}{RWA} \geq r_{CAR}$	$\frac{C}{TA} \geq r_{LR}$
Equilibrium expression for money supply	$M_{RR} = \frac{R}{r_{RR}}$	$M_{LCR} = \begin{cases} \frac{4(R+G)}{\mu r_{LCR}}, \ \mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}; \\ \frac{(R+G)(1+\theta-r_{LCR})+C}{r_{LCR}[\mu(1+\theta)-1]}, \ \mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}. \end{cases}$	$M_{CAR} = R+G+(\frac{1}{\gamma r_{CAR}}-1)C.$	$M_{LR} = (\frac{1}{r_{LR}}-1)C.$
Equilibrium expression for money multiplier	$m_{RR} = \frac{1}{r_{RR}}$	$m_{LCR} = \begin{cases} \frac{4(1+g)}{\mu r_{LCR}}, \ \mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}; \\ \frac{(1+g)(1+\theta-r_{LCR})+cr_{LCR}}{r_{LCR}[\mu(1+\theta)-1]}, \ \mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}. \end{cases}$	$m_{CAR} = 1+g+(\frac{1}{\gamma r_{CAR}}-1)c.$	$m_{LR} = (\frac{1}{r_{LR}}-1)c.$
Response of money supply and money multiplier to the shock to monetary base	$\frac{\partial M_{RR}}{\partial R} > 0, \frac{\partial m_{RR}}{\partial R} = 0.$	$\frac{\partial M_{LCR}}{\partial R} > 0, \frac{\partial m_{LCR}}{\partial R} < 0.$	$\frac{\partial M_{CAR}}{\partial R} > 0, \frac{\partial m_{CAR}}{\partial R} < 0.$	$\frac{\partial M_{LR}}{\partial R} = 0, \frac{\partial m_{LR}}{\partial R} < 0.$
Response of money supply and money multiplier to the shock to the concerned minimum policy ratio	$\frac{\partial M_{RR}}{\partial r_{RR}} < 0, \frac{\partial m_{RR}}{\partial r_{RR}} < 0.$	$\frac{\partial M_{LCR}}{\partial r_{LCR}} < 0, \frac{\partial m_{LCR}}{\partial r_{LCR}} < 0.$	$\frac{\partial M_{CAR}}{\partial r_{CAR}} < 0, \frac{\partial m_{CAR}}{\partial r_{CAR}} < 0.$	$\frac{\partial M_{LR}}{\partial r_{LR}} < 0, \frac{\partial m_{LR}}{\partial r_{LR}} < 0.$
Other determinants of money supply	NA	$\frac{\partial M_{LCR}}{\partial \mu} < 0, \frac{\partial M_{LCR}}{\partial G} > 0;$ $\frac{\partial M_{LCR}}{\partial C} > 0, \frac{\partial M_{LCR}}{\partial \theta} < 0, if\ IF < 0.75 * OF.$	$\frac{\partial M_{CAR}}{\partial G} > 0, \frac{\partial M_{CAR}}{\partial C} > 0,$ $\frac{\partial M_{CAR}}{\partial \gamma} < 0.$	$\frac{\partial M_{LR}}{\partial C} > 0.$
Other determinants of money multiplier	NA	$\frac{\partial m_{LCR}}{\partial \mu} < 0, \frac{\partial m_{LCR}}{\partial g} > 0;$ $\frac{\partial m_{LCR}}{\partial g} < 0, \frac{\partial m_{LCR}}{\partial c} > 0, if\ IF < 0.75 * OF.$	$\frac{\partial m_{CAR}}{\partial g} > 0, \frac{\partial m_{CAR}}{\partial c} > 0,$ $\frac{\partial m_{CAR}}{\partial \gamma} < 0.$	$\frac{\partial m_{LR}}{\partial c} > 0.$

[10] Monetary control: changing the required reserve ratio may restrict commercial bank balance sheet growth when reserve money cannot easily be increased, and may influence the spread between deposit and lending rates and thus impact the growth of monetary aggregates and thus inflation; Prudential purpose: reserves provide protection against both liquidity risk. See Simon (2011) for more discussion about the purpose of the reserve requirement.

[11] r_{RR} is the minimum required reserve ratio.

4.2 Collective impact of multiple regulations under different economic conditions

> "Regulatory measures must build upon each other and be interlocked to set consistent incentives. Otherwise, we run the risk of individual measures conflicting with each other. Such a lack of consistency might lessen the desired effects of the new regulations or even negate them entirely. Impact studies are an important tool in this context. "
>
> —Dombret (2013), Member of the Executive Board of the Deutsche Bundesbank

Up till now, we have obtained the equilibrium expressions for the broad money supply and the money multiplier when the bank only face one regulation. However, without a comprehensive analysis when multiple policy instruments simultaneously take effects, the evaluation of the impacts of Basel III on money creation is incomplete. When the bank is subject to more than one prudential regulations, its credit creation capacity is binded by the most stringent constraint. Therefore, by comparing the values of the money multiplier derived for each individual instrument in Equations 43,48 and 54 and solving for the minimum money multiplier, we can determine the effective binding regulation and obtain the corresponding expression for the money multiplier when multiple regulations are imposed at the same time, i.e.

$$m = min\{m_{LCR}, m_{CAR}, m_{LR}\}. \tag{57}$$

Correspondingly, the boundary conditions that mark the transitions of the binding constraint can be derived when the expressions for the money multiplier corresponding to either two regulations take the same value. In specific, the boundary condition between the LCR and CAR regulations is

$$\begin{aligned} \frac{4(1+g)}{\mu r_{LCR}} &= 1+g+(\frac{1}{\gamma r_{CAR}}-1)c, \\ or\ \frac{(1+g)(1+\theta-r_{LCR})+cr_{LCR}}{r_{LCR}[\mu(1+\theta)-1]} &= 1+g+(\frac{1}{\gamma r_{CAR}}-1)c. \end{aligned} \tag{58}$$

The boundary condition between the LCR and LR regulations is

$$\begin{aligned} \frac{4(1+g)}{\mu r_{LCR}} &= (\frac{1}{r_{LR}}-1)c, \\ or\ \frac{(1+g)(1+\theta-r_{LCR})+cr_{LCR}}{r_{LCR}[\mu(1+\theta)-1]} &= (\frac{1}{r_{LR}}-1)c. \end{aligned} \tag{59}$$

The boundary condition between the CAR and LR regulations is

$$1+g+(\frac{1}{\gamma r_{CAR}}-1)c = (\frac{1}{r_{LR}}-1)c. \tag{60}$$

For the two expressions for LCR regulation to take identity,

$$\frac{4(1+g)}{\mu r_{LCR}} = \frac{(1+g)(1+\theta - r_{LCR}) + c r_{LCR}}{r_{LCR}[\mu(1+\theta)-1]}. \tag{61}$$

Due to the mathematical complexity of the expression for the money multiplier in Equation 57, we set $r_{LCR} = 100\%, r_{CAR} = 7\%, r_{LR} = 3\%$ in the following analyses and use Fig. 4 as the major illustration for analysis. By setting the monetary base to be constant, we focus on the transitions of the effective binding regulation and the relative changes in the equilibrium values of the money multiplier across different economic states and bank balance sheet conditions.

To begin with, we categorize the concerning variables into two groups. The first group includes the variables that determine the features of the bank's uses of funds: the average maturity of loans θ and the average default risk of loans γ. The second group contains variables that characterize the bank's sources of funds: the average run-off ratio of bank liabilities μ and the capital to reserve ratio c. For the uses of funds, loans with longer maturity θ and higher default risk γ are often associated with higher profits. Nevertheless, these loans will also expose the bank to greater probabilities of maturity mismatch and insolvency problems. For the source of funds, the debt-financing source is usually stable during good times (low μ) and becomes flighty during economic downturns (high μ). The amount of bank capital, on the other hand, depends on how the bank makes a balance between profitability performance and risk resilience, and on how difficult to raise new equity.

Based on these reasoning, we vary the average maturity θ and default risk γ and show them respectively in the horizontal and vertical axes in all panels in Fig. 4. Correspondingly, the equilibrium values of the money multiplier are presented in color. To discuss the features of the bank's financing sources, we consider three scenarios: 1) the bank holds high level of capital $c = 2$ and faces low run-off ratio of debt financing $\mu = 0.1$; and 2) the bank holds low level of capital $c = 0.8$ and faces low run-off ratio of debt financing $\mu = 0.1$; and 3) the bank holds high level of capital $c = 2$ and faces high run-off ratio of debt financing $\mu = 0.55$. For all scenarios, the government bonds to reserve ratio g is kept fixed and equal to 3. Choice of the values of parameter c in these examples is made based on the statistics of the U.S. banking system in the from 1992 to 2009 as shown in Table 3. The exemplary values of parameter μ are determined based on the estimated run-off ratios for different types of liabilities listed in the official document from the Basel Committee on the liquidity coverage ratio regulation (Basel Committee on Banking Supervision, 2013). It is noteworthy that these scenarios are representative cases while there are other scenarios where the interactions of the three prudential regulations and the values for the money multipliers are different. Yet such differences are in scale, not in type, which will not lead to qualitative changes in our conclusions. Next, we will base our analysis on these three scenarios and demonstrate how the binding regulation changes with economic situation and how the bank's credit creation ability is affected.

Fig. 4(a) presents the benchmark case for Scenario 1 where all three regulations can be the effective binding constraint when the default risk of loans γ varies from 0 to 1 and the average loan maturity θ changes from 1 month to 15 years. When the default risk of loans is high, the bank is binded by the CAR regulation. When the default risk is relative low and average loan maturity is long, the LCR regulation takes effect. When the assets are both low in risk and short in maturity, the LR regulation serves as a backstop constraint on money creation. Also, in consistency with our result on the dependence of the money multiplier on loan maturity and default risk for individual regulations, the money multiplier drops when the bank holds assets with longer maturity and higher default risk. However, due to the piece-wise expression of the money multiplier, the same increment in θ and γ when their values are at different levels may have distinct effects on the value of the multiplier.

In Scenario 2, there is no change in the bank's debt-based financing source but the level of bank capital is much lower than that in Scenario 1. As a result, the capital constraint becomes the bank's biggest concern. As shown in Fig. 4(b), only capital requirements are taking effect. The CAR and LR regulations are respectively responsible for the situations of higher and lower default risk. Compared to the first scenario, the bank's ability to create money significantly drops with the decrease of its capital holdings, as indicated by the lower values of the money multiplier for the same default risk and loan maturity combination in Fig. 4(b) than (a). The money multiplier is negatively dependent on the default risk whereas it is unaffected by changes in the average maturity of loans.

In addition, Fig. 4(c-d) demonstrates the changes of the money multiplier in Scenario 3 where bank capital is sufficient but the run-off ratio of the bank's debt-based fundings is high. In this scenario, regardless of the average maturity and risk of loans, the bank is binded only by the LCR regulation. This result corresponds to the phenomenon of extreme liquidity shortage in the economic downturn when the roll-over of short term debt financing like wholesale funding are unlikely to happen or when depositors or other debtors for the bank start to withdraw funds due to risk aversion during market panic. Even though the bank's capital holdings are still high, we can observe a significant decrease of the money multiplier in Fig. 4(c-d) compared to Fig. 4(a) due to the instability of its debt financing. Moreover, the money multiplier under this situation is only dependent on the length of loan maturity yet such dependence is a discrete function due to the piece-wise definition of the net cash outflow in LCR regulation. To have better illustration, we show the values of the money multiplier under LCR regulation for loan with maturity less than 6 months in (c) and higher than 6 months in (d).

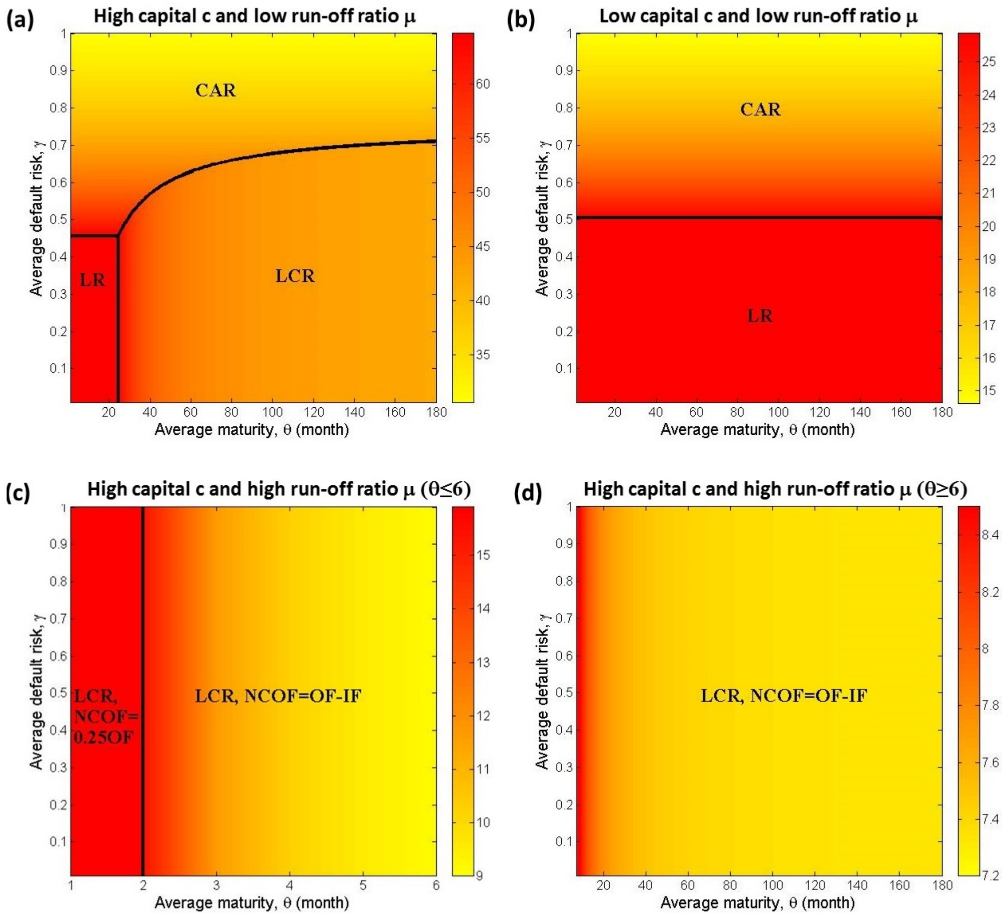

Figure 4: Binding regulations and corresponding values of the equilibrium money multiplier as a function of the average default risk γ ($\gamma \in [0,1]$) and the average maturity θ ($\theta \in [1,180]$) of loans under three representative scenarios with different combinations of the capital-to-reserve ratio c and the deposit run-off ratio μ. The values of the money multiplier are computed according to Equation 57 and indicated by color with red representing high values and yellow representing low values. Boundaries between different binding regulations are computed based on Equations 58,59,60,61 and presented by black lines that separate the state space of γ and θ. (a) Scenario 1: the bank holds high level of capital with $c = 2$ and faces low run-off ratio $\mu = 0.1$. In this case, all three regulations can be observed in the parameter space of the maturity length θ and default risk γ of loans. (b) Scenario 2: the bank faces low run-off ratio $\mu = 0.1$ but holds low level of capital $c = 0.8$. Only capital requirements can be observed in the parameter space. (c-d) Scenario 3: The bank holds high level of capital $c = 2$ but faces high liability run-off ratio $\mu = 0.55$ with (c) demonstrating results for maturity less than 6 months and (d) for maturity larger than 6 months. All results are obtained for $g = 3$. In both (c) and (d), the LCR regulation alone takes effect. In all three scenarios, the money multiplier is generally higher with high capital holdings, low run-off ratio, low default risk and short maturity length.

As shown in Fig. 4(c), when the average loan maturity is extremely short, i.e. less than 2 months, the net cash outflow is solely determined by the expected cash outflow. In this case, the money multiplier is independent of the average loan maturity and the loan default risk and is generally lower than Scenario 1 and 2. When the average loan maturity is larger than 2 months (Fig. 4(d)), the net cash outflow is governed by the difference between the total cash outflow and cash inflow. In this case, the bank faces large loss in its funding source, and at the same time, have trouble in claiming its own funds back. The money multiplier is a decreasing function of the average loan maturity: for an average maturity of 6 months, the money multiplier has already decreased to less than 9, which is $1/6$ of the maximum value in Scenario 1. Nevertheless, the decline in the multiplier due to the increment of loan maturity for more than 6 months is extremely marginal.

To summarize, when multiple prudential regulations are simultaneously taking effect, we find that 1) the effective binding regulation, by which the bank's ability to create money is constrained, varies across different economic states and bank balance sheet conditions; and 2) due to the transition of the effective binding regulation, the money multiplier depends on the parameters related to the economic state and bank balance sheet condition in a nonlinear way; and 3) in general, the money multiplier gets higher when the banking system holds higher level of capital, assets with shorter maturity and lower default or depreciation risk, and more stable debt-based financing source.

5 Concluding remarks

The aim of the Basel III accord is to improve the resilience of the banking system and prevent future crisis. However, it also bears the cost of restricting financial activities and downsizing the loan and money supply by the banking system. This paper focused on the immediate impact of the Basel III accord on the money creation process and provided a comprehensive analysis for the three pillar regulations in the Basel accord, including not only the enhanced risk-based capital adequacy regulation but also the requirements on the leverage ratio and the liquidity coverage ratio. Using both graphical illustration and a dynamic stock-flow consistent model, we elaborated on the central roles of commercial banks in money creation and the mechanism through which prudential regulations affect bank lending and money supply.

For each prudential regulation, we studied their standalone impact on money creation by obtaining the equilibrium expressions for the broad money supply and money multiplier and analyzing their corresponding determinants. We found that the money multiplier, instead of being constant as assumed in the traditional FRT, is a decreasing function of the monetary base under all three prudential regulations.

This result is consistent with the empirical observations of the plumbing of the money multiplier after the recent implementation of the QE policy (Goodhart et al., 2013). In addition, we demonstrated that the determinants of the banking system's capacity of money creation are regulation-specific, due to the differences in the mechanisms through which different prudential regulations take effect. Specifically, under the LCR regulation, the loosening of the minimum requirement of LCR, the shortening of loan maturity, the enhancement of the stability of the bank's debt financing source, the increase in the bank's holdings of bank capital and government bonds are all possible causes for the increase of the money supply. Under the CAR regulation, what affects the money creation process includes the minimum requirement of CAR, the default risk of loans, the amount of bank capital and government bonds. Lastly, the money supply under the LR requirement alone is solely dependent on the bank's capital holdings. In other words, when the bank only faces the LR regulation, increasing the monetary base will have no impact on the broad money supply. This result echoes the work of Martin et al. (2016) which demonstrate several scenarios where changes in bank reserves will have no or even negative impact on the bank's credit supply.

In the more complicated analysis, we considered the simultaneous imposition of all three regulations and how their interactions make a difference in the money creation process. Because the bank's capacity of money creation is binded by the most rigid constraint, the money multiplier under the collective influences of multiple regulations is obtained as the minimum value of the multipliers under each individual regulation, given the same monetary base and other things equal. For three representative scenarios of different financing source conditions for the bank, we demonstrated the transitions of the effective binding regulation and the corresponding changes in the money multiplier when there are variations in the risk and maturity structure of the bank's uses of funds. We found that the money creation capacity of the banking system is generally greater when its sources of funds contain sufficient capital and stable liabilities and its uses of funds are less risky and have short maturity. However, due to the dependence of the effective binding regulation and money multiplier on the economic state and bank balance sheet condition, the same policy action may have distinct consequences in different scenarios, which calls for cautiousness of the policy makers in choosing the appropriate policy instrument.

To sum up, this paper is inspired by the pioneering works on rethinking the roles of the banking system in money creation. We contribute to this line of thoughts by emphasizing the important roles of prudential regulation in money creation and by delineating why and how these regulations take effect. In addition, by providing a detailed theoretical analysis of how Basel III regulations impact on money creation, our work lays the foundation for more complicated studies on the macroeconomic impact of Basel III on economic growth. The results of this paper can be used as a reference for policy makers who attempt to make adjustment to current prudential regulations or utilize monetary policies to compensate the constraining effect of the Basel III accord on money supply.

Lastly, although the simplicity of the model is considered as a merit in the current analysis, it is also important to be aware of its limitations, including the assumption of representative bank, abstractions of interest rate and non-passive response of other economic entities. An extension of the model into more general stock-flow consistent models incorporating heterogeneous agents and more serious data calibration would be a fruitful possibility for future research.

Appendix

A Derivation of Equation 19

Combining Equations 9 and 12, we have

$$
\begin{aligned}
L(2)-L(1) &= LF(1)-RP(1)=LF(1),\\
L(3)-L(2) &= LF(2)-RP(2)=LF(2)-\tfrac{1}{\theta}LF(1),\\
L(4)-L(3) &= LF(3)-RP(3)=LF(3)-\tfrac{1}{\theta}[LF(2)+LF(1)],\\
&\vdots\\
L(\theta+1)-L(\theta) &= LF(\theta)-RP(\theta)=LF(\theta)-\tfrac{1}{\theta}[LF(\theta-1)+LF(\theta-2)+\ldots+LF(1)],\\
L(\theta+2)-L(\theta+1) &= LF(\theta+1)-RP(\theta+1)=LF(\theta+1)-\tfrac{1}{\theta}[LF(\theta)+LF(\theta-1)+\ldots+LF(1)],\\
L(\theta+3)-L(\theta+2) &= LF(\theta+2)-RP(\theta+2)=LF(\theta+2)-\tfrac{1}{\theta}[LF(\theta+1)+LF(\theta)+\ldots+LF(2)],\\
&\vdots\\
L(t-1)-L(t-2) &= LF(t-2)-RP(t-2)=LF(t-2)-\tfrac{1}{\theta}[LF(t-3)+LF(t-4)+\ldots+LF(t-\theta-2)],\\
L(t)-L(t-1) &= LF(t-1)-RP(t-1)=LF(t-1)-\tfrac{1}{\theta}[LF(t-2)+LF(t-3)+\ldots+LF(t-\theta-1)].
\end{aligned}
$$

Summing these equations up, we have

$$
L(t)-L(1)=\begin{cases} L(t-1)+\frac{\theta-1}{\theta}LF(t-2)+\ldots+\frac{1}{\theta}LF(t-1), 2\le t\le\theta+1;\\ L(t-1)+\frac{\theta-1}{\theta}LF(t-2)+\ldots+\frac{1}{\theta}LF(t-\theta), t\ge\theta+1.\end{cases} \tag{62}
$$

With $L(1)=0$, Equation 62 can be rewritten as

$$
L(t)=\begin{cases}\sum_{t'=1}^{t-1}\frac{\theta-t'+1}{\theta}LF(t-t'), 2\le t\le\theta+1;\\ \sum_{t'=1}^{\theta}\frac{\theta-t'+1}{\theta}LF(t-t'), t\ge\theta+1.\end{cases} \tag{63}
$$

Combining Equation 63 with Equation 15 and 17, we have : $\forall t \geq t^* \geq \theta+1$,

$$L(t) = L^* = \sum_{t'=1}^{\theta} \frac{\theta - t' + 1}{\theta} LF(t) = \frac{1+\theta}{2} LF^* = \frac{1+\theta}{2} RP^*. \tag{64}$$

In other words,

$$LF(t) = RP(t) = LF^* = \frac{2}{1+\theta} L^*, t \geq t^*. \tag{65}$$

B Rewriting the conditions of $IF^* \geq 0.75OF^*$ and $IF^* < 0.75OF^*$ as a function of μ, θ, g and c

For the first condition, $IF \geq 0.75OF$, we should have

$$\begin{aligned} &\frac{L^*}{1+\theta} \geq 0.75\mu D^* \\ \Rightarrow &\frac{D^* - (R+G-C)}{1+\theta} \geq 0.75\mu D^* \\ \Rightarrow &[1-0.75\mu(1+\theta)]D^* \geq R+G-C. \end{aligned} \tag{66}$$

For Equation 66 to hold, we should always have $1-0.75\mu(1+\theta) > 0$, i.e. $\mu < \frac{4}{3(1+\theta)}$. Substituting the corresponding expression for the equilibrium deposits under this condition, $D^* = \frac{4(R+G)}{\mu r_{LCR}}$, into Equation 66, we have

$$\begin{aligned} &[1-0.75\mu(1+\theta)]\frac{4(R+G)}{\mu r_{LCR}} \geq R+G-C \\ &\Rightarrow \mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g) - cr_{LCR}}, \end{aligned} \tag{67}$$

where $\frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}} < \frac{4}{3(1+\theta)}$ always holds because

$$\begin{aligned} &\frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g) - cr_{LCR}} - \frac{4}{3(1+\theta)} \\ = &\frac{4r_{LCR}(c-1-g)}{3(1+\theta)[(3\theta+3+r_{LCR})(1+g) - cr_{LCR}]} < 0. \end{aligned} \tag{68}$$

Therefore, the first condition of $IF \geq 0.75OF$ is equivalent to $\mu \leq \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}$. Correspondingly, the second condition of $IF < 0.75OF$ can be replaced by $\mu > \frac{4(1+g)}{(3\theta+3+r_{LCR})(1+g)-cr_{LCR}}$.

C The more generalized expressions for the money supply and money multiplier under the LCR regulation after relaxing the assumption of 50% inflow rate for bank loans

This assumption of 50% inflow rate for bank loans used in Equation 25 can be relaxed by the following equation:

$$IF(t) = \omega * RP(t), \tag{69}$$

where ω is denoted as the inflow rate of the repayments for outstanding bank loans. ω is generally higher when the counterparty to which bank loans are made has higher credit ratings and can successfully fulfil its debt obligations in stressed condition. Following similar procedures elaborated in Section 4.1, we can obtain the corresponding expressions for the money supply M and money multiplier m when the bank is constrained by the LCR regulation, i.e.

$$M_{LCR} = \begin{cases} \frac{4(R+G)}{\mu r_{LCR}}, \ \mu \leq \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \frac{(R+G)(1+\theta-2\omega r_{LCR})+2\omega r_{LCR}C}{r_{LCR}[\mu(1+\theta)-2\omega]}, \ \mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}. \end{cases} \tag{70}$$

$$m_{LCR} = \begin{cases} \frac{4(1+g)}{\mu r_{LCR}}, \ \mu \leq \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}; \\ \frac{(1+g)(1+\theta-2\omega r_{LCR})+2\omega c r_{LCR}}{r_{LCR}[\mu(1+\theta)-2\omega]}, \ \mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}. \end{cases} \tag{71}$$

It is straightforward to know that if $\mu > \frac{8\omega(1+g)}{(3\theta+3+2\omega r_{LCR})(1+g)-2\omega c r_{LCR}}$ (i.e. $IF < 0.75 * OF$), then $\frac{\partial M}{\partial \omega} > 0$, $\frac{\partial m}{\partial \omega} > 0$. In other words, if bank loans are made to borrowers with higher credit ratings who can provide larger cash inflows for the bank during stressed condition, the banking system has greater capacity to create money when constrained by the LCR regulation.

D Calibration of model parameter based on historical data for the U.S. banking system

Table 3: Historical data of capital and reserves for the U.S. banking system

Year	R **($ billion)**	C**($ billion)**	$CET1$**($ billion)**	C/R	$CET1/R$
1992	298	263	246	0.88	0.83
1993	273	297	277	1.09	1.01
1994	304	312	287	1.03	0.94
1995	307	350	318	1.14	1.04
1996	336	376	329	1.12	0.98
1997	355	418	354	1.18	1.00
1998	357	462	379	1.29	1.06
1999	366	480	378	1.31	1.03
2000	370	530	423	1.43	1.14
2001	390	594	469	1.52	1.20
2002	384	647	517	1.68	1.35
2003	387	692	527	1.79	1.36
2004	388	850	568	2.19	1.46
2005	400	912	604	2.28	1.51
2006	433	1030	666	2.38	1.54
2007	482	1143	715	2.37	1.48
2008	1042	1154	755	1.11	0.72
2009	976	1332	918	1.36	0.94
Mean	436.00	657.89	485.00	1.51	1.14
Min	273	263	246	0.88	0.72
Max	1042	1332	918	2.38	1.54

Notes: This table provides the historical data of reserves and capital for the U.S. banking system from 1992 to 2009 used for the calibration of the model parameter c, the capital-to-reserve ratio. Data are obtained by author based on the work of Slovik and Cournède (2011). Based on the ratio of bank capital to reserves (C/R) and the ratio of core-Tier 1 capital to reserves ($CET1/R$), we determine that $c = 0.8$ corresponds to relatively low capital positions and $c = 2$ indicates relatively high capital positions.

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