Online Appendix to Conventional vs. Unconventional Monetary Policy under Credit Regulation

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Appendix

A. Empirical Investigation

A.1 Data Description

Table 1: List of Low Credit Regulations countries with details about Public QE during Covid Pandemic

Country	First announcement date	End date	Where QE was also done of short maturity bonds	Size	Inactive pre-crisis
AU	19-03-2020			Unlimited	No
AU	03-11-2020	15-02-2022		A$100bn + A$100bn	
CA	12-03-2020	01-04-2020			No
CA	27-03-2020			Min C$5bn/week	
CA	15-04-2020	27-10-2021	Yes		
CO	23-03-2020			COP $4tn	No
CO	15-05-2020			COP $1.8nn	
IL	15-03-2020			NIS 85bn	
KR	19-03-2020	31.6.2021		KRW 14.5-16.5tn	
NZ	23-03-2020	23-07-2021		NZD 100bn	
PH	10-04-2020	30-06-2020			
SE	16-03-2020	31-12-2022	Yes	SEK 700bn	No
US	12-03-2020	13-04-2020		$60bn	No
US	15-03-2020			Unlimited	
ZA	25-03-2020				

Table 2: List of High Credit Regulations countries with details about Public QE during Covid Pandemic

Country	First announcement date	End date	Where QE was also done of short maturity bonds	Size	Inactive pre-crisis
GB	19-03-2020			£875bn	No
HU	07-04-2020	16-12-2021		HUF 3000bn (for revision)	
ID	18-06-2020		Yes		
IN	18-03-2020				No
IN	23-04-2020				
IN	07-04-2021	30-09-2021		INR 10tn (G-SAP 1.0) + 12tn (G-SAP 2.0)	
JP	13-03-2020			Unlimited	No
MX	12-03-2020			MXN $140bn (swap)	
PL	16-03-2020				
RO	20-03-2020				
TH	22-03-2020				
TR	31-03-2020		Yes		

A.2 Model Selection

Here, we present the model selection certeria for both the VAR model. Table 3 displays the moment model selection criteria for economies with low credit regulation, while Table 4 presents the moment model selection criteria for economies with high credit regulation, based on Andrews and Lu (2001). These criteria include the MMSC-Bayesian information criterion (MBIC), MMSC-Akaike information criterion (MAIC), MMSC-Hannan and Quinn information criterion (MQIC) and coefficient of determination (CD). Additionally, Hansen J statistics has also been reported.

Table 3: Model selection for low credit regulation economies

lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	0.9973861	53.80476	0.2618773	-170.0403	-42.19524	-94.01155
2	0.9988523	33.80713	0.3802418	-115.4229	-30.19287	-64.73708
3	0.9983577	16.72422	0.403656	-57.89081	-15.27578	-32.54788

Table 4: Model selection for high credit regulation economies

lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	0.2284283	53.03234	0.2863022	-155.4703	-42.96766	-87.96774
2	0.9443937	32.55997	0.4392279	-106.4418	-31.44003	-61.44008
3	0.987156	17.97738	0.3252231	-51.52351	-14.02262	-29.02264

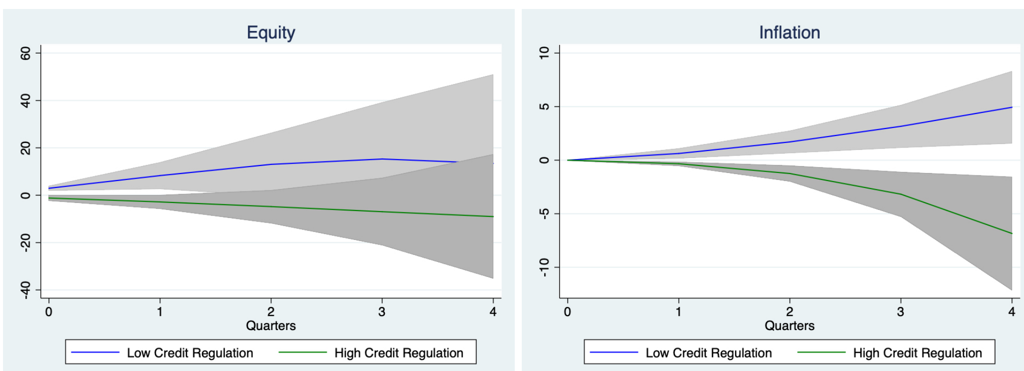
A.3 Further results

This section shows the result of the robustness section.

A.3.1 Impulse response for baseline model

First, we present the impulse responses of the other two variables, namely inflation and equity return to a shock in asset purchase in our baseline model.

Figure 1: Impact of a hundred basis point increase in central bank's claim on central government as a percentage of central bank assets on equity returns and inflation

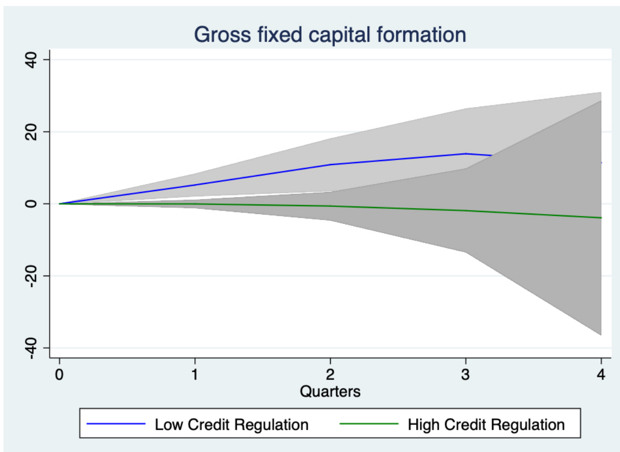


Note: The impulse response is generated using 1000 Monte Carlo simulation of system-GMM estimation of equation 1.

A.3.2 Impulse response for robustness check

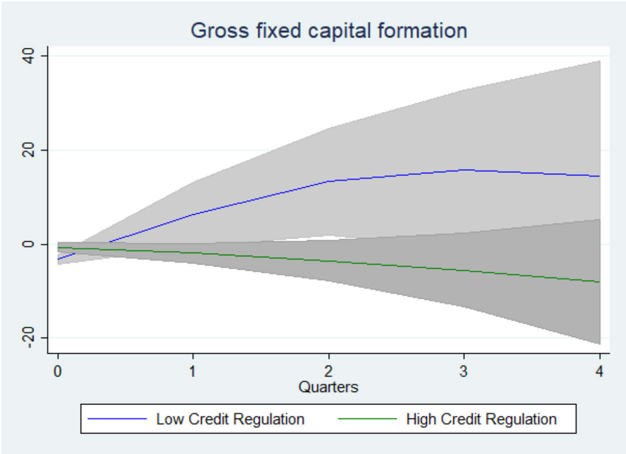
Next, we present the impulse responses of private investment to QE shocks in two additional models in the robustness section. Figure 2 shows the impulse response with defining ”Asset Purchase” as as the ratio of the central bank's net claims on central government to nominal GDP. Figure 3 shows the impulse response with an alternative identification scheme in our PVAR models where private investment is the most exogenous variable. Figure 4 shows the impulse response over an extended time span from 2014 to 2022 based on eight economies that were actively engaged in asset purchases prior to the pandemic.

Figure 2: Impact of hundred basis point increase in central bank's claim on central government as a percentage of nominal GDP on fixed capital formation in the economy



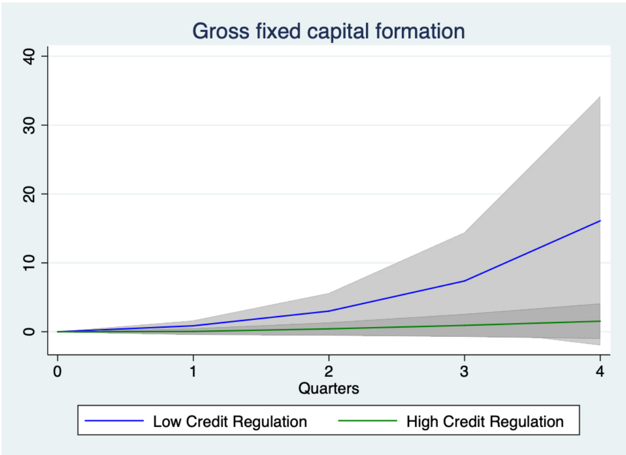
Note: The impulse response is generated using 1000 Monte Carlo simulation of system-GMM estimation of equation 1.

Figure 3: Impact of hundred basis point increase in central bank's claim on central government as a percentage of central bank assets on fixed capital formation in the economy



Note: The impulse response is generated using 1000 Monte Carlo simulation of system-GMM estimation of equation 1. The results are based on alternative identification scheme with investment growth being most exogenous.

Figure 4: Impact of hundred basis point increase in central bank's claim on central government as a percentage of central bank assets on fixed capital formation in the economy



Note: The impulse response is generated using 1000 Monte Carlo simulation of system-GMM estimation of equation 1. The estimation involves eight economies over the time span from 2014 to 2022.

B. Perpetual or Long-Term Bonds

We use the identical definition of long-term bonds as in section 2.1 of Sims and Wu (2021). However, for the sake of completeness, we reiterate the main features here.

Both wholesale firm and government issue perpetual bonds to finance their investment and consumption expenditure, respectively. The coupon payment on these bonds decay at a constant rate of $\kappa \in [0,1]$, such that a bond issued at t pays its holder dollar one at $t+1$, κ dollars at $t+2$, κ^2 at $t+3$ and so on. Let $B_{j,t-1}$ denote the total coupon liability of entity j in period t due to the bonds issued till period $t-1$. Also, let $NB_{j,t}$ denote the new bonds issued at t so that the following holds:

$$B_{j,t-1} = NB_{j,t-1} \cdot 1 + NB_{j,t-2} \cdot \kappa + NB_{j,t-3} \cdot \kappa^2 + ... \tag{A.1}$$

Using the above equation, we get the following identity:

$$NB_{j,t} = B_{j,t} - \kappa B_{j,t-1}$$

It is useful to note that one does not need to track the new issues at each date. Rather, those can be inferred using the total coupon liability.

Let the bonds issued at t be priced in the market at Q_t. It means that the present value of its associated stream of future coupon payments is priced as follows:

$$Q_t \equiv 1 + \kappa + \kappa^2 + \kappa^3 + ... = \frac{1}{1-\kappa} \tag{A.2}$$

The stream of future ($t+1$ onwards) coupon payments associated with bonds issued at $t-j$ is given by

$$\kappa^j + \kappa^{j+1} + ... = \frac{\kappa^j}{1-\kappa}$$

Using equation (A.2), the present value of the above stream of payments (or bonds issued at $t-j$) is $\kappa^j Q_t$ at t. This means that it is enough to know the price of new bonds to know the value of all outstanding bonds issued by entity j which is given by,

$$Q_t \cdot NB_{j,t} + \kappa Q_t \cdot NB_{j,t-1} + \kappa^2 Q_t \cdot NB_{j,t-2} + \ldots = Q_t(B_{j,t} - \kappa B_{j,t-1}) + \kappa Q_t [NB_{j,t-1} \cdot 1 + NB_{j,t-2} \cdot \kappa + NB_{j,t-3} \cdot \kappa^2 + \ldots]$$

Using equation (A.1), the last term on RHS of above equation equals $B_{j,t-1}$. So, the value of outstanding bonds issued till date t equals $Q_t B_{j,t}$.

C. Production Firms

C.1 Retail firm

A unit continuum of monopolistically competitive retailers indexed by $f \in [0,1]$ purchases wholesale output and resells it at $P_t(f)$ to the final good firm. The perfectly competitive final good firm combines retailers output according to CES technology:

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{\epsilon_p - 1}{\epsilon_p}} df \right)^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{B.1.1}$$

where ϵ_p is the elasticity of substitution between different varieties produced by retailers. The demand function for retailer $f's$ output is standard:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t} \right)^{-\epsilon_p} Y_t$$

Plugging it in equation (B.1.1) gives the final good price as an index of retailer prices:

$$P_t^{1-\epsilon_p} = \int_0^1 P_t(f)^{1-\epsilon_p} df \tag{B.1.2}$$

There exists nominal rigidites like Calvo (1983) such that retailers can reset their prices only with a probability of $1-\phi_p$ each period. Each retailer who resets price at t will try to maximize the present discounted value of the real dividends keeping in mind the possibility that it could never get to reset the price again in future. Its Lagranian will then look like:

$$\mathbb{L}_t = \mathbb{E}_t \sum_{j=0}^{\infty} {\phi_p}^j \Lambda_{t,t+j} \left\{ P_t(f)^{1-\epsilon_p} {P_{t+j}}^{\epsilon_p - 1} Y_{t+j} - p_{w,t+j} P_t(f)^{-\epsilon_p} {P_{t+j}}^{\epsilon_p} Y_{t+j} \right\}$$

Setting its derivative with respect to $P_t(f)$ equal to zero results in the following:

$$\Pi_t^{\#} = \frac{P_t^{\#}}{P_t} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{B.1.3}$$

where $P_t^{\#}$ is the reset price at t which is equal for all retailers who get to reset their price at t, and $x_{1,t}$ and $x_{2,t}$ are auxiliary variables defined as:

$$x_{1,t} = p_{w,t} Y_t + \phi_p \mathbb{E}_t \left(\Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_p} x_{1,t+1} \right) \tag{B.1.4}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E}_t \left(\Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_p - 1} x_{2,t+1} \right) \tag{B.1.5}$$

The reset price in (B.1.3) is a constant mark-up $\left(\frac{\epsilon_p}{\epsilon_p - 1}\right)$ over marginal cost which is given by $\frac{x_{1,t}}{x_{2,t}}$.

C.2 Capital Goods Firm

It converts the unconsumed (by household and government) output I_t into new capital $\hat{I}_t$. Its production function is given by:

$$\hat{I}_t = I_t \left[1 - S\left(\frac{I_t}{I_{t-1}} \right) \right]$$

where $S(.)$ denotes the investment adjustment cost function[1] similar to Christiano et al. (2005) that satisfies the following properties: $S(1) = S^{'}(1) = 0$ and $\kappa_I \equiv S^{''}(1) > 0$.

[1] Specifically, it takes the following form: $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$.

Its objective is to maximize the present discounted value of real profits at t given by:

$$\max_{I_t} \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+1} \left\{ p^k_{t+j} I_{t+j} \left[1 - S\left(\frac{I_{t+j}}{I_{t+j-1}} \right) \right] - I_{t+j} \right\}$$

The FOC is:

$$1 = p^k_t \left[1 - S\left(\frac{I_t}{I_{t-1}} \right) - S^{'}\left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + \mathbb{E}_t \left[\Lambda_{t,t+1} p^k_{t+1} \left(\frac{I_{t+1}}{I_t} \right)^2 S^{'}\left(\frac{I_{t+1}}{I_t} \right) \right]$$

D. Financial Intermediary

In this section, we show the derivation of equation 14 for modified leverage ratio ϕ and also show what happens to the model solution when we introduce short-term government bonds alongside the long-term ones.

D.1 Modified leverage ratio

Using the linear functional form assumption for continuation value ($V_{it} = a_t n_{it}$), equation (7) can be rewritten as follows:

$$a_t n_{it} = \mathbb{E}_t[\Lambda_{t,t+1} n_{i,t+1} \underbrace{(1 - \sigma + \sigma a_{t+1})}_{\Omega_{t+1}}] \tag{B.1.6}$$

Using equation (6), intermediary's real net-worth can also be written as follows:

$$n_{it+1} = \Pi^{-1}_{t+1}[(R^F_{t+1} - R^d_t) Q_t f_{it} + (R^B_{t+1} - R^d_t) Q_{Bt} b_{it} + (R^{re}_t - R^d_t) re_{it} + R^d_t n_{it}] \tag{B.1.7}$$

Multiply both sides of the above equation by $\Lambda_{t,t+1}\Omega_{t+1}$ and take expectations to get the following:

$$\mathbb{E}_t[\Lambda_{t,t+1}\Omega_{t+1}n_{i,t+1}] = \mathbb{E}_t[\Lambda_{t,t+1}\Omega_{t+1}\Pi_{t+1}^{-1}\{(R_{t+1}^F - R_t^d)Q_t f_{it} + (R_{t+1}^B - R_t^d)Q_{Bt}b_{it} + (R_t^{re} - R_t^d)re_{it} + R_t^d n_{it}\}] \tag{B.1.8}$$

The left hand side equals $a_t n_{it}$ from above. A binding leverage constraint in equation (8) implies $a_t = \theta_t \phi_t$. Further, using intermediary's first-order conditions and regulatory constraint, we make the following substitutions in equation (B.1.8):

$$R_t^{re} = R_t^d$$

$$R_{t+1}^B - R_t^d = \frac{\theta_t \tilde{\lambda}_t (1 + \Delta\gamma) - \tilde{\Lambda}_{t,t+1}(R_{t+1}^F - R_t^d)}{\tilde{\Lambda}_{t,t+1}\gamma} \; ; \; \tilde{\lambda} = \frac{\lambda}{1+\lambda}$$

$$Q_t f_{it} = \frac{n_{it}\phi_t}{1 + \Delta\gamma} \; ; \; Q_{Bt}b_{it} = \gamma Q_t f_{it}$$

After substitution, we get $\phi_t = \frac{\tilde{\Lambda}_{t,t+1}R_t^d}{\theta_t(1-\tilde{\lambda})}$. Putting back $\tilde{\lambda}$ from one of the above expressions, we get the form of ϕ_t as in equation (14).

D.2 Short-term government bonds

Here, we look at the impact of the inclusion of short-term government bonds in banks' portfolio on our model analysis. In the spirit of Hohberger et al. (2019), we consider imperfect substitution between long-term and short-term government bonds. Such imperfect substitution arises due to a transaction cost incurred by the banks upon adjusting their bonds portfolio mix between assets of different maturities. It is the presence of such adjustment costs that allows the central bank to flatten the yield curve through asset purchases.

To implement this in the model, we let the financial intermediaries always hold a mix of short-term and long-term bonds at a targeted value of κ^*, so that $Q_{B,t}^S b_t^S = \kappa^* Q_{B,t}^L b_t^L$.

Here, superscripts S and L denote short-term and long-term, respectively.

Considering both types of government bonds for regulatory constraint gives us the following:

$$Q_{B,t}^{L} b_t^L (1+\kappa^*) \geq \Gamma[(1+\kappa^*) Q_{B,t}^{L} b_t^L + Q_t f_t]$$

$$\Rightarrow Q_{B,t}^{L} b_t^L \geq \underbrace{\frac{\Gamma}{1-\Gamma} \frac{1}{1+\kappa^*}}_{\gamma^*} Q_t f_t$$

We can see that γ^* is simply a linear transformation of γ, hence there will be no non-trivial impact on our model analysis.

E. Steady State

We compute the steady state for a zero net inflation rate, which means gross inflation is unity, i.e., $\Pi = 1$. Aggregate price index (B.1.2) can be rewritten as:

$$P_t^{1-\epsilon_p} = (1-\phi_p) P_t^{\#^{1-\epsilon_p}} + \phi_p P_{t-1}^{1-\epsilon_p}$$

Using $\Pi_t^{\#} = \frac{P_t^{\#}}{P_t}$ and $\Pi_t = \frac{P_t}{P_{t-1}}$, we get

$$1 = (1-\phi_p) \Pi^{\#^{1-\epsilon_p}} + \phi_p \Pi_t^{\epsilon_p - 1}$$

Therefore, steady-state $\Pi^{\#} = 1$. Since retailers simply repackage the wholesale firm's output, therefore

$$Y_{w,t} = \int_0^1 Y_t(f) df = Y_t \int_0^1 \left(\frac{P_t(f)}{P_t} \right)^{-\epsilon_p} df = Y_t \nu_t^p$$

where $\nu_t^p = \int_0^1 \left(\frac{P_t(f)}{P_t} \right)^{-\epsilon_p} df$ is a measure of price-dispersion in the retailer prices. Writing

ν_t^p recursively, we get

$$\nu_t^p = (1-\phi_p)\Pi_t^{\#^{-\epsilon_p}} + \phi_p \Pi_t^{\epsilon_p} \nu_{t-1}^p$$

$\Pi = \Pi^{\#} = 1$ implies $\nu^p = 1$ and thus $Y_w = Y$. Investment does not change in steady state, so $\hat{I} = I$. Similarly, consumption doesn't change so $\Lambda = \beta$. From equation 13, we have $R^d = \frac{1}{\beta} = R^{re}$. In order to target the annual average deposit rate of 4 percent in the data, we set $\beta = 0.9901$. We normalize total labor and capital cost to unity, i.e., $p^k = L = L_d = 1$. We choose steady state utilization to be 1 so that utilization adjustment cost is δ_0.

We solve the DSGE model at a quarterly frequency. In order to get a steady state annual spread of $sp_B = 374$ basis points on government bonds, we set $R^B = (1+sp_B)^{\frac{1}{4}} * R^d$. Whereas, to get a spread of $sp_F = 526.4$ basis points on private bonds, we set $R^F = (1+sp_F)^{\frac{1}{4}} * R^d$. This gives us the prices for both government and private bonds as follows: $Q_B = (R^B - \kappa)^{-1}$ and $Q = (R^F - \kappa)^{-1}$.

Using (B.1.3), steady state marginal cost is

$$MC = \frac{\epsilon_p - 1}{\epsilon_p}$$

Using (22),

$$M_2 = \frac{\Lambda}{Q(1-\kappa\Lambda)}$$

which gives $M_1 = (M_2 - 1)\psi + 1$. Then, using (**??**), we get the steady-state capital as

$$K = \left(\frac{\alpha MC}{\frac{M_1}{\Lambda} - (1-\delta_0)M_1} \right)^{\frac{1}{1-\alpha}}$$

This means wholesale output is $Y_w = K^\alpha$. So, total output is $Y = Y_w$. From data, we use the steady-state balance sheet of central bank as the annual average fraction $fracb = 0.135$ of steady state output, i.e. $b_{cb} = Y * fracb/Q_B$. Also, from data, we use the steady-state government borrowing as the annual average fraction $bgy = 0.5184$ of output, i.e., $bG = bgy * Y/Q_B$. This gives us the steady-state value of government bonds with banks as $b = bG - b_{cb}$. From (16), $\hat{I} = \delta_0 K$ and from (17), $f_w = \frac{\psi \hat{I}}{Q(1-\kappa)}$. Market clearing implies $f = f_w$. A binding regulatory constraint means

$$\gamma = \frac{Q_B b}{Qf} \Rightarrow \Gamma = \frac{\gamma}{1+\gamma} \tag{C.1}$$

The above equation yields the regulatory constraint parameter corresponding to the other model parameters' values as used above.

Using (18), the steady state wage paid by wholesale firm is $w = MC(1-\alpha)K^{\alpha}$. From data, the government expenditure is fraction $gy = 0.27$ of total output, then $G = gy * Y$ and $C = Y - I - G$. Using (2), marginal utility of household is

$$\mu = \frac{1-\beta h}{C(1-h)}$$

and using (3), the relative utility of labor is

$$\chi = \mu w$$

We know M_2, so $\nu_2 = M_2 - 1$ and from (20), we get $\nu_1 = 1 + \psi \nu_2$. Since $\delta^{'}(1) = \delta_1$, therefore using (19), we have

$$\delta_1 = \frac{\alpha MCK^{\alpha-1}}{M_1}$$

Using (B.1.4) and (B.1.5), we get

$$x_1 = \frac{MC * Y}{1 - \phi_p \Lambda}$$

$$x_2 = \frac{Y}{1 - \phi_p \Lambda}$$

Steady state reserves are given by $re = Q_B b$. Let steady-state leverage of intermediaries be $levs = 4$, then net worth is $n = \frac{Qf+Q_Bb+re}{levs}$. Deposits are $d = Qf + Q_Bb + re - n$, and from (25), $X = n - \sigma(Qf[R^F - R^D + \gamma(R^B - R^D)] + R^Dn)$. Net revenue of CB is $T_{cb} = (R^B - R^{re})Q_Bb_{cb}$, and lump-sum tax paid by households using (23) is $T = G + bG - T_{cb} - Q_B(bG - \kappa bG)$. The modified leverage ratio is $\phi = \frac{Qf+\Delta Q_Bb}{n}$. But we don't know the value of Δ yet, so we solve the following sequence of non-linear equations to get Δ (starting with an initial assumption for Δ) :

$$\phi = \frac{Qf + \Delta Q_Bb}{n}$$

$$\overline{B} = \gamma(R^B - R^d) + R^F - R^d$$

$$\theta = \frac{\Lambda\Pi^{-1}(1-\sigma)[\phi\overline{B} + R^d(1+\Delta\gamma)]}{\phi(1+\Delta\gamma) - \Lambda\Pi^{-1}\sigma\phi[\phi\overline{B} + R^d(1+\Delta\gamma)]}$$

$$a = \theta\phi$$

$$\Omega = 1 - \sigma + \sigma a$$

$$\tilde{\zeta} = \frac{\tilde{\Lambda}[\Delta(R^F - R^d) - (R^B - R^d)]}{1+\Delta\gamma}$$

$$\tilde{\lambda} = \frac{\tilde{\Lambda}(R^B - R^d) + \tilde{\zeta}}{\theta\Delta}$$

$$\lambda = \frac{\tilde{\lambda}}{1-\tilde{\lambda}}\ ;\ \zeta = \tilde{\zeta}(1+\lambda)$$

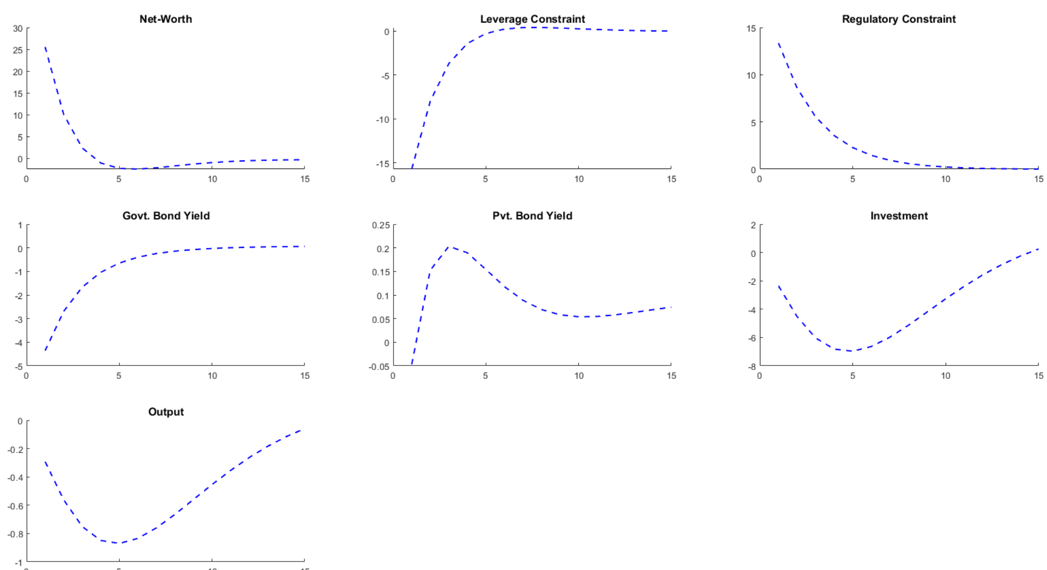
$$\tilde{\Lambda}(R^F - R^d) = \frac{\lambda\theta}{1+\lambda} + \frac{\zeta\gamma}{1+\lambda}$$

$$\tilde{\Lambda}(R^B - R^d) = \frac{\lambda\theta\Delta}{1+\lambda} - \frac{\zeta}{1+\lambda}$$

Once we know Δ, we can recompute the values for $\phi, \theta, a, \Omega, \zeta, \lambda$.

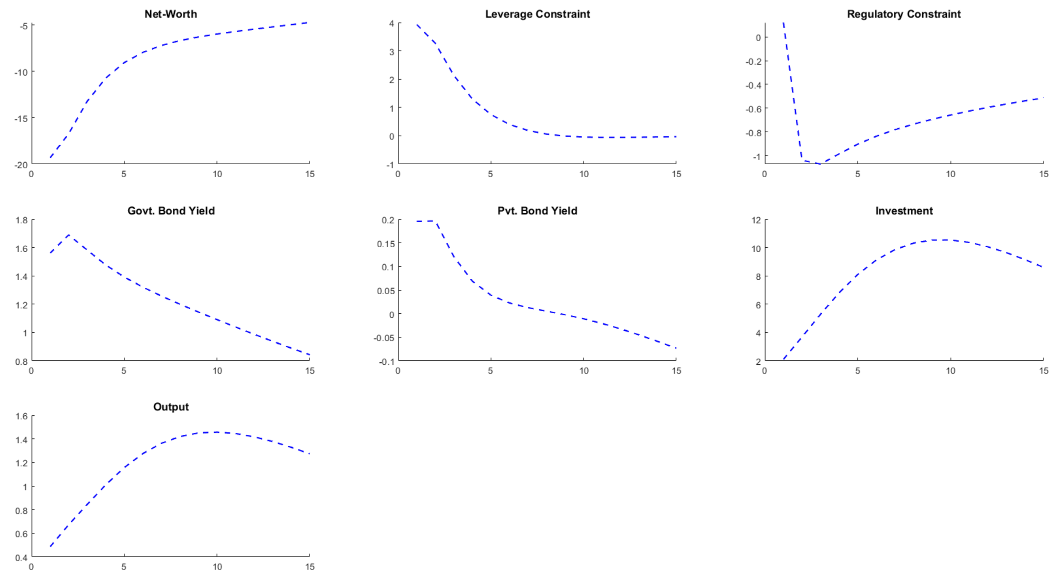
F. Sensitivity Analysis

Figure 5: Impulse Responses to a positive QE shock in the presence of credit regulations with low price stickiness ($\phi_p = 0.2$)



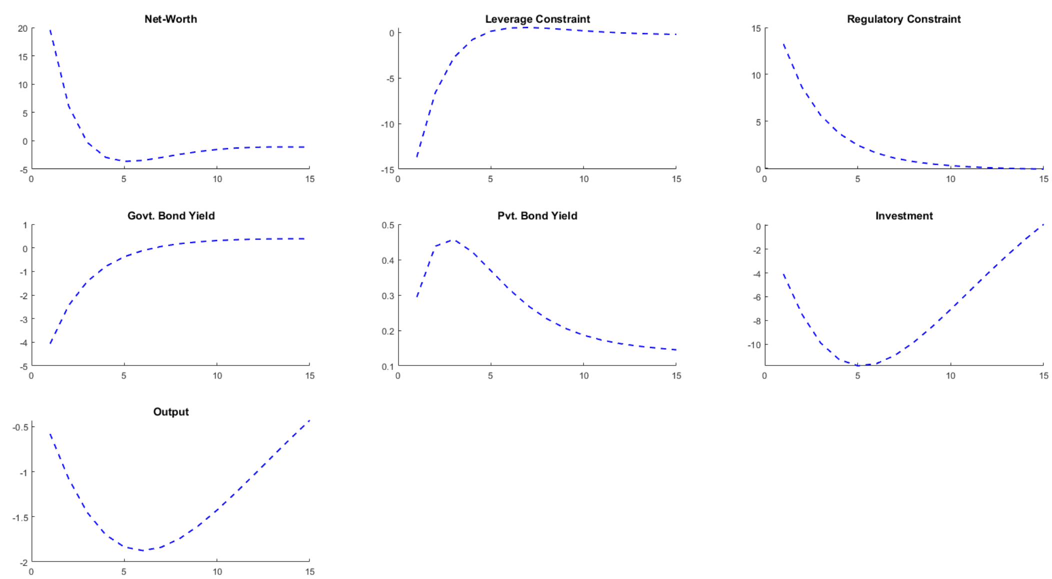
Note: All variables are in percentage points and all rates are annualized.

Figure 6: Impulse Responses to a negative policy rate shock in the presence of credit regulations with low price stickiness ($\phi_p = 0.2$)



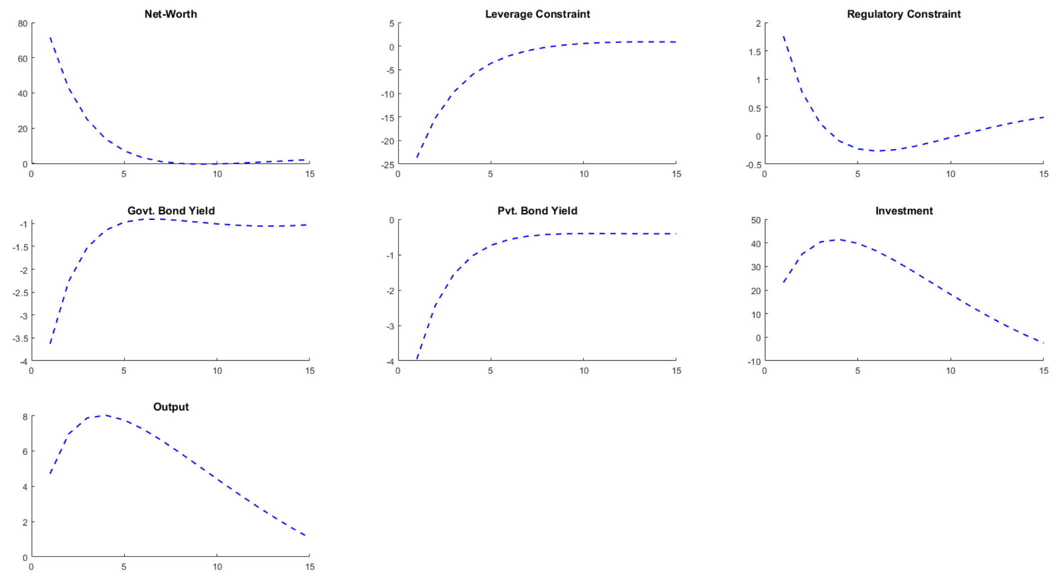
Note: All variables are in percentage points and all rates are annualized.

Figure 7: Impulse Responses to a positive QE shock in the presence of credit regulations with high price stickiness ($\phi_p = 0.9$)



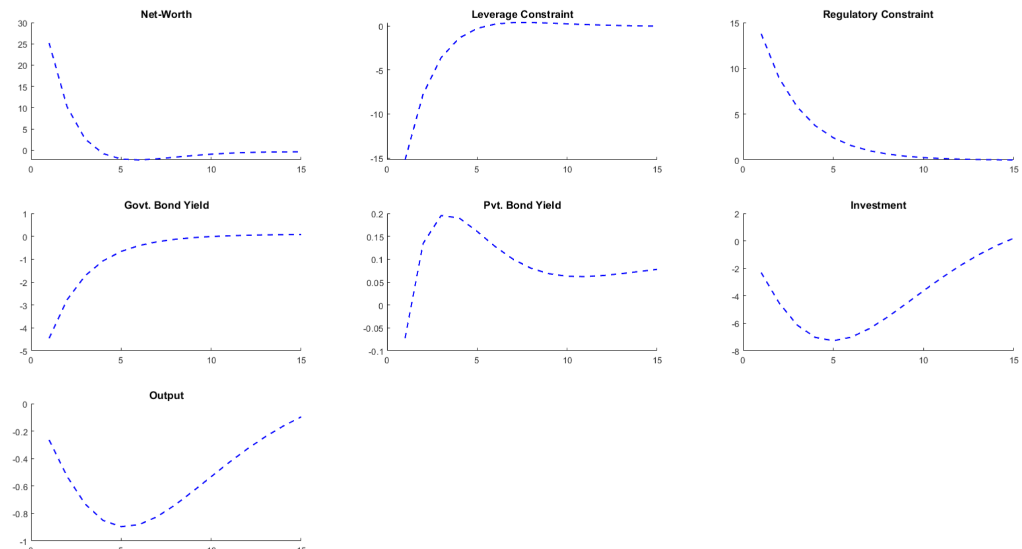
Note: All variables are in percentage points and all rates are annualized.

Figure 8: Impulse Responses to a negative policy rate shock in the presence of credit regulations with high price stickiness ($\phi_p = 0.9$)



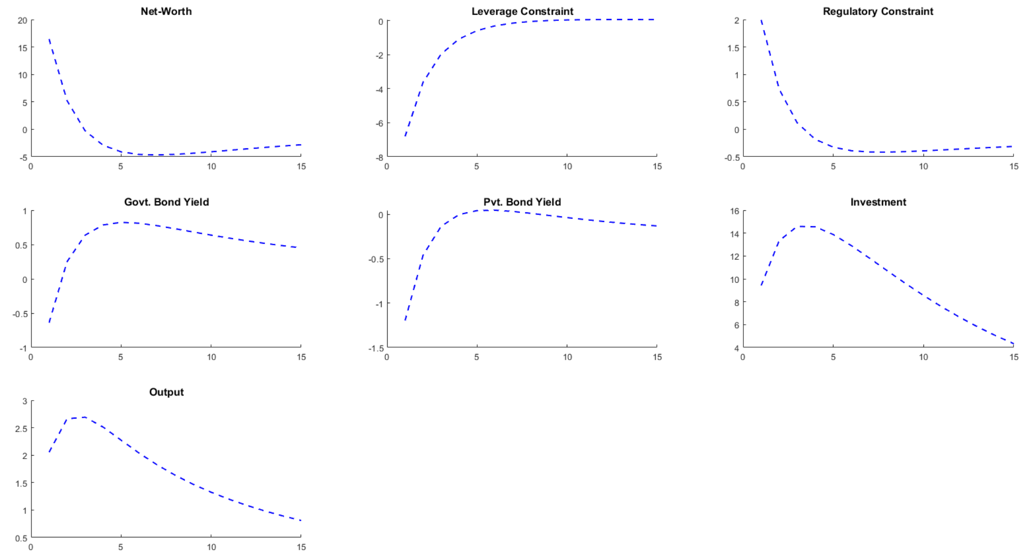
Note: All variables are in percentage points and all rates are annualized.

Figure 9: Impulse Responses to a positive QE shock in the presence of credit regulations with high loan-in-advance constraint parameter ($\psi = 1$)



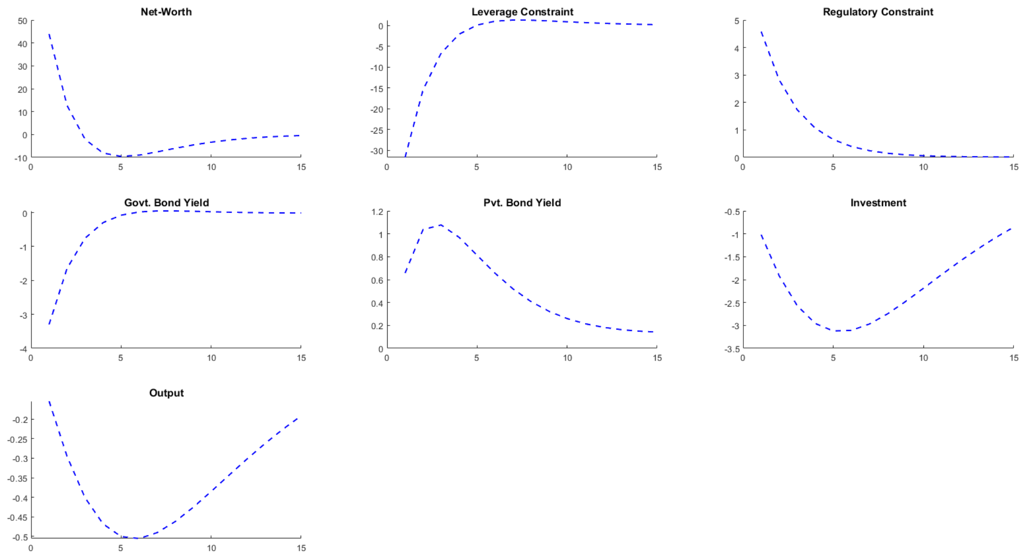
Note: All variables are in percentage points and all rates are annualized.

Figure 10: Impulse Responses to a negative policy rate shock in the presence of credit regulations with high loan-in-advance constraint parameter ($\psi = 1$)



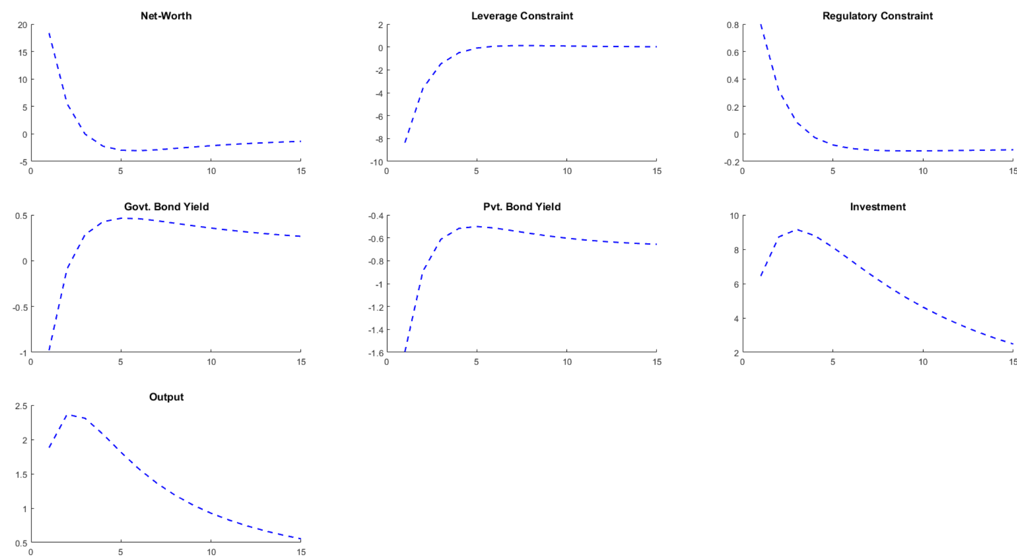
Note: All variables are in percentage points and all rates are annualized.

Figure 11: Impulse Responses to a positive QE shock in the presence of credit regulations with low loan-in-advance constraint parameter ($\psi = 0.1$)



Note: All variables are in percentage points and all rates are annualized.

Figure 12: Impulse Responses to a negative policy rate shock in the presence of credit regulations with low loan-in-advance constraint parameter ($\psi = 0.1$)



Note: All variables are in percentage points and all rates are annualized.

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