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Inside the Great Escape: a quantitative analysis considering the eligibility criteria of the Fed's liquidity facilities

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”Dentro del Gran Escape: un análisis cuantitativo considerando los criterios de selección de los programas de liquides de la Reserva Federal ”

Resumen

Este artículo reevalúa el impacto macroeconómico de las líneas de provisión de liquidez de la Reserva Federal implementadas durante el inicio de la Gran Recesión. Me baso en Del Negro, Eggertsson, Ferrero y Kiyotaki para levantar un supuesto en su modelo DSGE con rigideces nominales, rigideces reales y fricciones de liquidez para incluir un mecanismo que dé cuenta de los criterios de selección de la política monetaria no convencional. Levantaré un supuesto que dividirá la fricción de liquidez en dos: una que afectará a los activos y otra que afectará a los pasivos del hogar. Por lo tanto, la política monetaria no convencional del modelo responderá con liquidez agregada ante el shock en los mercados de activos, pero no ante el estrés en los mercados de pasivos. Obtengo resultados numéricos que se comparan con los datos y con los resultados del modelo de los autores. Mis resultados respaldan sus hallazgos ya que los efectos del shock de liquidez son grandes. Explica alrededor del 50% de la caída de la producción y aproximadamente el 75% de la caída de la inflación tras la quiebra de Lehman. Mis hallazgos también refuerzan el resultado de los autores de que las liquidez provista por la Reserva Federal impidió que la economía atravesara un episodio parecido a la Gran Depresión. Sin embargo, existen efectos cuantitativos de los criterios de elegibilidad, ya que las ganancias podrían sobreestimarse. A través de una profunda inmersión en el efecto de los criterios de elegibilidad, encuentro que la política monetaria no convencional puede ser inflacionaria y que no tiene ningún efecto si se dirige a mercados que no están estresados.

Palabras clave: Macroeconomía, Política Monetaria, Crisis Financiera, Banco Central

"Inside the Great Escape: a quantitative analysis considering the eligibility criteria of the Fed's liquidity facilities"

Abstract

This paper re-evaluates the macroeconomic impact of the Federal Reserve's liquidity provision facilities implemented during the onset of the Great Recession. I build on Del Negro, Eggertsson, Ferrero and Kiyotaki to lift an assumption in their DSGE model with nominal rigidities, real rigidities and liquidity frictions to include a mechanism that accounts for the eligibility criteria of the unconventional monetary policy. I will lift an assumption which will split the liquidity friction in two, one affecting the assets and one affecting the liabilities of the household. Therefore, the unconventional monetary policy of the model will respond with aggregate liquidity upon the shock in the assets markets, but not upon stress in the liabilities markets. I obtain numerical results that are compared with the data and with the authors' model results. My results support their findings as the effects of the liquidity shock are large. It explains about 50% of the drop in output and roughly 75% of the drop in inflation after Lehman bankruptcy. My findings also reinforce the result of the authors that the liquidity facilities of the Federal Reserve prevented the economy of going through an episode resembling the Great Depression. However, there are quantitative effects of the eligibility criteria as the gains might be slightly overestimated. Through a deep dive in the eligibility criteria effect I find that unconventional monetary policy can be inflationary and that it has no effect if it is targeted to markets which are not stressed.

Keywords: Macroeconomics, Monetary Policy, Financial Crisis, Central Banking

Códigos JEL: E44 Financial Markets and the Macroeconomy, E58 Central Banks and Their Policies, G01 Financial Crisis

1 Introduction

The Lehman Brothers collapse in September 15, 2008 was a turning point which unfurled the events that became known as the Great Recession. There were signs of stress before: one example was the housing market slowdown from early 2006 after the housing prices peaked, or the Bear Sterns stress which lead to the JP Morgan purchase in 2006 assisted by the Federal Reserve. So the period known as the Great Moderation was coming to an end before this turning point. However, it unfurled the events of a crisis in the sense that it stressed markets beyond a single case, creating financial panic and spreading worldwide.

I will build on the model designed by Del Negro, Eggertsson, Ferrero and Kiyotaki (Del Negro *et al.*, 2017) (DEFK) to incorporate the eligibility criteria of the targeted unconventional monetary policies performed by the Federal Reserve. The authors develop a Christiano, Eichenbaum and Evans (Christiano *et al.*, 2005) type of model with financial frictions to analyze what they call the great escape that the United States economy experienced from the 2008 credit crunch recession, with unconventional monetary measures as one of the main drivers. First they look at the Lehman episode to understand the gains of the unconventional monetary policy. Then they calibrate the model to simulate a situation similar to the Great Depression in the sense that the zero lower bound was binding for a longer period. They found that there existed a great escape of a depression as the unconventional monetary policy performed by the Federal Reserve had persistent gains in Output and Inflation all along the time span that the zero lower bound is binding, despite the fact that there were other shocks affecting the economy.

The change that I will introduce to the model is lifting an assumption taken by the authors of the paper. In DEFK, the household faces two financial frictions: a borrowing constraint (the entrepreneur can issue new equity only up to a certain fraction of the new investment) and a resaleability constraint (at any given time, the entrepreneur can sell only a fraction of equity holdings to get funding for an investment opportunity). The paper is solved with two resaleability constraints, one for the liabilities and one for the assets, but the authors assume that both idiosyncratic shocks are the same, resulting in one condensed constraint. This ends up placing intervention in the net position of the household as the unconventional monetary policy reacts to the dry up of the equity market given by that unique idiosyncratic shock to liquidity. In this work I lift this assumption and split the resaleability constraint in two, one for the capital pledged to others in the form of liabilities and one for the capital pledged by others held as an asset in the household balance sheet. If the constraint for the asset side of the balance sheet gets tight enough, the central bank will react providing aggregated liquidity. However, it will not be able to assist if the liabilities of the household become iliquid. By making this distinction, my goal is to capture the possibility that the Fed might not be able to provide liquidity to all the stressed markets, whereas in DEFK it is implicitly assumed that it can. Therefore, the financial frictions in this work (Inside the Great Escape model) are three.

This model tries to capture the mechanism of assisting the private sector through eligible bonds and quantify the macroeconomic implications. The spirit of this modification lies in the design and implementation of the unconventional monetary policies that responded to the 2008 credit crunch under Chairman Bernanke´s administration. This design faced legal, administrative and implementation restrictions which shaped the unorthodox policies taken by the administration (B. S. Bernanke, 2015). The results of this work will be compared against the results produced by the model developed by the authors, which will be considered as benchmark. Moreover, as the calibration is identical it is possible to directly compare the results and quantify the impact of this mechanism. In order to get a clear presentation, it will be used the term ”DEFK model” to refer to the model of the paper which inspired this work (Del Negro *et al.*, 2017) and it will be used ”IGE model” (Inside the Great Escape model) to refer to the results of this paper.

The slowdown experienced after Lehman collapsed was sluggish as the recovery was slow. By December 2008 the US economy had reached the zero lower bound, as the Federal Reserve lowered the Federal Funds rate to zero, where it remained for 7 years. Conventional monetary policy was exhausted. Additional measures were needed to avoid a depression and relax the stress in the financial markets. As a response to this, the Federal Reserve started a series of programs which were meant to provide liquidity to stressed financial markets, resembling measures taken by the Bank of Japan at the beginning of the 2000s. Figure 1 taken from the article (Williamson, 2016) plots the Federal Funds Rate for the period.

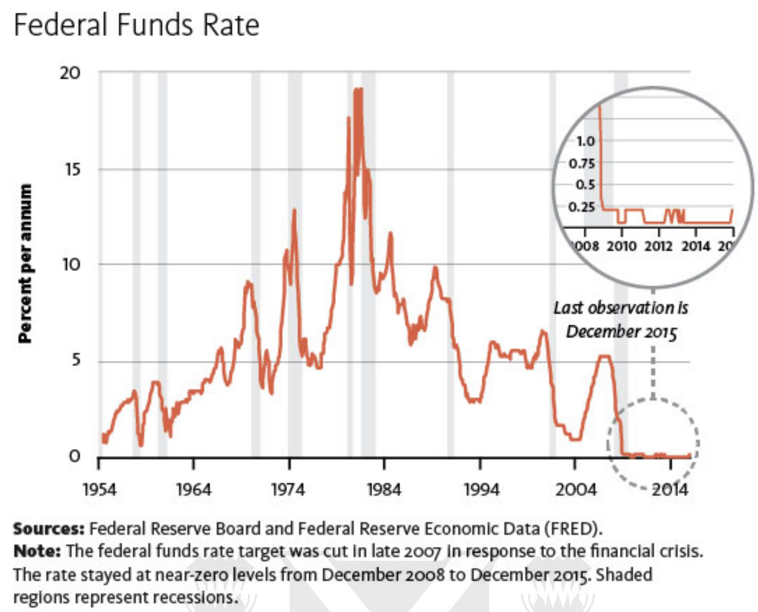

Figure 1: Federal Funds Rate: the zero lower bound

Buying assets is an essential part of the conventional monetary policy toolkit. Through the Federal Open Market Committee (FOMC) it buys an sells short term government securities (for example 3-month Treasury Bill) to hit the target of overnight fed fund rate. What made the policy implemented through these programs unconventional was the fact that the assets bought were long term (for example 30 Years Treasury Bond). This is known as quantitative easing (QE), which refers to purchases of unconventional assets by the central bank in order to pursue a particular goal(Williamson, 2016).

However, the U.S experience was different from that of Japan at the beginning of 2000s, as explained by former Chairman of the Federal Reserve Ben Bernanke ”The Federal Reserve's approach to supporting credit markets is conceptually distinct from quantitative easing (QE), the policy approach used by the Bank of Japan from 2001 to 2006. Our approach–which could be described as ”credit easing”–resembles quantitative easing in one respect: It involves an expansion of the central bank's balance sheet. However, in a pure QE regime, the focus of policy is the quantity of bank reserves, which are liabilities of the central bank; the composition of loans and securities on the asset side of the central bank's balance sheet is incidental. Indeed, although the Bank of Japan's policy approach during the QE period was quite multifaceted, the overall stance of its policy was gauged primarily in terms of its target for bank reserves. In contrast, the Federal Reserve's credit easing approach focuses on the mix of loans and securities that it holds and on how this composition of assets affects credit conditions for households and businesses. This difference does not reflect any doctrinal disagreement with the Japanese approach, but rather the differences in financial and economic conditions between the two episodes. In particular, credit spreads are much wider and credit markets more dysfunctional in the United States today than was the case during the Japanese experiment with quantitative easing. To stimulate aggregate demand in the current environment, the Federal Reserve must focus its policies on reducing those spreads and improving the functioning of private credit markets more generally."(B. Bernanke, 2009)

This approach of unconventional monetary policy was implemented in three stages. The first one, known as QE1 spanned from November 2008 to March 2010 and involved the purchase of long-term Treasury securities, agency securities and mortgage-backed securities. Second, the QE2 held between November 2010 and June 2011, was a $ 600 billion purchase of long-term Treasury securities. Last stood the QE3 that ran from September 2012 to October 2014, and was a large-scale purchase of mortgage-backed securities and long-term Treasury securities (Williamson, 2016). Figure 2 taken from the cited article shows the balance sheet of the Federal Reserve during this process.

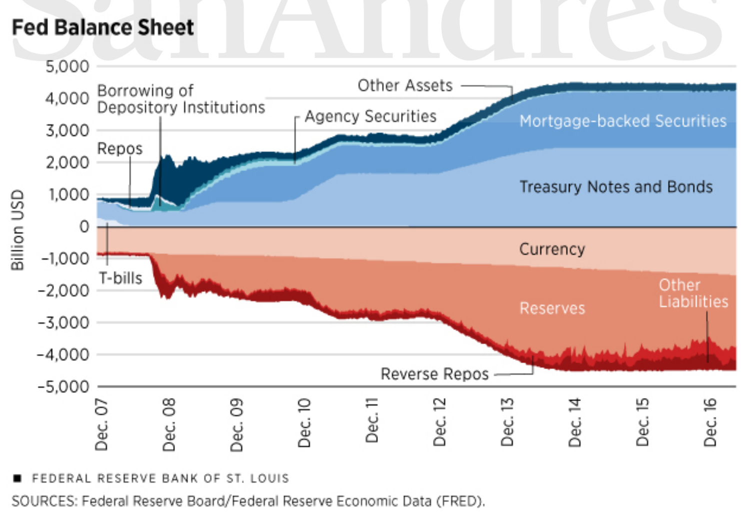

Figure 2: Federal Reserve Balance Sheet: The Process

For the implementation of this programs the Federal Reserve created Special Purposed Vehicles (SPV) to purchase the assets to the financial institutions in the market, and to pledge the asset as collateral to the Federal Reserve Bank of New York to get the funding. An example of this was the Commercial Paper Funding Facility, which was created in October 2008 to provide liquidity backstop to issuers of commercial paper in the United States. This was achieved through the creation of the SPV called CPFF LLC which had an eligibility criteria for the purchase of assets. As stated in the documentation released by the Federal Reserve (Adrian *et al.*, 2011), purchases of commercial paper could not be open to any firm needing access to short-term funding, as this would have deviated from the intent of offering a backstop to issuers whose short-term funding was disrupted by liquidity events rather than the firm's own credit event. To minimize credit risk, the Federal Reserve limited purchases to top-tier paper, rated A1/P1/F1 or higher, consistent with 2a-7 fund conventions in place at the time. This means that the scope of the unconventional monetary policy was limited, although the authors mention that for the time the program was implemented in late 2008, top-tier commercial paper was about 90% of the market.

Another example cited in the document (Adrian *et al.*, 2011) of eligibility was the expansion of eligible collateral for the Primary Dealer Credit Facility (PDCF) and the Term Securities Lending Facilities (TSLF), implemented in late 2008.

The cases of Lehman and Washington Mutual bankruptcies are examples of administrative and legal issues that the central authority might have to achieve for intervention. The Federal Reserve has the section 13(3) of the Federal Reserve Act, highly cited during the Great Recession which allows for lending to banks, financial institutions, private institutions and virtually any institution in need, in ”unusual and exigent circumstances”. This last condition might prove difficult to argue in Congress. It is essential to explain that saving a Wall Street giant is for the benefit of Main Street by stopping financial panic to spread and become a depression and not simply a bailout of a poorly managed institution with poor investment choices (B. S. Bernanke, 2015). On the other hand, Fannie Mae, Freddie Mac and AIG are examples of successfully interventions.

This rises two different questions: first regarding the Fed's power of action against markets drying up. During the Great Moderation period financial intermediation changed and banks relied more on money markets funded by this short term repo transactions of securitized products, the system became much more complex and interconnected, as suggested by former chairman Bernanke above. In this context, it is worth asking if the Fed is able to backstop a liquidity dry up with injections through eligible bonds to eligible issues.

There is literature analyzing the run on repo markets, which was a characteristic of the Great Recession post Lehman Brothers collapse. Gorton and Metrick (Gorton & Metrick, 2012) provide an empirical analysis to trace a path between the housing asset-backed subprime market dry up to markets which had no connection to housing. This dry up in housing translated into higher rate cuts in other markets and they conclude that the market was insolvent for the first time since the Great Depression. On that same line Covitz, Liang and Suarez (Covitz *et al.*, 2013) found that one third of the asset backed commercial papers had runs in the last months of 2007, which indicates that Asset-Backed Commercial Paper [1] markets may be a source of systemic risk. Martin, Skeie and von Thadden (Martin *et al.*, 2014) study expectation-driven runs in a general equilibrium model with collateral and liquidity constraint, and show that runs are possible and depend crucially on the microstructure of the funding market.

This last paper brings us to a discussion that took place in the literature regarding which markets where the ones who suffer the dry up or run. Martin, Skeie and von Thadden (Martin *et al.*, 2014) state through their analysis that there is a difference between the tri-party repo market and the billateral market. Tri-party market has a intermediary for the repo agreement to be celebrated (typically an investment bank or a financial institution operating in the money markets) while in bilateral markets the agreement is celebrated between the two private parts which are involved in the repo. Copeland, Martin and Walker (Copeland *et al.*, 2014) provided evidence that the rise in haircuts (hence the dry up) was only in the bilateral markets, while the haircuts in the tri-party markets remain stable. These matters were discussed in a Liberty Street Economics article (Copeland & Martin, 2017) which provided further evidence that the runs described for example by Gorton

[1] As defined by the Federal Deposit Insurance Corporation, Asset-backed commercial paper (ABCP) conduits issue short-term notes backed by trade receivables, credit card receivables, or medium-term financial assets with an original maturity of 270 days or less. (FDIC, 2017)

and Metrick (Gorton & Metrick, 2012) were not necessarily suffered by all the repo markets. In the same line, Kirshnamurthy, Nagel and Orlov (Krishnamurthy *et al.*, 2014) shed light over the inside mechanism. They found that repo funding extended by money markets funds contraction was insignificant relative to the asset-backed commercial papers contraction. The key issue was that the repo funding by money market funds was extended to key dealer banks with large exposures to private sector securities, which triggered the dry up. This meant that haircuts for money market funds to dealer (tri-party) markets rise less than bilateral markets, which led them to conclude that this dry up behavior was more of a credit crunch than a traditional bank run.

In this context which state the importance of microstructure of the funding markets, there is growing literature trying to shed light over the effectiveness of the Quantitative Easing and Credit Easing measures and the pass through mechanism from eligible to non eligible bonds. D'amico and Kaminska (D'Amico & Kaminska, 2019) study the effects of the Bank of England's QE and CE mesures on corporate bond prices and issuance. One of their results is that CE is much more effective than QE in reducing spreads and that for QE the pass through of the supply shock to corporate prices is significant. Shah and Maiki (Shah *et al.*, 2018) in the same line show that QE caused significant reduction in equity risk premiums (ERP) for the S&P 500.

These debates prove the importance of the eligibility criteria of the unconventional monetary policy and were an inspiration for this work, together with the recient pandemic that brought the need of these kind of policies again. As Covid-19 became a global pandemic in March 11, 2020 these policies resurfaced. The FOMC lowered the Federal Funds rate until it reached the zero lower bound in March 15, 2020. At this early point, conventional monetary policy was exhausted so measures resembling the monetary policy held under Bernanke's administration became necessary. The Figure below taken by a Brookings Institution article (Milstein & Wessel, 2021) show the number of facilities implemented to channel the unconventional monetary policy during Covid-19 pandemic. As it is observed, there were independent facilities for each segments or tranche of the financial markets: households, businesses, governments and financial markets. Each facility was design with it´s own eligibility criteria, amount of intervention and duration to target a specific sector of the economy.

Pandemic-era Federal Reserve facilities

The Fed established various emergency lending programs under Section 13(3) of the Federal Reserve Act to support households, businesses, governments, and financial markets.

Facility	Sector targeted	Funding	Date announced	Date opened	Date closed	Maximum capacity ($ bil.)	Peak assets ($ bil.)	Assets as of 12/8/21 ($ bil.)	Treasury backstop ($ bil.)
Commercial Paper Funding Facility (CPFF)	Commercial paper market	Fed, Treasury (ESF)	3/17/20	4/14/20	3/31/21	Unlimited	4.2	0.0	10.0
Main Street Lending Program (MSLP)*	Small and mid-sized businesses, non-profits	Fed, Treasury (CARES Act)	4/9/20	7/6/20†	1/8/21	600.0	16.6	13.4	75.0
Money Market Mutual Fund Liquidity Facility (MMLF)	Money market mutual funds	Fed, Treasury (ESF)	3/18/20	3/23/20	3/31/21	Unlimited	53.2	0.0	10.0
Municipal Liquidity Facility (MLF)*	State and local governments	Fed, Treasury (CARES Act)	4/9/20	5/26/20	12/31/20	500.0	6.4	4.2	35.0
Paycheck Protection Program Liquidity Facility (PPPLF)*	Small businesses	Fed	4/9/20	4/16/20	7/30/21	953.0‡	90.6	39.9	-
Primary Dealer Credit Facility (PDCF)	Broker-dealers	Fed	3/17/20	3/20/20	3/31/21	Unlimited	33.4	0.0	-
Primary Market Corporate Credit Facility (PMCCF)*	Large businesses	Fed, Treasury (CARES Act)	3/23/20	6/29/20	12/31/20	750.0	0.0	0.0	50.0
Secondary Market Corporate Credit Facility (SMCCF)*	Large businesses, exchange-traded funds	Fed, Treasury (CARES Act)	3/23/20	5/12/20†	12/31/20	Combined with PMCCF	14.3	0.0	25.0
Term Asset-Backed Securities Loan Facility (TALF)	Securities markets (e.g. student, auto, & credit card loans)	Fed, Treasury (CARES Act)	3/23/20	6/17/20	12/31/20	100.0	4.1	1.4	10.0

Source: Federal Reserve. ESF refers to the Treasury's Exchange Stabilization Fund.

* Programs new for 2020.

† The MSLP began purchasing loan participations on 7/6/20 for for-profit businesses and 9/4/20 for nonprofits. The SMCCF began purchasing ETFs on 5/12/20 and corporate bonds on 6/16/20.

‡ The PPPLF maximum capacity listed is the amount allocated to the PPP by Congress.

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Figure 3: Federal Reserve facilities during the Covid-19 Pandemic

Recent papers study how effective are the current measures taken by the Fed against Covid-19. D'amico, Kurakula and Lee (D'Amico *et al.*, 2020) find that the announcement of the Primary and Secondary Market Corporate Credit Facilities triggered large and positive jumps in eligible ETFs and their close substitutes, a discrete drop in credit risk perceived and a back-off of IG issuance together with a pick up of HY issuance. Gilchrist, Wei, Yue and Zakrajsek (Gilchrist *et al.*, 2020) study the efficacy of the Secondary Market Corporate Credit Facility and through a diff in diff analysis they show that the announcement had large effects on credit spreads, narrowing spreads 20 basis points on eligible bonds relative to their ineligible counterparties. This lowering spread had a larger effect on fallen angels (downgraded issuers from IG to HY).

In the light of this progress it can be observed that financial markets are highly interconnected with multiple funding sources, so the dry ups or runs may occur in particular market structures or tranches. If the run spreads and leads to a financial panic, it will bring systemic risk of a depression in the real economy. This characteristic states the importance of studying the unconventional monetary policy design of the central banks. In this sense, it can be concluded from the literature reviewed that the Fed action has a pass-through effect from eligible to non eligible issuers, but that mechanism is not perfect. Moreover, the common measure for the efficiency of the policy are spreads. These discussions bring us to the second question raised before: it is interesting to analyse the macroeconomic impact of this credit easing policies design.

It becomes then a relevant matter to study in a general equilibrium framework. As stated by former chairman Bernanke (B. Bernanke, 2009), the Federal Reserve's unconventional monetary policy approach focuses on the mix of loans and securities that it holds and on how this composition of assets affects credit conditions for households and businesses. This is why he defines the term as credit easing which is intended to stimulate aggregate demand by reducing spreads and improving the functioning of private markets, affected by wider spreads and dysfunctional credit markets. This particularly entwined and dysfunctional private markets demanded a specific design of unconventional monetary policy. The literature discussed above showed that runs resembling a credit crunch happened in particular segments of these dysfunctional private markets, although it implied systemic risks. Moreover, it proves that channeled unconventional monetary policy was effective in terms of credit spreads narrowing and with a certain pass through to segments not directly covered by the policy. To continue with this path and add to these discussions, it would be interesting to understand the macroeconomic impact of these credit easing programs in terms of output, inflation and key nominal and real variables through a general equilibrium approach.

The results of my work go in line with DEFK as the model explains more than 50% of the output drop after Lehman episode and around 75% of the inflation drop. Due to the eligibility criteria the quantitative results are slightly smaller relative to DEFK which might imply a small degree of over-prediction of gains. The great escape is confirmed by the IGE Model results, as there are important gains of unconventional monetary policy in a context resembling the Great Depression, although the statement that other shocks happened that explain the drop in output and inflation is reinforced because of the slight over-prediction of gains explained by the design of the unconventional monetary policy. Finally a deep dive into the policy design impact shows that if the policy is implemented in the stressed markets, the shock is quickly reverted and if the magnitude of the intervention is large it might prove inflationary and persistent, which makes it hard to tame. On the contrary, if the policy is directed to markets which are not stressed, there is a full scale recession and the pass through of the backstop is minimal, measured in terms of output and inflation gains.

In Section 2 I present the model in detail following DEFK, and I describe in depth the modifications made to account for this mechanism. In Section 3 I present the Calibration following the authors, with the description of the two new parameters that I include to account for this mechanism. In Section 4 I discuss the quantitative results, comparing them to the DEFK model and the data. Finally, I conclude the paper with some final remarks on the results.

2 The Model

This section introduces the model following DEFK (Del Negro *et al.*, 2017). It is a closed economy which has three main components: the household, the firms and the government. The main driver of the dynamics in this framework are the financial frictions, that will be described as the variations that I introduce to the model are presented in detail. The main focus of this paper is to lift an assumption of the financial frictions to shed some light over the macroeconomic effect of the eligibility criteria through which the unconventional monetary policy is channeled, a typical characteristic of the credit easing policies implemented by the Federal Reserve. The full details of the model are included in the Appendix following the presentation of the benchmark model (Del Negro *et al.*, 2017).

2.1 Household

Following the authors of the benchmark model, I build an economy populated by a continuum of identical households of measure one. Each household consists of a continuum of members indexed by j $\in$ [0, 1]. In every period, household members receive an i.i.d. draw that determines whether they are entrepreneurs or workers. The probability of being an entrepreneur is χ, which, by the law of large numbers, is also the fraction of entrepreneurs in the household. Each entrepreneur j $\in [0,\chi)$ has an opportunity to invest but does not work. Each worker member j $\in [\chi,1]$ supplies differentiated labor of type j but does not invest. The friction described below affects the transfer of funds from those who do not have an investment opportunity (the workers) to those who do (the entrepreneurs).

Let $C_t(j)$ denote the amount of the consumption good each member of the household purchases in the market place in period t. I hold the assumption for the representative household structure that, at the end of the period, all members bring the consumption purchases back to the household, and these goods get distributed equally among all members. Utility thus depends upon the sum of all the consumption goods bought by the different household members

$$C_t \equiv \int_0^1 C_t(j)dj \tag{1}$$

Let $H_t(j)$ be the hours worked by worker member j, then the household's objective will be to maximize the following expression

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{C_s^{1-\sigma}}{1-\sigma} - \frac{\omega}{1+\nu} \int_{\chi}^{1} H_s(j)^{1+\nu} dj \right] \tag{2}$$

where $\beta \in (0,1)$ is the subjective discount factor, $\sigma > 0$ is the coefficient of relative risk aversion, $\nu > 0$ is the inverse of Frisch elasticity of labor supply and $\omega > 0$ is a parameter that pins down the steady-state level of hours.

At the end of each period, the household also shares all the assets accumulated during the period among members. Entering the next period, therefore, each member holds an equal share of the household's assets. An important assumption I hold from the benchmark model is that, after the idiosyncratic shock is realized and each member knows its type, the household cannot reshuffle the allocation of resources among its members. Instead, those household members who would like to obtain more funds need to seek the money from other sources. The figure below taken from DEFK (Del Negro *et al.*, 2017) shows the household's balance sheet at the beginning of period t, expressed in terms of consumption goods. The bonds and others' equity together with the capital stock are on the Asset side of the sheet while the equity issued is on the Liabilities side. It is expressed in real terms.

Household's Balance Sheet (Tradable Assets)			
Assets		Liabilities	
nominal bonds	B_t/P_t	equity issued	$q_t N_t^I$
others' equity	$q_t N_t^O$		
capital stock	$q_t K_t$	net worth	$q_t N_t + B_t/P_t$

Figure 4: Household's Balance Sheet

Households own government-issued nominal bonds B_t, where P_t is the price level, K_t is physical capital, and N_t^O represents claims on other households' capital. Households' liabilities consist of claims on own capital sold to other households N_t^I , and net equity N_t is defined as

$$N_{t+1} = N_{t+1}^O + K_{t+1} - N_{t+1}^I \tag{3}$$

The household is subject to two financial frictions that constraint the evolution of assets and liabilities. Each entrepreneur cannot issue new equity more than a fraction θ of the investment undertaken in the current period plus a fraction $\phi_t^I \in (0,1)$ of the undepreciated capital stock previously not mortgaged $(K_t - N_t^I)$. Therefore, equity issued evolves according to

$$N_{t+1}^I \leq (1-\delta)N_t^I + \theta I_t(j) + (1-\delta)\phi_t^I(K_t - N_t^I)$$

Similarly, the entrepreneur cannot sell more than a fraction ϕ_t^O of holdings of the others' equity remained. Therefore, others' equity evolves according to

$$N_{t+1}^O \geq (1-\delta)N_t^O - (1-\delta)\phi_t^O N_t^O$$

The key assumption that is lifted to account for the eligibility criteria mechanism consists of considering different resaleability constraint for assets and liabilities. This way, I depart from the original model and the entrepreneur will face two different constraints. The assumption of the benchmark model is defined by $\phi_t^I = \phi_t^O = \phi_t$. This implies that the Fed can act over the net position of the household, as the constraint acts over the net position of the household N_t.

Departing from this assumption is interesting as it allows for an approach towards the macroeconomic effect of a partial intervention. As the policy might not affect all the financial instruments due to restrictions of the central authority (for example, administrative, legal, implementation limitations) and the pass through of the stress relieve measures might not be perfect, it is worth considering this possibility. As described before, in the implementation of the Fed policies there are different facilities for different sectors in the economy, which use different assets as collateral for liquidity provision, each with its own eligibility criteria. Moreover, there might exist legal limitations as it might not be able to reach for the stressed trench of the financial markets or the institution. Therefore, I find relevant this exercise as there might be a macroeconomic effect in the implementation of the policy due to this mechanism.

The flow chart presented below in Figure 5 shows the investment process of the household. The key aspect of the dynamics in the model are the financial frictions, the reason why the entrepreneur needs multiple funding sources to invest. As usual part of the investment is covered with capital she owns, another source are the equity issued (pledge on the capital she owns) and the assets resale (resale of capital pledged by other individuals). Entrepreneurs have limitations in the assets they can bring to the market to rise funding, the capital mortgaged and the benefits they can pledge from future benefits of the investments. So in the market, the household will seek funding until the indifference between assets, liabilities, investment and consumption as will be shown in the first order conditions below. The flow shows a key assumption from the benchmark model and sustained in this work that consist on the aggregation and equal distribution of resources between the individuals of the household to face the next period. As the shock that drives the economy away from the steady state is a liquidity shock, this mechanism is the central feature of the dynamics of the model.

The entrepreneur will face a financial cost for issuing equity, which is an addition to the model relative to the benchmark. This means that the household will need to allocate resources to pay for this financial cost in order to issue equity, thus increasing its liabilities. The decision on the liabilities position N_{t+1}^{I} today will include the financial cost. This term is included to pin down the dynamics of the model, as it works as a wedge between the assets and liabilities of the household.

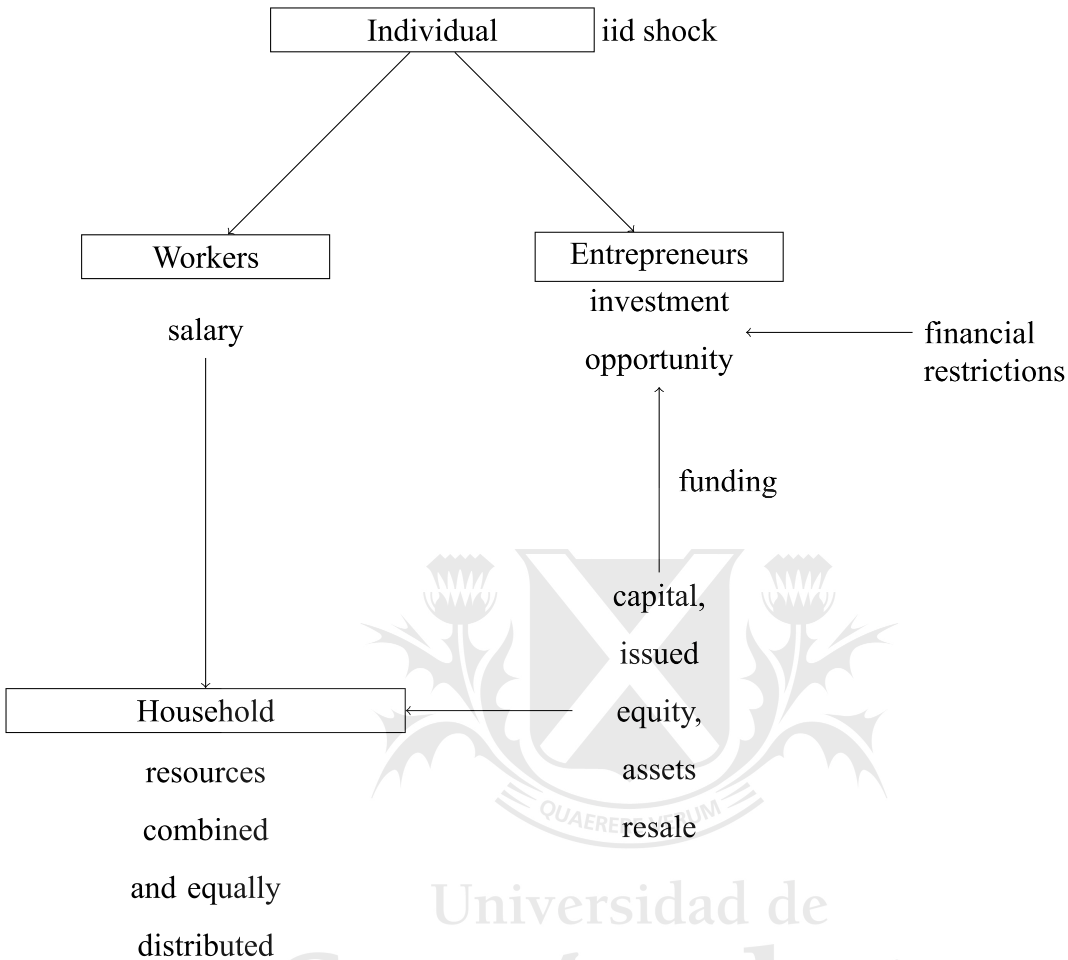


Figure 5: Household Investment Flow Chart

This way it is not going to be trivial the funding decision of the household between assets and liabilities sells. The consequence of introducing this financial cost is that the economy will return to the steady state after receiving the shocks.

$$\frac{\alpha}{2}(N^I_{t+1} - \overline{N^I})^2 \tag{4}$$

The owner of the capital will receive the rental income as well as the intermediate good producers and capital goods producers as dividend in proportion of capital ownership. The dividend per capital of ownership is defined as

$$R_t^k = r_t^k + \frac{D_t + D_t^I}{K_t}$$

were $D_t = \int_0^1 D_t(i)di$ are the per period real profit of intermediate goods producers and D_t^I are the per period real profit of capital good producers.

Considering this, budget constraint of the household is given by the following expression

$$\begin{aligned} &C_t(j) + p_t^I I_t(j) + q_t[N_{t+1}(j) - I_t(j)] + \frac{B_{t+1}(j)}{P_t} + \alpha(N_{t+1}^I - \overline{N}^I)^2 q_t \\ &= [R_t^k + (1-\delta)q_t]N_t + \frac{R_{t-1}B_t}{P_t} + \frac{W_t(j)}{P_t}H_s(j) - \tau_t \end{aligned} \tag{5}$$

The left hand side of equation (5) shows the uses of the resources held by the household, which are the consumption of the real good produced in the economy $C_t(j)$, the investment opportunity $I_t(j)$, the private equity purchase, the liquid paper provided by the government and the financial cost paid to issue equity. On the left side it is observed the source of wealth of the household: the interest produced by the net worth position (holdings of private equity and capital), interest of the government issued liquid bond and the salary, net of the lump sum tax τ.

Equation (5) holds with the definition provided in equation number (3). Considering this, the liquidity constraints are considered inside the budget constraint number (5). These liquidity constraints faced by the household are the following, for liabilities and assets respectively:

$$N_{t+1}^I = (1-\delta)N_t^I + \theta I_t(j) + (1-\delta)\phi_t^I(K_t - N_t^I)$$

$$N_{t+1}^O = (1-\delta)N_t^O - (1-\delta)\phi_t^O N_t^O$$

The bonds are considered to be government paper and it is assumed to be free of resaleability constraint, so are considered perfectly liquid. Households can only take a long position in it, so the perfectly liquid government paper is subject to the following constraint

$$B_{t+1}(j) \geq 0 \tag{6}$$

At the end of each period, the aggregated quantities are given by the following expressions

$$N_{t+1}^{O} = \int N_{t+1}^{O}(j)dj \tag{7}$$

$$N_{t+1}^{I} = \int N_{t+1}^{I}(j)dj \tag{8}$$

$$B_{t+1} = \int B_{t+1}(j)dj \tag{9}$$

$$K_{t+1} = (1-\delta)K_t + \int I_t(j)dj \tag{10}$$

2.1.1 Entrepreneurs

This subsection derives the investment equation that is essential for the entrepreneurs' decision and provides more detail of the financial friction introduced in this paper.

From the derivation above I get the expressions

$$N_{t+1}^{I} = (1-\delta)N_t^{I} + \theta I_t(j) + (1-\delta)\phi_t^{I}(K_t - N_t^{I}) \tag{11}$$

$$N_{t+1}^{O} = (1-\delta)N_t^{O} - (1-\delta)\phi_t^{O}N_t^{O} \tag{12}$$

$$B_{t+1}(j) = 0 \tag{13}$$

$$C_t(j) = 0 \tag{14}$$

As stated by the authors (Del Negro *et al.*, 2017), budget constraint (5) with $H_t(j) = 0$ gives the flow of funds of the entrepreneur. From this expression is clear that as long as the market price of equity q_t is larger than the price of newly produced capital p_t, entrepreneurs trying to maximize household´s utility will use all available resources to create capital. In this subset of equilibria

($q_t > p_t$) the entrepreneur will find much more profitable to sell all holdings of government and turn to private equity, so she will sell as much equity as she can and issue the maximum amount possible of equity to take advantage of this profitable spread. Because of this, equations (11)-(14) are binding.

I will now proceed to replace these equations -(11)-(14)- into the budget constraint of the household (5) to get the new investment equation. Working with the term $[\, N_{t+1} - I_t(j)\,]$ of the budget constraint and using our new net equity definition I get

$$C_t(j) + p_t^i\, I_t(j) + q_t\,[N_{t+1}^O(j) + K_{t+1}(j) - N_{t+1}^I(j) - I_t(j)] + \frac{B_{t+1}}{P_t} + \frac{\alpha}{2}(N_{t+1}^I - \overline{N}^I)^2\, q_t$$
$$= [\, R_t^k + (1-\delta)\, q_t\,]\, [N_t^O(j) + K_t(j) - N_t^I(j)] - \tau_t + \frac{(R_{t-1}B_t)}{P_t}$$

I begin with the following, using definitions in equations (11) and (12)

$$p_t^i\, I_t(j) + q_t\,[(1-\delta)\, N_t^O - (1-\delta)\, N_t^O\, \phi_t^O - (1-\delta)\, N_t^I - \theta\, I_t(j) - (1-\delta)\, \phi_t^i\, (K_t - N_t^I)$$
$$+ \frac{\alpha}{2}(N_t^I - \overline{N}^I)^2\, q_t - I_t(j) + K_{t+1}] = [\, R_t^k + (1-\delta)\, q_t\,]\, [N_t^O(j) + K_t(j) - N_t^I(j)] - \tau_t + \frac{(R_{t-1}B_t)}{P_t}$$

then

$$p_t^i\, I_t(j) + q_t\,[(1-\delta)(1-\phi_t^O)\, N_t^O - (1-\delta)\,(1-\phi_t^I)\, N_t^I + \frac{\alpha}{2}(N_t^I - \overline{N}^I)^2\, q_t + (1-\delta)\, \phi_t^I\, K_t$$
$$+ \theta I_t(j)] = [\, R_t^k + (1-\delta)\, q_t\,]\, [N_t^O(j) + K_t(j) - N_t^I(j)] - \tau_t + \frac{(R_{t-1}B_t)}{P_t}$$

finally I arrive to the equation

$$(p_t^i - q_t\, \theta) I_t(j) = q_t\,[(1-\delta)\,(1-\phi_t^I)\, N_t^I - (1-\delta)\, \phi_t^I\, K_t - (1-\delta)(1-\phi_t^O)\, N_t^O] - \frac{\alpha}{2}(N_t^I - \overline{N}^I)^2\, q_t$$
$$+ R_t^k\, [N_t^O(j) + K_t(j) - N_t^I] + (1-\delta)\, q_t\, [N_t^O(j) + K_t(j) - N_t^I] - \tau_t + \frac{(R_{t-1}B_t)}{P_t}$$

Rearranging terms I get the final expression for Investment

$$I_t(j) = \frac{[\, R_t^k + (1-\delta)\, q_t\, \phi_t^O\,]\, N_t^O + [\, R_t^k + (1-\delta)\, q_t\, \phi_t^I\,][\, K_t - N_t^I] - \frac{\alpha}{2}(N_t^I - \overline{N}^I)^2\, q_t - \tau_t + \frac{(R_{t-1}B_t)}{P_t}}{(p_t^i - q_t\, \theta)} \tag{15}$$

This expression is the equivalent of equation (13) of the benchmark DEFK (Del Negro *et al.*, 2017) model. It shows that there is an effect on the investment of the individual when there is a liquidity spread between assets and liabilities. Whenever assets constraint gets tighter, there is a negative impact on investment as there is less funding available.

The aggregate investment of the economy is defined as follows

$$I_t = \int_0^{\chi} I_t(j)dj$$
$$= \frac{[\,R^k_t + (1-\delta)\,q_t\,\phi^O_t\,]\,[N_t + N^I_t - K_t] + [\,R^k_t + (1-\delta)\,q_t\,\phi^I_t\,][\,K_t - N^I_t] - \frac{\alpha}{2}(N^I_t - \overline{N}^I)^2\,q_t - \tau_t + \frac{(R_{t-1}B_t)}{P_t}}{(p^i_t - q_t\,\theta)}$$

The denominator represents the liquidity needs for one unit of investment (the gap between the investment goods price and the amount the entrepreneur can finance by issuing equity), similar to DEFK model. On the numerator it is observed the effects of the different liquidity constraints. If the assets liquidity tightens up (ϕ^O_t decreases), other things equal, there is less liquidity available in the economy. There is a spread increase with negative impact through the asset channel. This term tries to capture the macroeconomic effect of a discrepancy in liquidity between the household's assets and liabilities mentioned above.

I follow DEFK (Del Negro *et al.*, 2017) and define the real value of liquid assets at the end of the period as follows

$$L_{t+1} \equiv \frac{B_{t+1}}{P_t}$$

Then I can rewrite the aggregated investment of the economy as follows:

$$I_t = \int_0^{\chi} I_t(j)dj \tag{16}$$
$$= \frac{[\,R^k_t + (1-\delta)\,q_t\,\phi^O_t\,]\,[N_t + N^I_t - K_t] + [\,R^k_t + (1-\delta)\,q_t\,\phi^I_t\,][\,K_t - N^I_t] - \frac{\alpha}{2}(N^I_t - \overline{N}^I)^2\,q_t - \tau_t + \frac{R_{t-1}\,L_t}{\pi_t}}{(p^i_t - q_t\,\theta)}$$

2.1.2 Workers

Aggregation of workers' and entrepreneurs' budget constraint, considering definition presented in equation (3) in order to account for the assets and liabilities constraints

$$\begin{aligned} C_t + p^I_t I_t + q_t[N^O_{t+1} + K_{t+1} - N^I_{t+1} - I_t] + \frac{B_{t+1}}{P_t} + \frac{\alpha}{2}(N^I_t - \overline{N}^I)^2\,q_t \\ = [R^k_t + (1-\delta)q_t][N^O_t + K_t - N^I_t] + \frac{R_{t-1}B_t}{P_t} + \int_{\chi}^{1} \frac{W_t(j)H_t}{P_t}dj - \tau_t \end{aligned} \tag{17}$$

2.1.3 Optimality Conditions

Households choose C_t, I_t, N^I_{t+1}, $N^O_{t+1}$and B_{t+1} in order to maximize utility (2) subject to (16) and (17). The decision faced by the household is expressed in the following Lagrangian.

$$\mathbb{E}_t \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\omega}{1+\nu} \int_{\chi}^{1} H_t^{1+\nu} dj \right] \right.$$
$$+ \xi_{t+s} \left\{ [R_{t^k} + (1-\delta) q_t] N_t + \frac{B_{t-1} B_t}{P_t} + \frac{W_t H_t}{P_t} + \tau_t - C_t \right.$$
$$\left. - p_t^I I_t - q_t [N_{t+1} - I_t] - \frac{B_{t+1}}{P_t} - \frac{\alpha}{2} (N_t^I - \overline{N}^I)^2 \, q_t \right\} + \eta_{t+s}$$
$$\left\{ \left[\frac{[\, R_t^k + (1-\delta)\, q_t\, \phi_t^O \,]\, [N_t + N_t^I - K_t] + [\, R_t^k + (1-\delta)\, q_t\, \phi_t^I \,][\, K_t - N_t^I] \, - \frac{\alpha}{2} (N_t^I - \overline{N}^I)^2 q_t + \frac{B_{t-1} B_t}{P_t} - \tau_t}{(p_t^I - \theta q_t)} \right] \chi \right.$$
$$\left. \left. - I_t \right\} \right\}$$

The first order conditions are the following, with η_t and ξ_t as the Lagrange multipliers of (16) and (17), respectively:

$[C_t]$

$$C_t^{-\sigma} = \xi_t$$

$[I_t]$

$$\xi_t (q_t - p_t^I) = \eta_t$$

$[B_{t+1}]$

$$\xi_t = \beta_t \mathbb{E}_t \left[\frac{R_t}{\pi_{t+1}} \left(\xi_{t+1} + \eta_{t+1} \frac{\chi}{p_{t+1}^I - \theta_{t+1} q_{t+1}} \right) \right]$$

$[N^O_{t+1}]$

$$q_t \xi_t = \beta_t \mathbb{E}_t \left\{ \xi_{t+1} [R_{t+1}^k + (1-\delta) q_{t+1}] + \chi \frac{[R_{t+1}^k + (1-\delta) q_{t+1} \phi_{t+1}^O]}{(p_{t+1}^I - \theta q_{t+1})} \eta_{t+1} \right\}$$

$[N^I_{t+1}]$

$$q_t \left[\xi_t - \left(\xi_t + \eta_t \frac{\chi}{(p_t^I - \theta q_t)} \right) \alpha (N_{t+1}^I - \overline{N}^I) \right] = \beta_t \mathbb{E}_t \left\{ -\xi_{t+1} [R_{t+1}^k + (1-\delta) q_{t+1}] \right.$$
$$\left. - \chi \frac{[R_{t+1}^k + (1-\delta) q_{t+1} \phi_{t+1}^I]}{(p_{t+1}^I - \theta q_{t+1})} \eta_{t+1} \right\}$$

It stems from the first order conditions that the household chooses investment determined by the spread between the private asset price and the price of investment, in terms of consumption of the only final good produced in the economy. Following DEFK (Del Negro *et al.*, 2017) I focus in the equilibria $q_t > p_t^I$. For the financial assets it is observed the effect of the convenience yield in the Euler equations. In the government bond market the household is indifferent upon buying and additional unit if it is compensated by the real interest rate plus an effect of the convenience yield. This means that a drop in the private asset price q_t, then the price of future consumption drops, which means a tight market. The assets hold a similar condition with the additional effect of the resaleability constraint ϕ^O. If the constraint tightens (drop in ϕ^O), the price of future consumption drops and the effect is similar. The liabilities condition is analogous, but affected by the other constraint ϕ^I. The only difference is the financial cost of issuing equity. This confirms that the household has a cost in terms of consumption of the final goods for issuing equity and it is affected by the convenience yield.

I first define the premium of liquidity from relaxing the investment constraint as

$$\Lambda_t = \chi \frac{q_t - p_t^I}{p_t^I - \theta q_t} \tag{18}$$

I follow the DEFK model and define the convenience yield as the expected value of the premium of liquidity of the next period as

$$CY_t = \mathbb{E}_t(\Lambda_{t+1}) \tag{19}$$

Replacing the first order conditions of consumption and investment into the first order conditions of the perfectly liquid government paper, net equity and the assets of the household, respectively, and focusing on the $(q_t > p_t^I)$ set of results I get the following expressions.

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ C_{t+1}^{-\sigma} \frac{R_t}{\pi_{t+1}} \left[1 + \Lambda_{t+1} \right] \right\} \tag{20}$$

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ C_{t+1}^{-\sigma} \frac{R_{t+1}^k + (1-\delta) q_{t+1}}{q_t} \left[1 + \Lambda_{t+1} \frac{R_{t+1}^k + (1-\delta) q_{t+1} \phi_{t+1}^O}{R_{t+1}^k + (1-\delta) q_{t+1}} \right] \right\} \tag{21}$$

$$C_t^{-\sigma}\left[1-\left(1+\Lambda_t\right)\alpha(N_{t+1}^I - \overline{N}^I\right] = \beta\mathbb{E}_t\left\{C_{t+1}^{-\sigma}\frac{R_{t+1}^k+(1-\delta)q_{t+1}}{q_t}\left[1+\Lambda_{t+1}\frac{R_{t+1}^k+(1-\delta)q_{t+1}\phi_{t+1}^I}{R_{t+1}^k+(1-\delta)q_{t+1}}\right]\right\} \quad (22)$$

Equations (16), (17), (18), (19), (20), (21) and (22) describe the household's choice of investment, consumption and portfolio for a given set of prices.

2.1.4 Comments on the Mechanics of the Household

It stems from the resolution of the problem above that capital and financial instruments are almost perfect substitutes, as the difference is only given by the financial frictions. In fact, financial instruments are pledge on capital. The problem might be considered almost of a representative agent in the aggregation as by assumption individuals consolidate their positions at the end of each period, in which the assets and liabilities are equal. This reinforces the statement of substitution between capital and financial instruments. However, in the marginal decision the model might be considered of heterogeneous agents, as the entrepreneur and the worker have different decisions to make. The entrepreneur is limited in the possibility of using her own capital to finance the investment, and it is limited in the possibility of selling assets in the market to gather funds. These limitations work as a wedge between capital and financial instruments in the margin as it needs both to carry on the investment opportunity. This means that the marginal decision of this heterogeneous agents leaves a trace in the aggregate, which is why there are no perfect substitutes. This trace is given by the financial frictions.

It will be explored below in the Results section the possibility of public policy oriented to stressed markets only (for example, a reaction of the government to a liquidity squeeze in the assets markets) with the goal of assessing the power of eligibility criteria in unconventional monetary policy. This is possible through this framework because of the trace described above in these comments. As in the marginal decision the household faces two different financial constraints when going to the market, it is possible in the aggregation to assess the squeeze in liquidity produced by each of the frictions separately. The liquidity is provided changing the aggregated portfolio position of the private sector which is defined considering both financial instruments as a consequence of the marginal trace described above, thus the important relation between the aggregated portfolio position and the individual marginal decision of the household. This is what allows for the numerical exercises performed in Section 4 of this work.

2.2 Convenience Yield

From this subsection on, the definitions and derivations are equivalent to the DEFK model (Del Negro *et al.*, 2017), with the exceptions of equation (26), (30) and (32).

The authors use the convenience yield, as defined by Krishnamurthy and Vissing-Jorgensen (Krishnamurthy & Vissing-Jorgensen, 2012), to account for the premium that the agents are willing to pay for holding Treasuries, which are assumed to be more liquid than the privately issued paper. This yield arises in the model because liquid assets relax the financing constraint in the next period.

$$CY_t = \left[\frac{\chi(q_{t+1} - p^I_{t+1})}{p^I_{t+1} - \theta q_{t+1}}\right] \tag{23}$$

The authors express CY_t as a spread because is the way it is observed in the data. As shown in the optimality conditions of the household, the gross nominal interest rate in the liquid one-period asset satisfies Euler equation (20). Then the Euler equation of a security not offering convenience services (other things equal) becomes

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ C_{t+1}^{-\sigma} \frac{R_t^0}{\pi_{t+1}} \right\} \tag{24}$$

Where R_t^0 is the gross nominal interest rate.

2.3 Government

In this economy the government has three ways of conducting public policy: conventional monetary policy, fiscal policy and unconventional monetary policy, also known as credit easing policy. Together they form the government budget constraint.

Conventional monetary policy is given by equation (25) below and consist of setting the nominal interest rate following as standard feedback rule and subject to the zero lower bound, with $\psi_\pi > 0$ and $\psi_y > 0$.

$$R_t = \max \left\{ R\pi_t^{\psi_\pi} \left(\frac{Y_t}{Y} \right)^{\psi_y}, 1 \right\} \tag{25}$$

Credit easing policy consist of buying private paper, given by N_{t+1}^g as a function of liquidity of the assets.

$$N_{t+1}^g = \psi \left(\phi_t^O - \phi^O \right) \tag{26}$$

This rule is similar to the DEFK model, but the government will step into the market and provide aggregate liquidity only when the liquidity of the assets is tight enough relative to a steady state parameter. With this rule I try to account for the effect of the eligibility criteria channel, as it will not step in when the liquidity on the liabilities side is tight. This action changes the aggregated composition of the portfolio, which aims to capture the macroeconomic impact of the eligibility criteria of the Fed's liquidity facilities.

The government budget constraint is given by the following expression

$$q_t N_{t+1}^g + \frac{R_{t-1}B_t}{P_t} = \tau_t + \left[R_t^k + (1-\delta)q_t \right] N_t^g + \frac{B_{t+1}}{t} \tag{27}$$

The funding of the government relies on net taxes, income of equity holdings and bonds issuance. The uses of that funding are paying debt and purchasing private paper. Considering this, the government is subject to a solvency rule given by equation (28).

$$\tau_t - \tau = \psi_\tau \left[\left(\frac{R_{t-1}B_t}{P_t} \frac{RB}{P} \right) \right] - q_t N_t^g \tag{28}$$

2.4 Market Clearing and Equilibrium

Market-clearing conditions for composite labor and capital use are

$$H_t = \int_0^1 H_i t di$$

and

$$K_t = \int_0^1 K_i t di$$

In equilibrium, capital evolves according to the following rule

$$K_{t+1} = (1-\delta)K_t + I_t \tag{29}$$

Capital stock is owned by either households or government according to

$$K_{t+1} = N_{t+1} + N_{t+1}^g \tag{30}$$

And the aggregate resource constraint requires that

$$Y_t = C_t + \left[1 + S\left(\frac{I_t}{I}\right)\right] I_t \tag{31}$$

and the following assumption is used as a clearing condition

$$N_{t+1}^I = N_{t+1}^O \tag{32}$$

The total factor productivity and resaleability $(A_t, \phi_t^O, \phi_t^I)$ follow an exogenous Markov process. In addition to these, I have five endogenous state variables of $(K_t, N_t^g, R_{t1}, L_t, w_{t1}, \Delta_{t1})$ - aggregate capital stock, government ownership of capital, a real liquidity measure, the real wage rate and the effect of price dispersion from the previous period. The recursive competitive equilibrium is given by ten quantities $(C_t, I_t, H_t, Y_t, \tau_t, K_{t+1}, N_{t+1}, N_t^g, N_t^O, L_{t+1})$, and fifteen t+1 prices $(R_t, q_t, {p^I}_t, w_t, {r^k}_t, {R^k}_t, mc_t, \lambda_t, \pi_t, {\pi^w}_t, {X^p}_{1t}, {X^p}_{2t}, {X^w}_{1t}, {X^w}_{2t}, \Delta_t)$ as a function of the state variables $(K_t, {N^g}_t, R_{t1} L_t, w_{t1,t1}, A_t, {\phi^O}_t, {\phi^I}_t)$ which satisfies the twenty five equilibrium conditions listed in the Appendix section, including the household budget constraint (17) which is satisfied by Walras' Law once all the market clearing condition and the government budget constraints are satisfied.

The following is the definition of expected rate of return on equity

$$R_t^q = \mathbb{E}_t\left[\frac{R_{t+1}^k + (1-\delta)q_{t+1}}{q_t}\right]$$

2.5 Comments About Model Assumptions

As explained above, the most important mechanism of this model are the financial frictions, through which the dynamics of the model occur. It is assumed that private individuals sell and buy assets directly in the financial markets, subject to the resaleability (for assets and for liabilities) and the limitation in equity that each individual can issue as a fraction of capital. The liquidity squeeze in this market produce the dynamics relevant for the analysis in variables such as Output, Inflation, interest rates, and more. By doing this some crucial aspects of the crisis are left aside, such as financial intermediaries (which where essential to explain the magnitude and extension of the crisis) and money, which was injected through the quantitative measures described above. This is a limitation of the model, despite the fact that there is a useful insight in this reduced approach.

Following the quote of Chairman Bernanke above, the concept of liquidity stated in the model is broad and complex. There is no money in the transactional role (similar to more traditional models such as Cash in Advance or Money in Utility) but there is credit in the role of allowing investment to occur through financial markets, as there are private agents with resources but no investment opportunities and other agents with investment opportunities but no resources. In this sense, the liquidity achieved through financial markets in the model is accurate to explore the squeeze experienced during the Great Recession. The price of this liquidity broad concept is expressed through the convenience yield, which is the base for the calibration of the model. This variable is considered a premium due to relaxation of the investment constraint (Del Negro *et al.*, 2017). By focusing in this variable which tries to capture the repo market liquidity shock, there are aspects that are left aside such as other components of the repo market or other commercial paper funding.

It should be noted, however, that further exploring the possibilities of financial intermediaries, fire sales of assets and the presence of money in a more traditional role is of high interest and value for future research. Channeling the public policy considering eligibility criteria through large interconnected financial institutions could add value to this framework as would capture an essential aspect of the crisis, for example showing how interconnected institutions spread financial panics and how the stress relieve policy in one institution or tranche has a pass through to the rest of the system. In that same line, considering money in the implementation through the description of a demand for money in this broad concept of liquidity might shed light over the dynamics of inflation in this process.

3 Data and Calibration

The calibration of the IGE model is based on the benchmark model, which is calibrated at quarterly frequency data that spans for (1953:I - 2008:III) in the United States. Figure 6 below shows the parameters calibrated in the DEFK model, as presented in DEFK (Del Negro *et al.*, 2017). In the following sections I describe briefly the calibration used by the authors and in much more detail the calibration process of the two parameters added in this paper.

3.1 Steady-State Parameters

For steady state parameters, the DEFK calibration consists of three main sources. Two are based on the empirical estimation of the convenience yield of Krishamurthy and Vissing-Jorgensen (Krishnamurthy & Vissing-Jorgensen, 2012) (KVJ) and the construction of the liquidity share based on the data of the Flow of Funds. And the third source is a sanity check performed once the calibration values were obtained, based on the computation of the average spread of each financial asset that belongs to a sample of daily data of 18 assets, and its associated degree of liquidity using an equation derived in section B.7 from the online appendix of the benchmark model. This sample was used in the calibration of the liquidity shock, so further details are provided in the following section.

The first source is the replication of the results from KVJ using the DEFK model, which provides two targets that will be the base of the steady state calibration: the steady state convenience yield and the average liquidity share (measured as Treasury bonds relative to GDP). The model provides an average convenience yield of 0.455 which is in line with the liquidity share of the sample data, 0.4.

The second source consist of the construction of the liquidity share using the Flow of Funds, defined as follows

$$LS_t = \frac{B_{t+1}}{B_{t+1} + P_t q_t K_{t+1}}$$

The construction is defined in section A.1 of the online appendix of DEFK. They take two quantities: B_{t+1} which is the dollar value of t US Government liabilities (empirical counterpart of the liquid assets in the model) and $P_t q_t K_{t+1}$ which are the net claims on private assets (consolidate balance sheet of household, non-corporate and corporate).

These two sources provide the targets from which the steady state values for the financial frictions are calibrated. As a sanity check for this calibration, the authors use the following equation derived in section B.7 of the online appendix (Del Negro *et al.*, 2017) as a sanity check

$$1 - \phi^j = \frac{1 + CY}{CY} \frac{(ytm^{T,j} - ytm^{T,l})\beta(1 + CY)}{1 + (ytm^{T,j} - ytm^{T,l})\beta(1 + CY)}$$

where $ytm^{T,j}$ and $ytm^{T,l}$ are the steady-state real yields to maturity for zero coupon bond j with maturity T and the liquid security of the same maturity (described in section B.7 of the online appendix of DEFK). This equation is used for computing the associated degree of liquidity, as ϕ^j accounts for the degree of liquidity of each of the assets j of a cross-section chosen by the authors. These assets are associated with liquidity as they are of different types and maturities. They used this equation with each asset on the set to get the liquidity component of each asset and calibrate the shock (this is described in the following subsection). This sanity check goes in line with the results obtained through the two sources described above. This process gives the steady state financial frictions parameters observed in Figure 6 below.

Two new parameters are introduced in this paper for the computation of the IGE Model, that are calibrated in the steady state using existing literature. The first one is the liabilities to capital ratio, upon which the steady state capital and assets are calibrated. This is based on the leverage and haircuts of the repo market pre-Recession. I follow the definitions provided by Geanokoplos

(Geanakoplos, 2010) and the assumption that $N^O = N^I$, so I get the following

$$\frac{Assets}{Liabilities} = \frac{N^O + K}{N^I} = Leverage$$

$$1 + \frac{K}{N^I} = Leverage$$

$$\frac{N^I}{K} = \frac{1}{Leverage - 1}$$

From Geanakoplos (Geanakoplos, 2010) I get that the average leverage pre-Lehman crash was approximately 33 to 1, which means a haircut of 3 percent. This means that households were able to take 100 in loans with only 3 in cash. This result goes in line with the haircuts provided by Gorton and Metrick (Gorton & Metrick, 2012). Taking Leverage as 33, I get a ratio of liabilities over capital of 0.03, which is used in the calibration of the model.

The other parameter is α which is calibrated as 0.1. The requirement for this parameter is to be greater than zero as there are no quantitative differences if this condition is met. The chosen number is 0.1, but Table 5 of the Appendix 7.4 shows the robustness of the model for calibrations of positive numbers with differences that goes from 0.1 to 1000. The table shows the numerical result for 16 quarters of Output for the liquidity shocks in the IGE Model with intervention. The same is true for the entire span of the shock (300 quarters) and for the rest of the variables.

3.2 Parameters Characterizing the Dynamics

These parameters are calibrated following the benchmark model DEFK (Del Negro *et al.*, 2017). As there are no new parameters in our model necessary to characterize the dynamics of the model, for the details of the calibration please consult DEFK (Del Negro *et al.*, 2017) and its online appendix.

3.3 Liquidity Shock and Policy Response

For the simulation of the crisis and the Great Escape exercise, I follow DEFK (Del Negro *et al.*, 2017) in the calibration of the shock. It is calibrated using a similar approach than the steady state:

the target will be the change in convenience yield. However, as there is no time series estimated to directly compare against the model, the authors take a different approach and the convenience yield is estimated using financial data.

Because the representative iliquid asset does not mirror directly a specific asset, the authors take a panel of 18 different assets of different maturity and type and take the common factor using 10 year time span of daily data. It is shown in the online appendix that the common factor explains most of the asset volatility, with few exceptions.

In order to replicate the convenience yield change of 180 basis points and use that shock as a target for the calibration, the average convenience yield of the 18 assets is compared against the asset with the largest liquidity shortage after Lehman: BBB CDS Bond. This asset has the largest liquidity shock (3.42 spread annualized). So computing the average convenience yield pre-crisis (1.33 spread annualized) and comparing it with the assumed iliquid asset gives a difference of approximately 210 basis points, which will be the value of the calibration (-0.218). The authors compare these results with Gorton and Metrick (Gorton & Metrick, 2012) and they find consistence. For the IGE model, I use the same calibration of the liquidity shock for both assets (N^O) and liabilities (N^I) markets, so both markets (through the definitions of ϕ^O and ϕ^I) are shocked with a -0.218 magnitude.

For the persistence of the shock ρ_ϕ, the authors define the shock to last 6 quarters, which is a mid point between Moore (Moore, 2008) and Rodebusch (Rudebusch *et al.*, 2009). The parameter ψ_K is calibrated to generate a government intervention of 10 percent of GDP (1.4T), consistent with increase in the asset side of the Fed. For the Great Escape exercise, the parameter is calibrated to last 20 quarters, as the idea is to simulate a shock that replicates the conditions of the Great Depression, where the shocks were binding for a much longer period. These two calibrations of the persistence of the shock are used in the Baseline scenario and Great Escape scenario, respectively.

For the purpose of the inside great escape analysis I used the same calibration as the IGE Model with intervention in the assets markets. Both liquidity markets are shocked with the same magnitude (-0.218) but one at a time. Otherwise, the calibration is the same than in the Baseline scenario.

Steady-state parameters

ϕ Resaleability constraint	θ Borrowing constraint	β Discount factor	$\varkappa$ Probability of investment opportunity	δ Depreciation rate	γ Capital share	$\frac{B/P}{4Y}$ Annualized s.s. liquidity
0.309	0.792	0.993	0.009	0.024	0.340	0.400

Parameters characterizing the dynamics

σ Relative risk aversion	ν Inverse Frisch elasticity	$S''(1)$ Investment adjustment cost	ζ_p Price Calvo probability	ζ_w Wage Calvo probability	λ_p Price s.s. markup	λ_w Wage s.s. markup
1.000	1.000	0.750	0.750	0.750	0.100	0.100

ψ_π Taylor rule inflation response	ψ_y Taylor rule output response	ψ_τ Tax rule response
1.500	0.125	0.100

Liquidity shock and policy response

Baseline			Great escape		
$\Delta\phi$ Size of liquidity shock (percent log change)	ρ_ϕ Shock persistence	ψ_k Policy intervention	$\Delta\phi$ Size of liquidity shock	ρ_ϕ Shock persistence	ψ_k Policy intervention
−0.218	0.953	−4.801	same	0.984	same

Notes: The table shows the parameter values of the model for the baseline calibration. The last row also reports the size and the persistence of the shock, and the coefficient in the government rule for purchases of private assets in the Great Escape calibration.

Figure 6: Parameters

4 Results

In this section I describe the results of the three quantitative exercises performed in this work. The exercises are defined as follows:

Simulating Financial Crisis. In this subsection I follow the authors and present the results for IGE model with Baseline calibration and compare it against DEFK (benchmark) model with Baseline calibration and the data for the period of the Great Recession. The exercise replicates the shock of the collapse of Lehman Brothers and the reaction of monetary policy to that particular event.

Great Escape. For this exercise I present the sensitivity analysis for Baseline and Great Escape scenarios. I compare the IGE model results with DEFK model, for both scenarios. Baseline is defined as the liquidity shock binding for 6 quarters while Great Escape is defined as a liquidity shock binding for 20 quarters. Otherwise calibrations are the same, as the aim of this sensitivity analysis is to replicate the conditions of the Great Depression and analyse the gains of unconventional monetary policy doing a quantitative analysis between an economy without unconventional monetary policy and the alternative with unconventional monetary policy, in the context of the Great Depression. For IGE Model, both assets and liabilities are shocked with the liquidity shock (so ϕ^O and ϕ^I both have a shock of -0.218) but there is only intervention in the assets markets N^O.

Inside the Great Escape. Once I stated the quantitative gains of a limited scope in the unconventional monetary policy relative to a full intervention in the net equity of the private sector, I deep dive in the eligibility criteria quantitative effect of the unconventional monetary policy. I take the Baseline scenario calibration of the IGE model with intervention in the assets markets and I compare the results for a shock only in the assets markets vs a shock only in the liability markets.

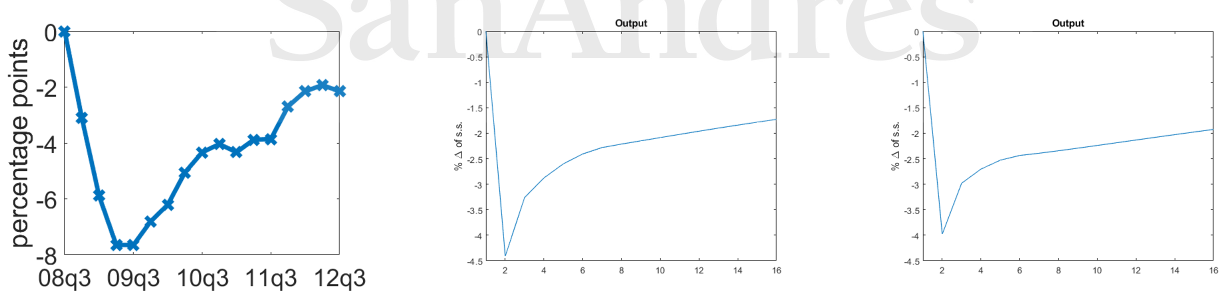
4.1 Simulating Financial Crisis: The Impact on Macroeconomic and Financial Variables

I follow the exercise of DEFK (Del Negro *et al.*, 2017) and present the response of output, inflation and the nominal interest rate to the liquidity shocks. Our exercise divert from the original in that the liquidity shock affects both assets and liabilities in the same magnitude (ϕ^O and ϕ^I in the model), but the government is able to provide liquidity through unconventional monetary policy only in response to the assets shock ϕ^O. So the liquidity shock in DEFK (ϕ) is of the same magnitude (-0.218) than the two affecting IGE model (ϕ^O and ϕ^I). Otherwise the design of the exercise is equivalent, which allows to directly compare the results. The results for complementary variables that complete the story of the economy response to the shock are also included.

The exercise is designed as follows: two large unexpected shocks hit the economy in t, coming from a steady state in t-1. Both have the same magnitude, and no more shocks occur in the future. As stated by the authors (Del Negro *et al.*, 2017), the model is solved using a Newton-Raphson algorithm to examine the nonlinear perfect foresight path, considering that the nominal interest rate may be constrained endogenously by the zero lower bound in the early stage. Figures 7 to 13 of below present the results. The right hand side plots the predicted path of the variables by IGE model, conditional on the liquidity shock on assets and liabilities of the same magnitude than the DEFK model with intervention only responsive to the assets liquidity shortage (-0.218 shock for ϕ^O and ϕ^I). The charts in the centre plot the predicted path of variables by the DEFK model for 16 quarters. The left column shows the changes in the data for 16 quarters as presented in DEFK (Del Negro *et al.*, 2017). The persistence of the shock is 6 quarters.

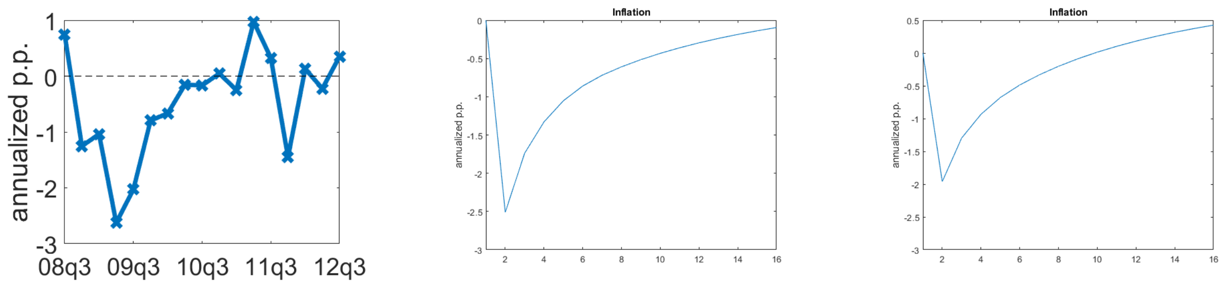
The authors (Del Negro *et al.*, 2017) find that the liquidity shock fails to account for three main aspects of the crisis following Lehman bankruptcy, which they consider are related. DEFK model underpredicts the equity prices drop, it accounts roughly for half of the output drop and the zero lower bound recovers after seven quarters, while it is observed in the data that it remained near zero for a longer period. This means that there are other shocks that explain the behavior of the variables not accounted for in the model. However, the behavior of the variables go in line with what is observed in the empirical counterparts. As they mention in their paper, it focuses on the macroeconomic consequences of the disruption in the financial system following Lehamn's bankruptcy, and the effect of the Federal Reserve policies to mitigate such a disruption.

For the IGE model results are expected to be in the same line, although quantitatively smaller. The liquidity shock is not fully compensated by the aggregated liquidity provided by the government, as the unconventional monetary policy only reacts to one of the resaleability shocks.



(a) Data (b) DEFK Model (c) IGE Model

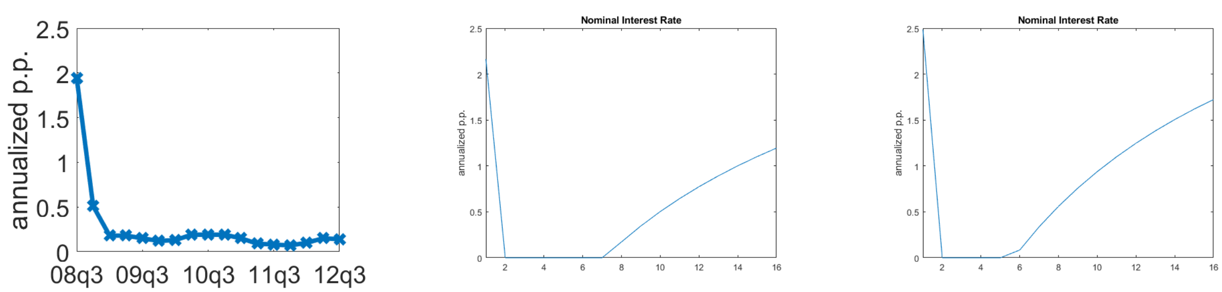
Figure 7: Output



(a) Data (b) DEFK Model (c) IGE Model

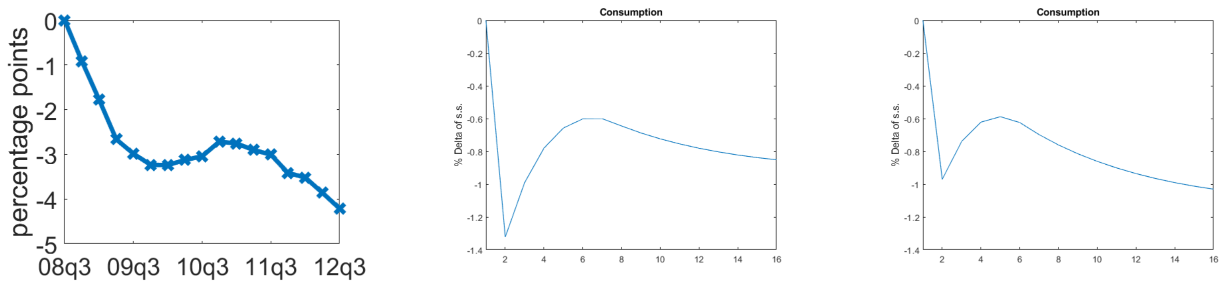
Figure 8: Inflation

The results of the exercise go in line with DEFK model, as the liquidity shock explains a large portion of the response of the economy to the Lehman Brothers episode. DEFK model explains about 58% and IGE model explains roughly 52% in Output (-4.4 versus -3.98, respectively, relative to the -7.8 drop observed in the data). The difference in response of inflation is higher, as DEFK explains 96% while my model explains about 75% (-2.62 was the total drop in the data, while the models predicted -2.5 and -1.96 respectively). A major difference is that in the IGE model predicts a slightly positive inflation after quarter 9 while the DEFK model has negative inflation for the entire time span (16 quarters), which is closer to what is observed in the data. These results suggest that there is a quantitative difference considering the scope of intervention of the government through unconventional monetary policy, meaning that the central bank has access or the ability to react to certain financial instruments, but not to all of them. The under-prediction of the IGE model accounting for this mechanism is about 6% for output and 20% for inflation.



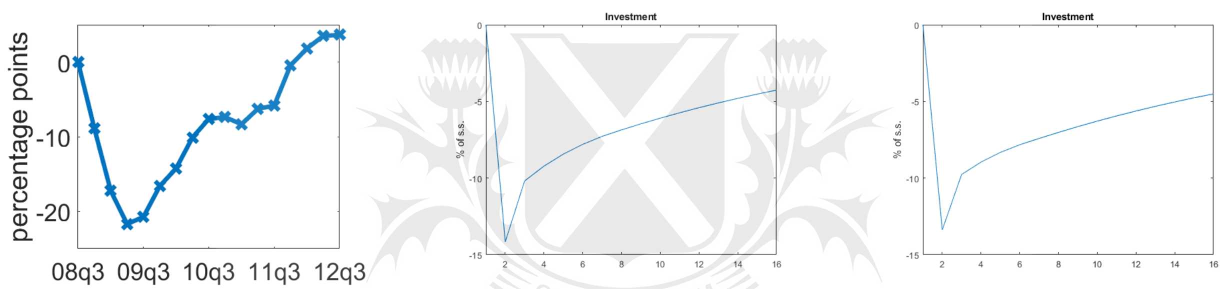
(a) Data (b) DEFK Model (c) IGE Model

Figure 9: Nominal Interest Rate



(a) Data (b) DEFK Model (c) IGE Model

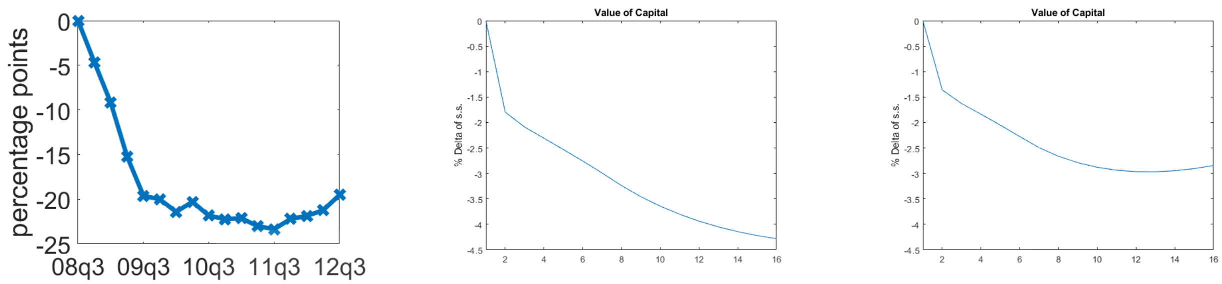
Figure 10: Consumption



(a) Data (b) DEFK Model (c) IGE Model

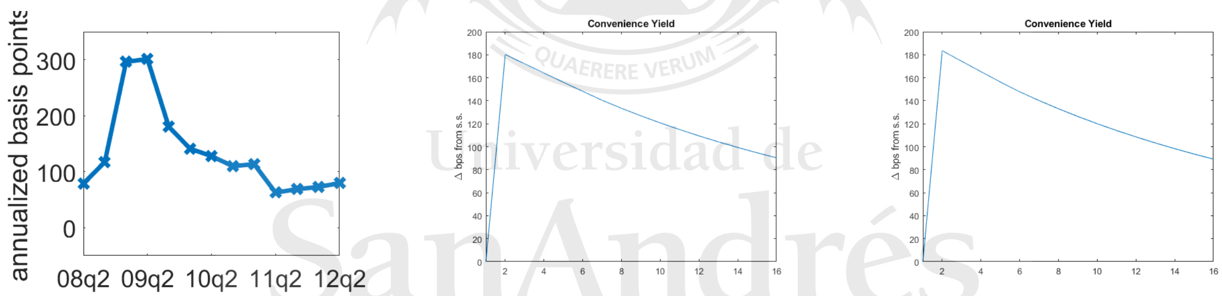
Figure 11: Investment

The IGE model hits the zero lower bound as shown in Figure 9 above, analogous to DEFK model. The difference is that the ZLB is binding for 7 quarters in the DEFK model while it is binding for 5 quarters in the IGE Model. This result goes in line with the higher inflation observed of the positive inflation prediction. However, it is far from what is observed in the data as the interest rate remained near zero for a longer period. Figures 10 and 11 show the response of Consumption and Investment, respectively, which allows to deep dive in the output results. The numbers observed are in line with DEFK model, showing a smaller quantitative response relative to the data. Investment is under-predicted as DEFK explains roughly 64% while IGE model explains 60% (-14.2% and -13.4%, respectively, versus -22.3% in the peak loss of the data). I agree with the authors that this under-prediction might be explained by the absence of an explicit residential sector. The peak loss predicted in Consumption is quantitatively smaller in IGE model relative to DEFK in the peak loss quarter (about -1.3% in benchmark versus about -1% in the IGE Model, relative to the 3% fall in the data). However, the effect in quarter 5 reverts. It is observed that the IGE model prediction for consumption better replicates the behavior observed in the data, even though the results are quantitatively smaller.



(a) Data (b) DEFK Model (c) IGE Model

Figure 12: Value of Capital



(a) Data (b) DEFK Model (c) IGE Model

Figure 13: Convenience Yield

For the value of capital observed in Figure 12 I get similar quantitative result than in DEFK model, as the IGE model prediction replicates the drop in the value of assets despite the fact that is not able to fully account for the drop. As discussed by the authors in DEFK (Del Negro *et al.*, 2017),the model is able to replicate the drop in capital value due to the nominal frictions and the ZLB, in contrast with the discussion on Shin (Shi, 2015) which would predict a rise in the value of capital upon a resaleability shock due to demand pressures in the financial assets markets. The difference relative to the DEFK model are two fold: first, DEFK model is able to account for roughly one fifth of the drop while the IGE model reaches roughly a 3% peak loss. Second, the IGE model is able to replicate the upturn observed in the data for the last quarters. Both the smaller quantitative result and the fastest upturn might have to do with the fact that there is an additional financial instrument in the model(N^I in addition to N^O, rather than the net worth position N in DEFK).

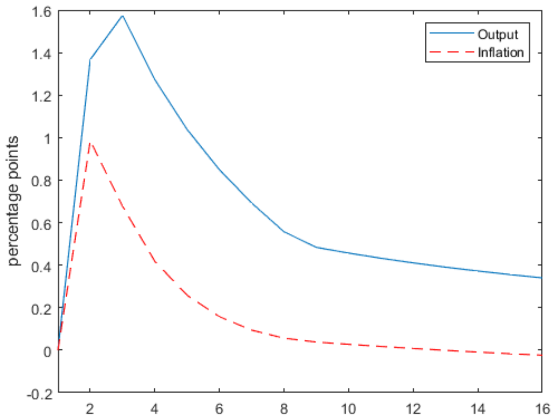
The convenience yield has no significant discrepancies relative to DEFK model, and predicts roughly 55% of the increase. The behavior observed of the spikes in 2008:IV and 2009:I, as discussed by the authors, responds to aspects not accounted for in the model together with the fact that the deterministic simulations of the model are set to match the expectations of the duration of the ZLB, but not the expected duration of the crisis (Del Negro *et al.*, 2017).

The effects shown by our model are in line with DEFK in the sense that they replicate the behavior of the data but are not able to fully replicate the magnitude of the shock. The main differences are in in inflation, with a diffrence of roughly 20% and the ZLB is binding for 2 less quarters than DEFK. As discussed by the authors, there are other shocks to be considered in the analysis of the Great Recession. Moreover, through these results I observe that there is a macroeconomic quantitative effect in the scope of the intervention of unconventional monetary policy, which will be further explored in the following exercises.

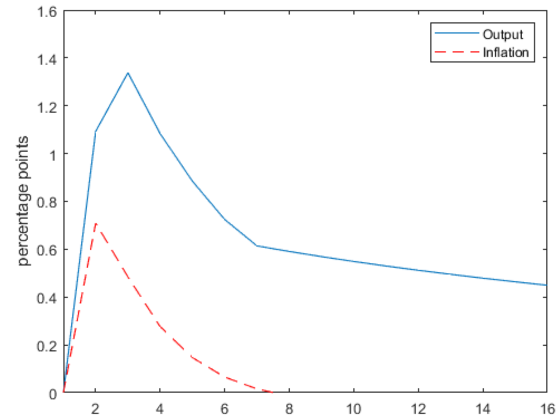
4.2 Great Escape: What Would Have Happened in the Absence of Liquidity Facilities Considering Intervention on Assets?

I present an analysis equivalent to the one presented in DEFK (Del Negro *et al.*, 2017), to asses whether there was a gain in output and inflation with the unconventional monetary policy of the government. This means that I will be able to compare the gains in output and inflation of the Government intervention through unconventional monetary policy relative to no intervention, comparing the baseline scenario and Great Escape for both the DEFK and our model. The difference for IGE model exercise is that the intervention only responds to assets market liquidity shortage (which translates into a shock in ϕ^O), and not the net position of equity of the private sector. This means that the scope of the intervention is di□erent between models.

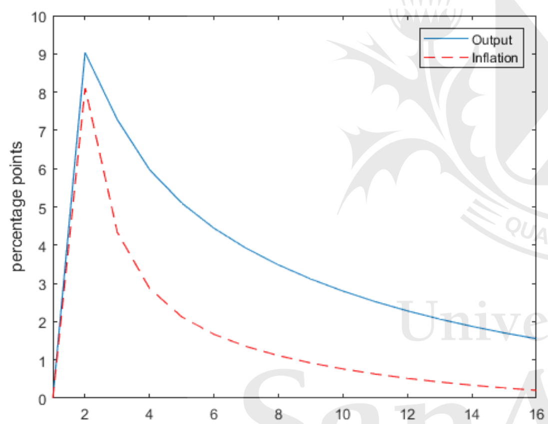
As explained above, the Baseline and the Great Escape scenarios divert in the persistence of the shock. In Baseline, the liquidity shock is binding for 6 quarters while in the Great Escape it is binding for 20 quarters. The reason for this kind of analysis is to provide quantitative evidence on the gains of unconventional monetary policy in a context similar to the Great Depression, which had more persistent effects resulting in a much longer crisis. Both kind of analysis are relevant, as one allows to understand the response to the model in the situation of a particular shock in the economy (the Lehman Brothers bankruptcy) while the other calibration will show quantitative results of unconventional monetary policy in a context of a long lasting crisis resembling the Great Depression. In the end, it will be answered if there was a Great Escape or not. Figure 14 below presents our results.



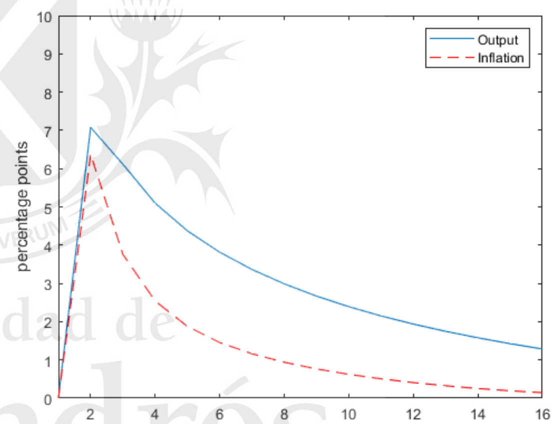
(a) DEFK Baseline



(b) IGE Baseline



(c) DEFK Great Escape



(d) IGE Great Escape

Figure 14: The Effect of the Liquidity Facilities on Output and Inflation in the Baseline

The first line of Figure 14 show the results for Baseline scenario. Gains of output (blue line) produced by intervention in the IGE model are significant, as losses would have been -5.1% instead of -3.98%, which means 27% more severe in the absence of unconventional monetary policy. This result is in line with the 32% gain of the DEFK model, with the difference in gains between models if 0.3%. Gains in inflation (red doted line) are about 0.7% (-2.7% without intervention versus roughly -2% with intervention) for IGE model, which represent an ease of 36%. This result is in line with the 40% ease produced by DEFK model (-3.5% versus -2.5%). The difference relative to DEFK in peak gains is about 0.3% which represents a 39% under-prediction. The details in the numbers are presented in Tables 1 and 2 below, for output and inflation respectively.

Output - Baseline			
Metrics	DEFK Model	IGE Model	Data
Peak Loss Period Intervention	Q1	Q1	Q4
Peak Loss Intervention	-4.41	-3.98	-7.8
Percentage Explained by Liquidity Shock intervention	58%	52%	
Peak Loss Period No Intervention	Q1	Q1	
Peak Loss No Intervention	-5.79	-5.07	
Percentage Explained by Liquidity Shock no intervention	75%	66%	
Percentage Gain by Intervention	32%	27%	
Peak Difference Loss	1.38	1.09	
Total Gain	19.38	24.61	

Table 1: Output - Baseline Numbers

Inflation - Baseline			
Metrics	DEFK Model	IGE Model	Data
Peak Loss Period Intervention	Q1	Q1	Q3
Peak Loss Intervention	-2.51	-1.96	-2.62
Percentage Explained by Liquidity Shock intervention	96%	75%	
Peak Loss Period No Intervention	Q1	Q1	
Peak Loss No Intervention	-3.5	-2.67	
Percentage Explained by Liquidity Shock no intervention	133%	102%	
Percentage Gain by Intervention	40%	36%	
Peak Difference Loss	0.99	0.71	
Tota Gain	-1.89	-9	

Table 2: Inflation - Baseline Numbers

It is worth noting the line discussed by the authors in DEFK (Del Negro *et al.*, 2017), that the effect of gains does not correspond only to the to the fist quarter, but it occurs all along the time span analyzed in this exercise. As the authors explain, by assumption in both of the models the resaleability constraint cannot be relaxed directly by intervention, so this is why there is a direct impact in the first quarter. It affects asset prices and consumption through expectations. However, in the following quarters the effect remains (therefore the gains are observed in the entire time span of the exercise) because unconventional monetary policy provides aggregate liquidity and the household constraint is shifted towards liquid assets.

Moreover, the authors discuss the results of the convenience yield, stating that there is a quantitative effect but is quantitatively smaller than the macroeconomic effect presented in this exercise. This suggests that literature looking at spreads might not be an entirely accurate way of measuring policy success. In this same line, as discussed in the introduction there is recent literature suggesting that credit easing is much more effective than quantitative easing in reducing spreads, like D'amico and Kaminska (D'Amico *et al.*, 2020) or Shah and Maiki (Shah *et al.*, 2018) who discuss the reduction in equity risk premiums for for the S&P 500 by quantitative easing. This results reinforce the argument stated by the authors as even with eligibility criteria in the financial instruments of the intervention there are significant macroeconomic gains that can be measured in other dimensions, like output and inflation.

These results which state that there are quantitative differences in gains due to the limited scope of the unconventional monetary policy might shed light over the discussion regarding the importance of eligibility over the credit policy of recent years. Gilchrist, Wei, Yue and Zakrajsek (Gilchrist *et al.*, 2020) for example found that there was a reduction in spread of eligible bonds by the announcement of credit easing policies, while D'amico, Kurakula and Lee (D'Amico *et al.*, 2020) found results in the same line through the announcement of the Primary and Secondary Market Corporate Credit Facilities. Through the findings discussed in this paper it might prove relevant to include macroeconomic effects in the discussion of the eligibility as a complement of the microstructure and pass through studied by recent literature, as there are other relevant variables to explore in terms of gains and how effective is the policy.

The second line of Figure 14 above has the results resembling the Great Depression in the sense that the liquidity shock is much longer. As stated above, this analysis is relevant as the Great Recession was not a single event, but a persistent crisis. Gains in output are considerable, as losses in Output would have been -15% without intervention relative to a -8% drop with intervention, which represents a 88% ease in losses. DEFK model results for the same exercises gives a 93% ease (roughly -19% drop versus -10%), which means an under-prediction of gains of 5%. A similar result can be observed for Inflation, as the crisis would have doubled losses (12% versus 5.6%). These numbers are in line with DEFK in the sense that losses would have been doubled, while the IGE model under-predict gains in 14%. Tables 3 and 4 for Output and Inflation, respectively, provide the numbers that complete the analysis.

Output - Great Escape Analysis			
Metrics	DEFK Model	IGE Model	Data
Peak Loss Period Intervention	Q1	Q1	Q4
Peak Loss Intervention	-9.68	-8.05	-7.8
Percentage Explained by Liquidity Shock intervention	126%	105%	
Peak Loss Period No Intervention	Q1	Q1	
Peak Loss No Intervention	-18.71	-15.13	
Percentage Explained by Liquidity Shock no intervention	244%	198%	
Percentage Gain by Intervention	93%	88%	
Peak Difference Loss	9.03	7.08	
Tota Gain	99.04	91.24	

Table 3: Output - Great Escape Numbers

Inflation - Great Escape			
Metrics	DEFK Model	IGE Model	Data
Peak Loss Period Intervention	Q1	Q1	Q3
Peak Loss Intervention	-6.93	-5.56	-2.62
Percentage Explained by Liquidity Shock intervention	164%	112%	
Peak Loss Period No Intervention	Q1	Q1	
Peak Loss No Intervention	-15.8	- 11.92	
Percentage Explained by Liquidity Shock no intervention	574%	455%	
Percentage Gain by Intervention	128%	114%	
Peak Difference Loss	8.87	6.36	
Tota Gain	20.80	12.48	

Table 4: Inflation - Great Escape Numbers

The results are in line with the benchmark in the sense that the drop in Output and Inflation would have been a size not seen since the Great Depression. However, our model show that the gains both in Output and Inflation are quantitatively smaller than the benchmark, suggesting that there is a macroeconomic effect in the scope of the intervention.

As shown by DEFK, there existed a Great Escape from the recession explained by the unconventional monetary policy intervention. However, the scope of the intervention in terms of the ability or possibility of the central authority to act over one market or financial instrument rather than the net position of the private sector has a quantitative macroeconomic effect that should be considered. As there exist costs in unconventional monetary policy intervention (which are not considered in this kind of models), the design of the unconventional monetary policy should be considered as there is a macroeconomic quantitative effect.

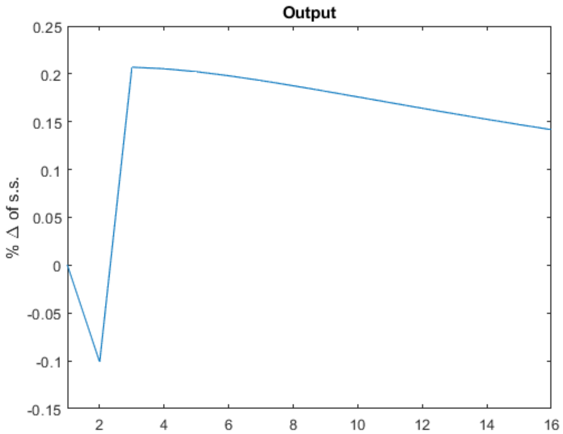
4.3 Inside the Great Escape: What Would Have Happened with Different Targets for the Liquidity Facilities?

In this section I am going to deep dive in the quantitative effect of the eligibility criteria in the unconventional intervention. The exercise is divided in two parts: the first part will show the results for the IGE Model with intervention in liabilities markets N^I and liquidity shocks in ϕ^I and ϕ^O. Through this exercise I will compare if there is a quantitative effect in changing the market in which the central authority is able to intervene (upon a full scale dry up of liquidity in the private sector financial instruments). The second exercise will present the results of IGE Model with intervention in the assets markets N^O but the liquidity shock will affect only one market at a time. I intend to measure the gains in intervention on the financial instrument which is suffering the financial stress.

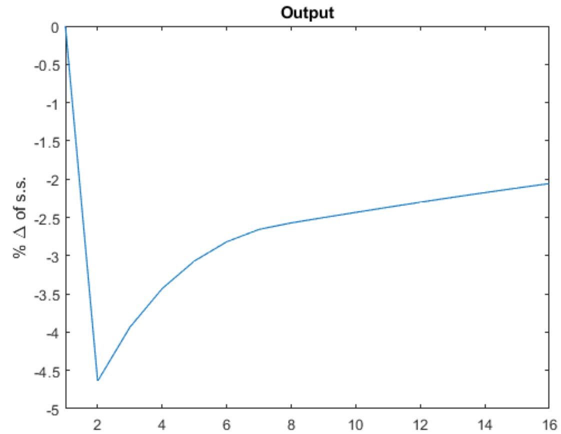
Figures 18 to 24 in the Appendix section shows the results for the first part of the exercise. Left column consist of the data as presented in the previous section while centre are populated with the results of the IGE Model with liquidity shock in both markets and intervention in asset markets. The right column has an equivalent exercise, but with intervention in the liability markets. As it can be observed, the results are quantitatively identical. This means that if the liquidity shock affects the entire financial sector (both assets and liabilities markets), it does not have a quantitative effect whether the central authority intervenes in one or the other. This is explained by the fact that in this model, aggregate liquidity is provided as unconventional monetary policy to relax the private sector budget constraint. Then the decision of the private sector shifts from the stressed assets to the liquid asset, no matter which is the financial instrument which is making the unconventional monetary policy equation react.

It is interesting to understand what happens when the financial instrument that triggers the reaction of unconventional monetary policy is not stressed, while other financial instruments are. An example of this kind of situation might be an unconventional monetary policy which accepts only Investment Grade instruments as collateral for the SPVs through which the liquidity is provided. Therefore, if there is liquidity stress in a market funded by High Yield (HY) assets, there should be no reaction of the policy. This might suggest that unconventional monetary policy might not be effective in terms of reach to boost confidence and assist stressed financial institutions in the markets for HY instruments starting from IG instruments.

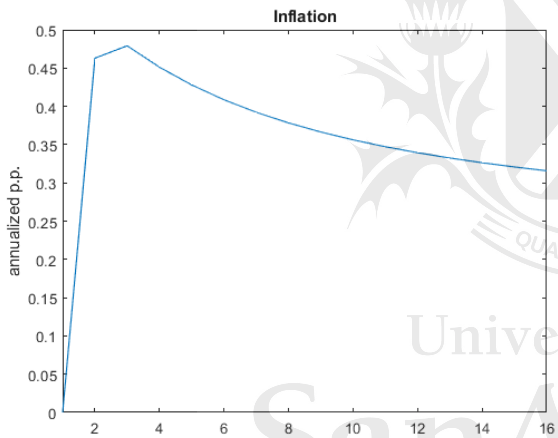
Another example might be a situation in which the policy maker is not able to reach for the stressed market due to legislation or jurisdiction. Despite the fact that the Federal Reserve has the section 13(3) of the Federal Reserve Act, highly cited during the Great Recession which allowed for lending to banks and other financial institutions, it is not always feasible a direct lending. There are political, administrative and implementation factors to be considered that might not always align towards the goal of stabilization of the financial markets. As mentioned above in the introduction of this work, some examples during the Great Recession period where Lehman Brothers or Washington Mutual Fund, which filed for bankruptcy and contributed to the financial panic in the repo markets in particular and in general to questions in other sources of funding. On the other hand, the rescues of Freddie and Fannie or the collaboration between the Federal Reserve and the Treasury in the rescue of AIG are examples of successful implementation in the targeted policy.



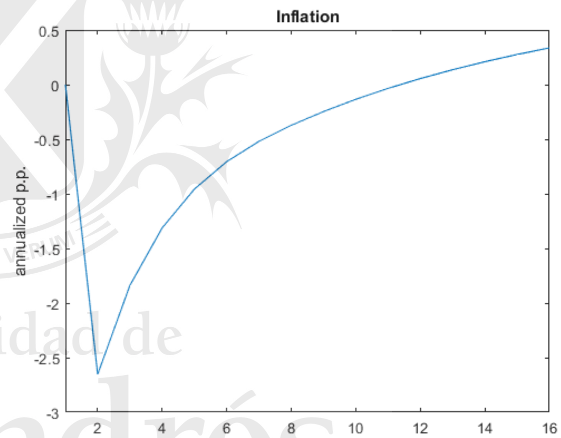
(a) Shock in assets



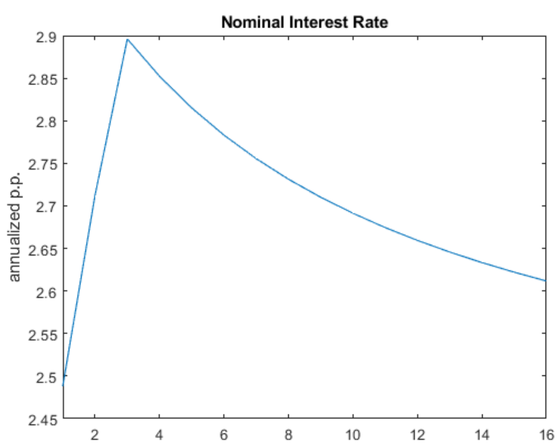
(b) Shock in liabilities



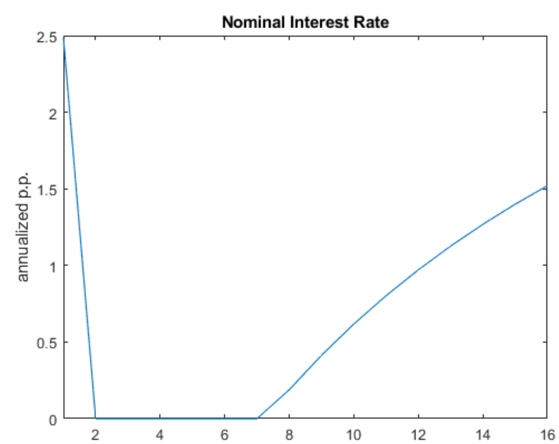
(c) Shock in assets



(d) Shock in liabilities



(e) Shock in assets



(f) Shock in liabilities

Figure 15: Output, Inflation and Federal Funds Rate Sensitivity Analysis: Response to shocks in assets and liabilities markets respectively with intervention in the assets markets

Figure 15 above show the results of the second part of the deep dive of the escape. These charts present the IGE Model response on 6 quarter shock persistence (baseline scenario) with intervention in the assets markets ϕ^O to a shock in the assets markets only (left column) and liabilities markets only (right column).

Overall it can be observed that when the financial authority is able to react over the stressed market, the shock is completely and quickly overturned. In contrast, when there is no possibility of intervention in the stressed market, the crisis is steep and harsh. This result is expected.

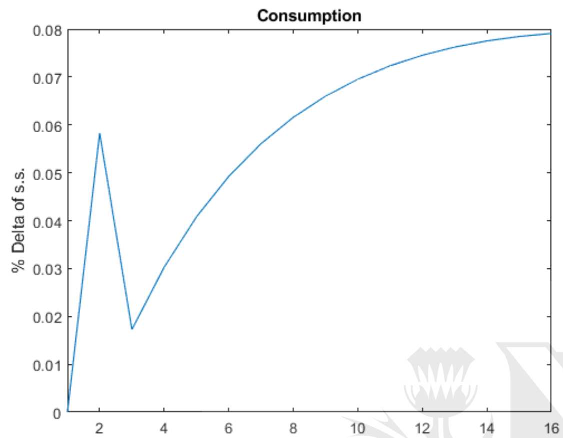
In the left column (or effective intervention) of Figure 15, we observe a mild contraction of o.1% in the first quarters for Output, and is quickly reverted after quarter 3. This is explained because of an increase in capital due to the liquidity provision of the central authority through equation (30). It reacts through equation (26) to the liquidity shortage and provides N^G which relaxes through capital the private sector budget constraint. This explains the increase in investment and consumption, as returns on capital decrease through equation (58). This process pushes inflation, as observed in Figure 15, which is explained by the Phillips Curve described in equations (51) to (53). By Taylor rule in equation (25) the conventional monetary policy reacts and we see thus an increase observed in the nominal interest rate.

It is worth noting that there is a slight decrease in the first quarter of the value of capital, but after the aggregate liquidity is provided there is a full recovery which goes in line with the capital increase through N^G in equation (30) as mentioned above. At the same time it produces a decrease in the convenience yield due higher real interest rates given by the reaction of the Taylor rule.

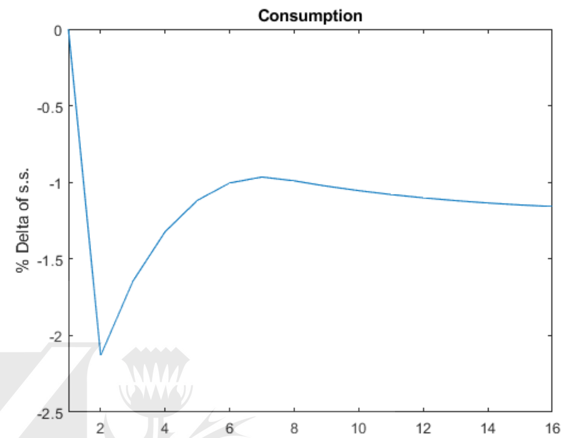
In the opposite direction we observe that if the central authority is not able to react to the liquidity stress, the budget constraint tightens and produce losses much more severe than in the Baseline scenario. Losses in Figure 15 are more than 4.5% and 2.5% in Output and Inflation, which are 18% and 38% much severe, respectively. Figure 16 shows that this is explained by consumption, as it doubles the peak losses relative to Baseline scenario (2% relative to 1%) while investment shows similar losses. In that same line, the nominal interest rate remains at the zero lower bound for two more quarters.

Figure 17 shows the full scale of the liquidity tightening, as the convenience yield is around 25%

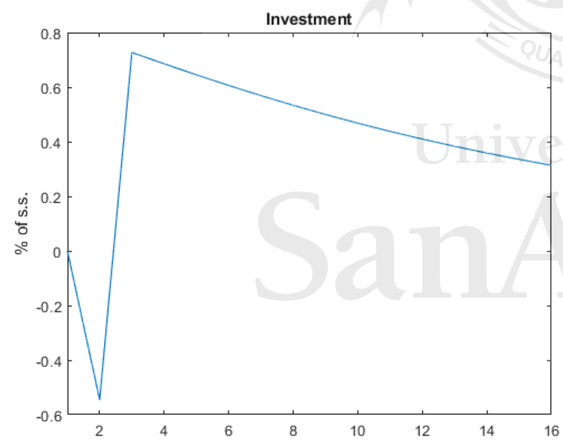
tighter relative to Baseline while value of capital shows a losses 0.5% higher (about 17% tighter). This is expected as there is no cushion to the liquidity tightening so there is a sharp decrease in the first quarters while the recovery is sluggish and takes more than 16 quarters to revert.



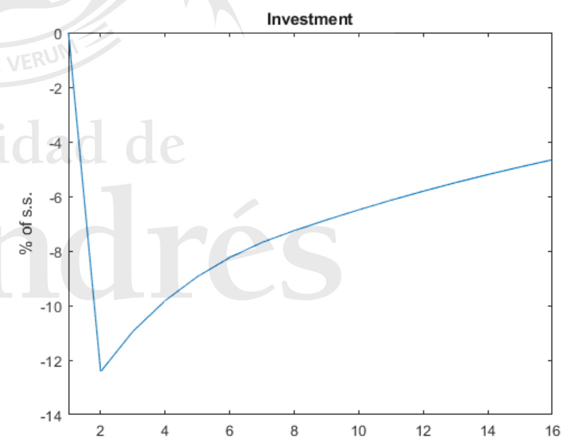
(a) Shock in assets



(b) Shock in liabilities

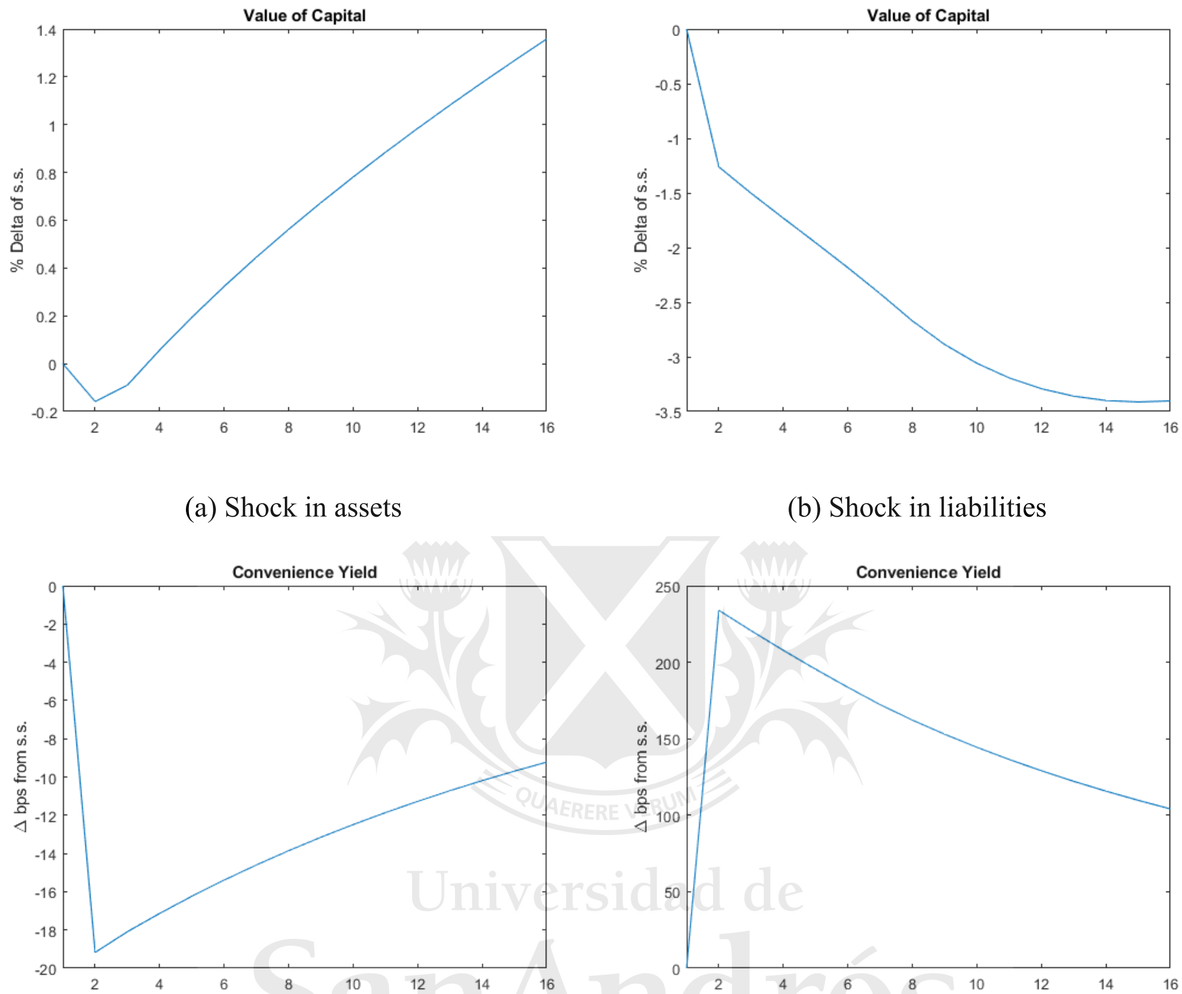


(c) Shock in assets



(d) Shock in liabilities

Figure 16: Consumption and Investment Sensitivity Analysis: Response to shocks in assets and liabilities markets respectively with intervention in the assets markets



(a) Shock in assets

(b) Shock in liabilities

(c) Shock in assets

(d) Shock in liabilities

Figure 17: Value of Capital and Convenience Yield Sensitivity Analysis: Response to shocks in assets and liabilities markets respectively with intervention in the assets markets

The full scale shock proves that there is a slower recovery and much more severe conditions if there is no aggregate liquidity supply. On the contrary, if there is a quick and large intervention, the shock is quickly reverted and it creates output gains, although it brings inflation upwards, that remains high for the entire time span of the analysis. This is true also because the magnitude of the intervention was calibrated for a full scale liquidity provision as in the DEFK model (1.4Tn Dollars) (Del Negro *et al.*, 2017).

It stems from the analysis above the importance of targeting unconventional monetary policy to the stressed financial instruments or markets as there are large gains, although it might bring a cost if the assistance package is very large. This debate had an uprising post COVID-19 era, upon which the world experienced a high inflation period. If the unconventional monetary policy is large and vast (a package that is large in scale in terms of dollar amount and in the facilities which creates to assist different tranches of the financial system), then it might bring costs if there is a supply shock with inflationary pressures. For example, Russian invasion to Ukraine in 2022 made energy and food prices soar, thus starting an inflationary process. This might prove much difficult to tame if the economy is somewhere after a liquidity shock compensation (for example, COVID-19 measures through the liquidity facilities presented in Figure 3 above), represented by the quarters after the shock that we analyzed in the charts above. This suggests that as unconventional monetary policy effect is sluggish and the economy was slowly returning to long term equilibrium, inflation might become harder to tame.

It is essential to notice that this kind of analysis is beyond the scope of this work. We assume that there is one shock in this economy that explains the movement of the variables, thus abstracting from real shocks such as the one cited in the paragraph above. There are aspects of the behavior of the variables that are not able to be captured in this kind of model design. However, it might prove useful to research further in these aspects as there are questions opened by the results of this work. It would be interesting to expand the model and create a real shock that might happen in a liquidity abundant economy due to unconventional monetary policy and thus measure the contribution of this factors to a possible inflationary process.

5 Conclusion

The Federal Reserve channeled liquidity into stressed markets considering eligible financial instruments or eligible tranches of the financial markets during the 2008 credit crunch. I considered it was worth measuring the macroeconomic effects of this characteristic. Therefore, this paper builds on the work from Del Negro, Eggertsson, Ferrero and Kiyotaki (Del Negro *et al.*, 2017) to quantify the macroeconomic effect of the eligibility criteria of the Federal Reserve unconventional monetary policy implementation. I lifted an assumption in the DSGE model with financial frictions used by the authors to account for an additional resealeability constraint, which faced the private sector to independent liquidity shortages in assets and in liabilities. The economy is shocked with a liquidity shortage resembling the Lehman Brothers bankruptcy. The results are compared to the data and to the benchmark model.

The findings of the authors are confirmed by the results of this work. If the zero lower bound would have been binding as long as it was during the Great Depression, a Great Escape would have occured as liquidity provided by the unconventional monetary policy would have sustained the recovery. However, there exist material differences when accounting for the eligibility criteria, which suggests that gains might be overestimated. This differences reinforces the notion that although the liquidity shock was one key feature to explain the Great Recession, there have been other factors to consider.

As there exist quantitative effects of the eligibility criteria, it is worth considering the implementation of the policy in terms of efficiency. As proved by the deep dive performed over the intervention, if it is implemented with precision, that is to say acting if possible over the stressed markets, the overturn will be quick. Moreover, if the intervention is large and precise, it might create inflationary pressures that might be difficult to tame as the shock persists over time. So not only the precision, but the magnitude of the unconventional monetary policy should be considered, although the study of the magnitude of the intervention is outside the scope of this work. Of course practical implementation is far from simple and it might prove not easy for the policy maker to reach precisely for the stressed markets or financial agents. The central authority might face legal, administrative, or implementation limitations such as not being able to provide funding against certain types of collateral or not being able to directly assist to the stressed financial institution due to a legal conflict. In the same line, the decision regarding the magnitude of the intervention is complex as it might not be clear the depth of the crisis and it might prove difficult to obtain funding (for example, due to authorization of the Congress or cooperation with the Treasury).

Considering the contributions and limitations of this work, it is interesting to consider some possible extensions of this framework that could allow to explore the aspects discussed above in future works.

- Unconventional monetary policy is implemented providing credit lines to stressed markets. A credit line is opened for a specific tranche of the financial markets or if possible even to a specific institution, to satisfy a specific goal (for example, stop the panic in the repo funding market). This is why Chairman Bernanke insisted in calling these policy tools ”credit easing”. However, in the end the final result of the process is more funding available in the market, that is to say, more money. So a natural expansion would consist of including some form of money demand in this framework to clarify the behavior of inflation. If money is included changing the model through for example a new budget constraint requiring money for transactions in goods and in financial markets (a Cash in Advance approach), it would be possible to derive a money demand which would shed light over the inflationary process.

- Another crucial aspect of the 2008 Credit Crunch was financial intermediation. The main event that triggers the liquidity shock is the Lehman Brothers bankruptcy, that is to say, the bankruptcy of a financial intermediator which fueled the panic in the markets where their funding relied (or even in the entire financial system if the institution was large enough). So it should be useful to consider an expansion including financial intermediation. Although the panic was not a classic run on bank deposits, the logic was similar in the sense that it started as a run on repo funding making the financial institutions relying on those markets illiquid in a highly connected and complex financial system. It would be possible to include a financial intermediation sector in the model which, as part of the private sector, channel funds from individuals with excess liquidity to individuals with investment opportunities in need of funds. The intermediation might be subject to asymmetric information problems as it might not have perfect information over the borrower. Then a possible shock might be liquidity shortage due to funds channeled to individuals who are not solvent once the information on the borrower is revealed, thus resembling the subprime mortgages lending.

- The Federal Reserve has implementation processes that might prove valuable to model and include in this framework. The behavior of the central authority in this model is defined by a reaction function that depends on a liquidity threshold. That is to say that the reaction of the Fed is instantly activated the period following the liquidity shortage. However, how the central authority decides which tranche or financial institution to assist remains unclear in this mechanism as implicitly it is assumed that the central authority can perfectly observe the shortages. Although it is possible to monitor funding in different markets and even monitor the position of large financial institution through the study of their balance sheets, it is not always obvious which institution or market to assist to backstop a run that might imply systemic risk. Therefore, it is interesting to expand this framework to account for the central authority decision. A possible way can be to provide the authority with the ability to decide on which kind of asset to assist with a function, although it might be subject to an asymmetric information problem as there might not be possibly to clearly state if there is systemic risk or if it is simply a problem of poor investment choices. The central authority intervention might be subject to a game theory problem in deciding how and upon what to react.

- Another debate that is not considered in this framework is the welfare measure of the policy implemented by the central authority. Chairman Bernanke (B. S. Bernanke, 2015) stated that the unconventional monetary policy performed during the 2008 Credit Crunch had the main goal of avoiding a major depression that ended up affecting Main Street. There was a debate at the time regarding if the federal government should assist Main Street rather than saving large financial institutions or specific tranches of the financial markets of Wall Street. Therefore it stems as important to measure the welfare costs or benefits of this unconventional monetary policies. This might help to clarify which kind of policy is much more desirable having a household welfare goal.

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6 Appendix

6.1 The Model in Detail

This section provides the details and resolution of the model sections which are not changed by this work. As a consequence, the following subsections are cited directly from the online appendix of DEFK (Del Negro *et al.*, 2017).

6.2 Final and Intermediate Goods Producers

The Producers definition and characterization of the model are along the standard lines of Christiano, Eichenbaum and Evans (Christiano *et al.*, 2005) and Smets and Wouters (Smets & Wouters, 2007). From this point until Section 2.6 we will cite DEFK (Del Negro *et al.*, 2017) Online Appendix for the presentation of the remaining of the model, as it is identical:

Perfectly competitive final good producers combine intermediate goods, Y_{it}, to sell a homogeneous final good Y_t to households and capital producers. Each intermediate good producer pays a fixed cost, and hires capital and a composite labor to produce output. Facing a downward sloping demand curve with monopoly power parameter λ_p for its product, each producer sets its price on a staggered basis, where $1\xi_p$ is the probability of resetting the price in each period. As in Erceg et al. (Erceg *et al.*, 2000), we introduce wage rigidities assuming labor unions represent each type of imperfectly substitutable labor inputs $H_t(j)$, which are combined into a homogeneous composite sold to the intermediate firms. Facing a downward sloping demand curve with monopoly power λ_w, each union sets the wage of each type of labor on a staggered basis so that in each period a new wage is set for a particular type of labor with probability $1\xi_w$. Finally, perfectly competitive capital producers produce investment goods, sold to the entrepreneurs at price p_t^I , under decreasing returns to scale technology. The total cost of producing I_t investment goods equals $I_t[1 + S(I_t/I)]$, where I is investment in steady state. We assume $S(1) = S'(1) = 0$ and $S''(I_t/I) > 0$ so that the price of investment goods differs from the price of consumption goods in the short run.

Following this story, equation (25) is the technology through which final good producers combine intermediate goods Y_{it}, where $i \in [0, 1]$ indexes for intermediate good producing firms

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{1}{1+\lambda_p}} di \right]^{1+\lambda_p} \tag{33}$$

where $\lambda_p > 0$, and their demand for the intermediate good is given by the following expression.

$$Y_{it} = \left[\frac{P_{it}}{P_t} \right]^{-\frac{1+\lambda_p}{\lambda_p}} Y_t \tag{34}$$

P_{it} is the nominal price of good i. And the aggregate price level given by the zero profit optimality condition of competitive final good producers is given by

$$P_t = \left[\int_0^1 P_{it}^{-\frac{1}{\lambda_p}} di \right]^{\lambda_p} \tag{35}$$

The production function of the intermediate goods is given by the following technology

$$Y_{it} = A_t K_{it}^{\gamma} H_{it}^{1-\gamma} - \Gamma \tag{36}$$

Intermediate goods firms operate in a monopolitstic competition environment and set prices on a staggered process following Calvo (Calvo, 1983), taking real wage w_t and rental rate of capital as given. The mechanism is as follows: with probability $1 - \zeta_p$ the firm adjust the price, while the complement is the probability that the price remains fixed. For the price change event, the firm chooses price $\tilde{P}_{it}$ to maximize the present discounted value of the following expression

$$D_{is} = P_{is} Y_{is} - w_s H_{is} - r_s^K K_{is} - \Gamma$$

for $s > t$ where D are the profits, conditional on not changing prices in the future subject to the demand for its own good.

6.2.1 Labor Agencies and Wage Setting

Competitive labor agencies combine j-specific labor inputs into a composite H_t following

$$H_t = \left[\left(\frac{1}{1-\chi} \right)^{\frac{\lambda_\omega}{1+\lambda_\omega}} \int_\chi^1 H_t(j)^{\frac{1}{1+\lambda_\omega}} dj \right]^{1+\lambda_\omega} \tag{37}$$

with $\lambda_\omega > 0$. The zero profit condition implies that

$$W_t H_t = \int_\chi^1 W_t(j) H_t(j) dj \tag{38}$$

And the demand for j^{th} labor input is

$$H_t(j) = \frac{1}{1-\chi}\left[\frac{W_t(j)}{W_t}\right]^{-\frac{1+\lambda_\omega}{\lambda_\omega}} H_t \tag{39}$$

where W_t is the aggregated wage index that comes out of the zero profit condition of labor agencies.

$$W_t = \left[\frac{1}{1-\chi}\int_\chi^1 W_t(j)^{-\frac{1}{\lambda_\omega}} dj\right]^{\lambda_\omega} \tag{40}$$

Wages of each type are set on a staggered basis following Erceg (Erceg *et al.*, 2000) and has a similar logic as described above for intermediate goods producers. The probability of the union resetting wages is given by $1-\zeta_w$.

6.2.2 Capital Producers

Capital goods producers transform consumption goods into investment goods in a competitive environment, and face the problem of choosing I_t to maximize the profits

$$D_t^I = \left\{p_t^I - \left[1 + S\left(\frac{I_t}{I}\right)\right]\right\} I_t \tag{41}$$

taking p_t^I as given. The price of consumption and investment goods differ due to the adjustment costs, measured by the deviation from actual investment relative to the steady state value.

6.2.3 Optimality Conditions

Wage Setting Decisions Competitive labor agencies chooses $H_t(j)$ to maximize their profits

$$W_t H_t - \int_\chi^1 W_t(j) H_t(j) dj$$

Subject to equation (29). The first order condition of this problem determines the demand for the j^{th} labor input given by equation (31).

Price setting on a staggered basis. In each period, with probability $1-\zeta_w$ a union is able to settle a new wage, with the complementary probability remaining fixed. Household must provide whatever labor is provided at that wage. Unions choose the wage $\tilde{W}_t$ (j) to maximize

$$\mathbb{E}_t \sum_{s=t}^{\infty} (\beta\zeta)^{s-t} \left[\frac{C_s^{1-\sigma}}{1-\sigma} - \frac{\omega}{1+\nu} \int_{\chi}^{1} H_s(j)^{1+\nu} dj \right]$$

The first order condition is the following

$$\mathbb{E}_t \sum_{s=t}^{\infty} C_s^{-\sigma} \left[\frac{\tilde{W}_t(j)}{P_s} - (1+\lambda_w) \frac{\omega H_s(j)^{\nu}}{C_s^{-\sigma}} \right] H_s(j) = 0$$

All the labor unions face the same problem and I focus in the symmetrical problem. The first order condition of this problem becomes.

$$\mathbb{E}_t \sum_{s=t}^{\infty} C_s^{-\sigma} \left\{ \frac{\tilde{w}_t}{P_s} - (1+\lambda_w) \frac{\omega \left[\left(\frac{\tilde{w}_t}{\pi_{t,s} w_s} \right)^{-\frac{1+\lambda_w}{\lambda_w}} H_s \right]}{C_S^{-\sigma}} \right\} \left(\frac{\tilde{w}_t}{\pi_{t,s} w_s} \right)^{-\frac{1+\lambda_w}{\lambda_w}} H_s \tag{42}$$

By the law of large numbers, the probability of changing the wage corresponds to the fraction of types who actually do change their wage. Consequently, from expression (32), the real wage evolves according to

$$w_t^{-\frac{1}{\lambda_w}} = (1-\zeta_w) \tilde{w}_t^{\frac{1}{\lambda_w}} + \zeta_w \left(\frac{w_{t-1}}{\pi_t} \right)^{-\frac{1}{\lambda_w}} \tag{43}$$

Defining the wage inflation as

$$\pi_t^w = \frac{W_t}{W_{t-1}}$$

and using (31), (30) becomes

$$\left(\frac{1-\zeta_w {\pi^w}_t^{\frac{1}{\lambda_f}}}{1-\zeta_w} \right)^{\lambda_w+(1+\lambda_w)\nu} = \frac{{X^w}_{1t}}{{X^w}_{2t}} \tag{44}$$

were X_{1t}^{w} and X_{2t}^{w} are the expected present value of marginal disutility of work and real marginal wage revenue as

$$X_{1t}^{w} = \frac{\omega}{(1-\chi)^{\nu}} H_{t}^{(1+\nu)} + \beta\zeta_{w}\mathbb{E}_{t}\left(\pi^{w}{}_{t+1}{}^{\frac{(1+\lambda_{w})(1+\nu)}{\lambda_{w}}} X_{1t+1}^{w}\right) \tag{45}$$

$$X^{w}{}_{2t} = \frac{1}{(1+\lambda_{w})} C_{t}^{(-\sigma)} w_{t} H_{t} + \beta\zeta_{w}\mathbb{E}_{t}\left(\pi^{w}{}_{t+1}{}^{\frac{1}{\lambda_{w}}} X^{w}{}_{2t+1}\right) \tag{46}$$

Final and Intermediate Goods Producers Final good producers maximize profits according to the following equation

$$P_{t}Y_{t} = \int_{0}^{1} P_{t}(i)Y_{t}(i)di$$

Subject to (25). The solution provides the demand for the generic intermediate good i^{th} given by (26). The zero profit condition implies that the aggregated price level is given by (27).

Monopolistically competitive intermediate goods producers hire labor from households and rent capital from entrepreneurs to produce intermediate goods according to the production technology (28) and subject to the demand condition (26). We solve the problem for inter- mediate goods producers in two steps. First, we solve for the optimal amount of inputs (capital and labor) demanded. For this purpose, intermediate goods producers minimize costs

$$r_{t}^{k} K_{it} + w_{t} H_{it}$$

subject to (28). Let mc_{it} be the Lagrange multiplier on the constraint, the real marginal cost. The first order condition implies that the capital-labor ratio at the firm level is independent of firm-specific variables as

$$\frac{K_{it}}{H_{it}} = \frac{K_{t}}{H_{t}} = \frac{\gamma}{1-\gamma}\frac{w_{t}}{r_{t}^{k}} \tag{47}$$

Then the marginal cost is independent of firm-specific variables as

$$mc_{it} = mc_t = \frac{1}{A_t}\left(\frac{r_t^k}{\gamma}\right)^{\gamma}\left(\frac{w_t}{1-\gamma}\right)^{1-\gamma} \tag{48}$$

The second step consists of characterizing the optimal price setting decision in the event that firm i can adjust its price. Recall that this adjustment occurs in each period with probability $1 - \zeta_p$, independent of previous history. If a firm can reset its price, it chooses $\tilde{P}_t(i)$ to maximize

$$\mathbb{E}_t \sum_{s=t}^{\infty} (\beta\zeta)^{s-t} C_t^{-\sigma} \left[\frac{\tilde{P}_t}{P_s} - mc_s\right] Y_s(i)$$

subject to (26). The first order condition for this problem is

$$\mathbb{E}_t \sum_{s=t}^{\infty} (\beta\zeta)^{s-t} C_t^{-\sigma} \left[\frac{\tilde{P}_t}{P_s} - (1+\lambda_f) mc_s\right] Y_s(i)$$

All intermediate goods producers face an identical problems. As for the wage setting decision, we focus on a symmetric equilibrium in which all firms choose the same price $\tilde{P}_t(i) = \tilde{P}_t$. Let $\tilde{p}_t = \tilde{P}_t / P_t$ denote the optimal relative price. The first order condition for optimal price setting becomes

$$\mathbb{E}_t \sum_{s=t}^{\infty} (\beta\zeta)^{s-t} C_t^{-\sigma} \left[\frac{\tilde{p}_t}{\pi_{t,s}} - (1+\lambda_f) mc_s\right] \left(\frac{\tilde{p}_t}{\pi_{t,s}}\right)^{-\frac{1+\lambda_f}{\lambda_f}} Y_s = 0 \tag{49}$$

By the law of large numbers, the probability of changing the price coincides with the fraction of firms who actually do change the price in equilibrium. Therefore, from expression (27), inflation depends on the optimal reset price according to

$$1 = (1-\zeta_p)\tilde{p}_t^{-\frac{1}{\lambda_f}} + \zeta_p \left(\frac{1}{\pi_t}\right)^{-\frac{1}{\lambda_f}} \tag{50}$$

Using (43), the price setting rule (41) becomes

$$\left(\frac{1-\zeta_p \pi_t^{\frac{1}{\lambda_f}}}{1-\zeta_p}\right)^{-\lambda_f} = \frac{X_{1t}^p}{X_{2t}^p} \tag{51}$$

where X_{1t}^p X_{2t}^p and are expected present value of real marginal cost and real marginal revenue

$$X_{1t}^{p}=C_t^{-\sigma}Y_t mc_t+\beta\zeta_p\mathbb{E}_t\left(\pi_{t+1}^{\frac{1+\lambda_f}{\lambda_f}}X_{1t+1}^{p}\right) \tag{52}$$

$$X_{2t}^{p}=\frac{1}{1+\lambda_f}C_t^{-\sigma}Y_t+\beta\zeta_p\mathbb{E}_t\left(\pi_{t+1}^{\frac{1}{\lambda_f}}X_{2t+1}^{p}\right) \tag{53}$$

The evolution of real wage is given by

$$\frac{w_t}{w_{t-1}}=\frac{\pi_t^w}{\pi_t} \tag{54}$$

The fact that the capital-output ratio is independent of firm-specific factors implies that we can obtain an aggregate production function

$$A_tK_t^{\sigma}H_t^{1-\sigma}-\Gamma=\int_0^1 Y_t(i)di=\sum_{s=0}^{\infty}\zeta_p(1-\zeta_p)^{(t-s)}\left(\frac{\tilde{p}_{t-s}}{\pi_{t-s,t}}\right)^{-\frac{1+\lambda_f}{\lambda_f}}Y_t$$

Defining the effect of price dispersion as

$$\Delta_t=\sum_{s=0}^{\infty}\zeta_p(1-\zeta_p)^{t-2}\left(\frac{\tilde{p}_{t-s}}{\pi_{t-s,s}}\right)^{-\frac{1+\lambda_f}{\lambda_f}}$$

the aggregate production function becomes

$$A_tK_t^{\sigma}H_t^{1-\sigma}-\Gamma=\Delta_tY_t \tag{55}$$

Using (42), we can define Δ_t recursively as

$$\Delta_t=\zeta_p\Delta_{t-1}.\pi_t^{\frac{1+\lambda_f}{\lambda_f}}+(1-\zeta_p)\left(\frac{1-\zeta_p\pi_t^{\frac{1}{\lambda_f}}}{1-\zeta_p}\right)^{1+\lambda_f} \tag{56}$$

Capital Producers Capital producers transform consumption into investment goods and operate in a competitive national market. Their problem consists of choosing the amount of investment goods produced I_t to maximize (33) taking the price of investment goods p_t^I as given. The first order condition for this problem is

$$p_t^I = 1 + s\left(\frac{I_t}{I}\right) + S'\left(\frac{I_t}{I}\right)\frac{I_t}{I} \tag{57}$$

Dividend of Equity The dividend per unit of equity is the sum of rental rate of capital and the profits of intermediate goods producers and capital goods producers per unit of capital as

$$R_t^k = r_t^k + \frac{Y_t - w_t H_t - r_t^k + p_t^I I_t - I_t[1 + S(\frac{I_t}{I})]}{K_t} \tag{58}$$

6.3 List of Equilibrium Equations

This section lists the equilibrium equations of the model. As stated above, there are twenty five equations, which are the following (in order): $(16, 18, 20, 21, 22)$, $(36 - 40)$ and $(43 - 59)$.

These equations solve the system for the following variables:

$$(C_t, I_t, H_t, Y_t, \tau_t, K_{t+1}, N_{t+1}, N_t^g, N_t^O, L_{t+1}, R_t, q_t, p_t^I, w_t, r_t^k, R_t^k, mc_t, \lambda_t, \pi_t, \pi_t^w, X_{1t}^p, X_{2t}^p, X_{1t}^w, X_{2t}^w, \Delta_t)$$

Equations (in order as listed above):

$$I_t = \int_0^\chi I_t(j)dj$$
$$= \frac{[\,R_t^k + (1-\delta)\,q_t\,\phi_t^O\,]\,[N_t + N_t^I - K_t] + [\,R_t^k + (1-\delta)\,q_t\,\phi_t^I\,][\,K_t - N_t^I] + \frac{\alpha}{2}(N_t^I - N^I)^2 - \tau_t + L_t)}{(p_t^i - q_t\,\theta)}\chi$$

$$\Lambda_t = \chi\frac{q_t - p_t^I}{p_t^I - \theta q_t}$$

$$C_t^{-\sigma} = \beta\mathbb{E}_t\left\{C_{t+1}^{-\sigma}\frac{R_t}{\pi_{t+1}}\left[1 + \Lambda_{t+1}\right]\right\}$$

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ C_{t+1}^{-\sigma} \left[\frac{R_{t+1}^k + (1-\delta) q_{t+1}}{q_t} + \Lambda_{t+1} \frac{R_{t+1}^k + (1-\delta) q_{t+1} \phi_{t+1}^I + \alpha \left(N_t^I - N^I \right)}{q_t} \right] \right\}$$

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ C_{t+1}^{-\sigma} \left[\frac{R_{t+1}^k + (1-\delta) q_{t+1}}{q_t} + \Lambda_{t+1} \frac{R_{t+1}^k + (1-\delta) q_{t+1} \phi_{t+1}^O}{q_t} \right] \right\}$$

$$\left(\frac{1 - \zeta_w {\pi_t^w}^{\frac{1}{\lambda_w}}}{1 - \zeta_w} \right)^{\lambda_w + (1+\lambda_w)\nu} = \frac{X_{1t}^w}{X_{2t}^w}$$

$$X_{1t}^w = \frac{\omega}{(1-\kappa)^\nu} H_t^{(1+\nu)} + \beta \zeta_w \mathbb{E}_t \left({\pi_{t+1}^w}^{\frac{(1+\lambda_w)(1+\nu)}{\lambda_w}} X_{1t+1}^w \right)$$

$$X_{2t}^w = \frac{1}{(1+\lambda_w)} C_t^{(-\sigma)} w_t H_t + \beta \zeta_w \mathbb{E}_t \left({\pi_{t+1}^w}^{\frac{1}{\lambda_w}} X_{2t+1}^w \right)$$

$$\frac{K_{it}}{H_{it}} = \frac{K_t}{H_t} = \frac{\gamma}{1-\gamma} \frac{w_t}{r_t^k}$$

$$mc_{it} = mc_t = \frac{1}{A_t} \left(\frac{r_t^k}{\gamma} \right)^\gamma \left(\frac{w_t}{1-\gamma} \right)^{1-\gamma}$$

$$\left(\frac{1 - \zeta_p \pi_t^{\frac{1}{\lambda_p}}}{1 - \zeta_p} \right)^{-\lambda_p} = \frac{X_{1t}^p}{X_{2t}^p}$$

$$X_{1t}^{p} = C_t^{-\sigma} Y_t mc_t + \beta \zeta_p \mathbb{E}_t \left(\pi_{t+1}^{\frac{1+\lambda_p}{\lambda_p}} X_{1t+1}^{p} \right)$$

$$X_{2t}^{p} = \frac{1}{1+\lambda_p} C_t^{-\sigma} Y_t + \beta \zeta_p \mathbb{E}_t \left(\pi_{t+1}^{\frac{1}{\lambda_p}} X_{2t+1}^{p} \right)$$

$$\frac{w_t}{w_{t-1}} = \frac{\pi_t^w}{\pi_t}$$

$$A_t K_t^{\gamma} H_t^{1-\gamma} - \Gamma = \Delta_t Y_t$$

$$\Delta_t = \zeta_p \Delta_{t-1} . \pi_t^{\frac{1+\lambda_p}{\lambda_p}} + (1-\zeta_p) \left(\frac{1 - \zeta_p \pi_t^{\frac{1}{\lambda_f}}}{1-\zeta_p} \right)^{1+\lambda_f}$$

$$p_t^I = 1 + s\left(\frac{I_t}{I}\right) + S'\left(\frac{I_t}{I}\right)\frac{I_t}{I}$$

$$R_t^k = r_t^k + \frac{Y_t - w_t H_t - r_t^k + p_t^I I_t - I_t[1 + S(\frac{I_t}{I})]}{K_t}$$

$$R_t = \max\left\{ R \pi_t^{\psi_\pi} \left(\frac{Y_t}{Y}\right)^{\psi_y}, 1 \right\}$$

$$N_{t+1}^{g} = \psi^{o} \left(\phi_t^{O} - \phi^{O} \right)$$

$$q_t N_{t+1}^g + \frac{R_{t-1}B_t}{P_t} = \tau_t + \Big[R_t^k + (1-\delta) q_t \Big] N_t^g + \frac{B_{t=1}}{t}$$

$$\tau_t - \tau = \psi_\tau \left[\left(\frac{R_{t-1}B_t}{P_t} \frac{RB}{P} \right) \right] - q_t N_t^g$$

$$K_{t+1} = (1-\delta)K_t + I_t$$

$$K_{t+1} = N_{t+1} + N_{t+1}^g$$

$$N_{t+1}^I = N_{t+1}^O$$

$$Y_t = C_t + \left[1 + S\left(\frac{I_t}{I} \right) \right] I_t$$

6.4 Steady State

I will study the steady state of this economy to get the long term equilibrium of the system. In order to do this I will analyze the state where there is no change in the total factor of production, the resaleability constraints, the nominal price level and the endogenous quantities and prices. The steady state is equal relative to the benchmark model for the following equations:

From equation (37) we get

$$\frac{K}{H} = \frac{\gamma}{1-\gamma} \frac{w}{r^k} \tag{59}$$

As the firms all charge the same price, $\tilde{p} = 1$ and the marginal cost is equal to the inverse of the markup as follows

$$mc = \frac{1}{A}\left(\frac{r^k}{\gamma}\right)\left(\frac{w}{1-\gamma}\right)^{1-\gamma} = \frac{1}{1+\lambda_p} \tag{60}$$

I follow the DEFK (Del Negro *et al.*, 2017) and choose the fixed cost of production in order to get a zero profit condition for the long term equilibrium

$$Y = mc(Y + \Gamma) \tag{61}$$

Using these three equations into (45) I get

$$\frac{Y}{K} = \frac{r^k}{\gamma} \tag{62}$$

Because the ratio between capital and hours is a function of the capital-output ratio (from the production function), equation (57) also yields an expression for the real wage as a function of the rental rate

$$w = (1-\gamma)\left(\frac{A}{1+\lambda_f}\right)^{\frac{1}{1-\gamma}}\left(\frac{\gamma}{r^k}\right)^{\frac{\gamma}{1-\gamma}} \tag{63}$$

In steady state, the real wage is equal to a markup over the marginal rate of substitution between labor and consumption

$$w = (1+\lambda_w)\frac{\omega H^{\nu}}{C^{-\sigma}} \tag{64}$$

From first order condition (19) and using the fact that $p^I = 1$ because $(S(1) = S'(1) = 0)$ from (48), we can solve for the steady state real interest rate as a function of q

$$\beta^{-1} = r\left(1 + \chi\frac{q-1}{1-\theta q}\right) \tag{65}$$

From the government budget constraint (51) we get the tax

$$\tau = (r-1)L \tag{66}$$

In steady state the zero profit condition implies that

$$R^k = r^k \tag{67}$$

From now on we divert in the calculations relative to the benchmark model (Del Negro *et al.*, 2017). The goal is to define q and r^k in order to get the rest of the equations solved. To do so we use the first order conditions of the household (21) and investment equation (15) as follows.

We will work first with the expression of aggregated investment. From expresion (15) we get

$$I = \chi \frac{[\, r^k + (1-\delta)\, q\, \phi^O \,]\, N^O + [\, r^k + (1-\delta)\, q\, \phi^I \,]\, [K - N^I] + \frac{\alpha}{2}(N^I - \overline{N}^I)^2 - \tau + rL}{(p^i - q\,\theta)}$$

We make an assumption stating that equity issued equals the cost threshold in steady state $N^I = \overline{N}^I$. In steady state aggregated capital equals government plus private equity, then we get $N = K$ as in steady state we know that $N^G = 0$ and we assume $N = N^O + K - N^I$ and $N^I = N^O$. We get the following

$$I = \chi \frac{[\, r^k + (1-\delta)\, q\, \phi^O \,]\, [N + N^I - K] + [\, r^k + (1-\delta)\, q\, \phi^I \,]\, [K - \overline{N}^I] + L}{(p^i - q\,\theta)}$$

$$I = \chi \frac{[\, r^k + (1-\delta)\, q\, \phi^O \,]\, N - [\, r^k + (1-\delta)\, q\, (\phi^O - \phi^I) \,]\, [\overline{N}^I - K] + L}{(p^i - q\,\theta)}$$

where we eliminate taxes from equation (64). We get that in steady state the Investment equals depreciated capital

$$\delta = \frac{I}{K} \tag{68}$$

Combining the two previous expressions and that $p^i = 1$ we get

$$\delta\,(1-\theta q) = \chi \left[[\, r^k + (1-\delta)\, q\, \phi^O] + [\, r^k + (1-\delta)\, q\, (\phi^O - \phi^I)] \left[\frac{\overline{N}^I}{K} - 1 \right] + \frac{L}{K} \right]$$

From equation (60) we get that in steady state

$$\delta\,(1-\theta q) = \chi\left[[r^k + (1-\delta)\,q\,\phi^O] + [\,r^k + (1-\delta)\,q\,(\phi^O - \phi^I)]\left[\frac{\overline{N}^I}{K} - 1\right] + \frac{L}{Y}\,\frac{r^k}{\gamma}\right]$$

Where $\frac{L}{Y}$ is ratio of liquid assets to GDP that we take as exogenous in the calibration following the original paper.

Rearranging terms we can get a relation between r^k and q.

$$\delta - \left[\theta\,\delta + (1-\delta)\,\phi^O\,\chi + (1-\delta)\,\chi\,(\phi^O - \phi^I)\left(\frac{\overline{N}^I}{K} - 1\right)\right] q = \chi\left(1 + \left(\frac{\overline{N}^I}{K} - 1\right) + \frac{L}{Y}\,\frac{1}{\gamma}\right) r^k \quad (69)$$

Now we turn to the first order condition (21). We get the following

$$\frac{1}{\beta} = \frac{[r^k + (1-\delta)q]}{q} + \frac{\chi}{(1-\theta q)q}[r^k + (1-\delta)\phi^O q][q-1]$$

$$q\left[\frac{\beta^{-1} - (1-\delta)(1-\theta\,q) - \kappa(q-1)\,\phi^O(1-\delta)}{(1-\theta q) + \kappa(q-1)}\right] \quad (70)$$

Inserting r^k expression from (69) into (68) we get an expression for q.

6.5 Liquidity Constraint

The following is the derivation of the Liquidity Constraint of the Benchmark Model. The equations used are the following:

Equations (3)

$$N_t = N_t^O + K_t - N_t^I$$

and (9) of the Model

$$K_{t+1} = (1-\delta)K_t + \int I_t(j)dj$$

From the Online Appendix of the paper, equations (A-10) and (A-11). For liabilities,

$$N_{t+1}^{I}(j) \leq (1-\delta)\, N_t^I + \theta\, I_t(j) \; + (1-\delta)\, \phi_t^I\, (K_t - N_t^I)$$

For assets,

$$N_{t+1}^{O}(j) \geq (1-\delta)\, N_t^O - (1-\delta)\, \phi_t^O\, N_{t+1}^O$$

and the following assumption

$$\phi_t^O = \phi_t^I = \phi_t$$

Calculations:

$$N_{t+1}^{O}(j) - N_{t+1}^{I}(j) \geq (1-\delta)\, N_t^O - (1-\delta)\, \phi_t^O\, N_t^O - (1-\delta)\, N_t^I - \theta\, I_t(j) \; - (1-\delta)\, \phi_t^I\, (K_t - N_t^I)$$

$$N_{t+1}^{O}(j) - N_{t+1}^{I}(j) \geq (1-\delta)\, N_t^O - (1-\delta)\, \phi_t^O\, N_t^O - (1-\delta)\, N_t^I - \theta\, I_t(j) \; - (1-\delta)\, \phi_t^I\, K_t + (1-\delta)\, \phi_t^I\, N_t^I$$

Using equation (3)

$$N_{t+1}^{O}(j) - N_{t+1}^{I}(j) \geq (1-\delta)\, (N_t^O - N_t^I) - (1-\delta)\, \phi_t\, (N_t^O - N_t^I + K_t) - \theta\, I_t(j)$$

Adding K_{t+1} and using equaiton (9) from the model

$$N_{t+1}(j) \geq (1-\delta)\, (N_t^O - N_t^I) - (1-\delta)\, \phi_t\, N_t - \theta\, I_t(j) + (1-\delta)\, K_t + \int_0^1 I_t(j) dj$$

$$N_{t+1}(j) \geq (1-\delta)\, N_t - (1-\delta)\, \phi_t\, N_t - (1-\theta)\, \int_0^1 I_t(j) dj$$

$$N_{t+1} \geq (1-\delta)\, N_t - (1-\delta)\, \phi_t\, N_t + (1-\theta)\, I_t$$

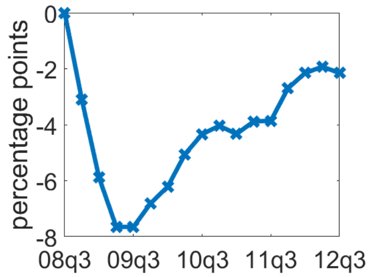
$$N_{t+1} \geq (1-\delta)\, (1-\phi) N_t + (1-\theta)\, I_t$$

6.6 Calibration Robustness Table

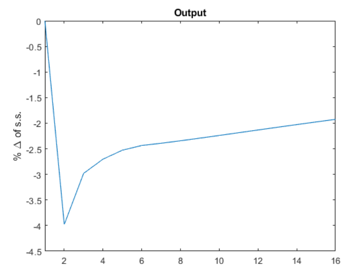
Alpha Values						
o.1 - Calibration	1	10	1000	Differences		
0	0	0	0	0	0	0
-3.9792	-3.9792	-3.9792	-3.9792	0	0	0
-2.9802	-2,9802	-2.9802	-2.9802	0	0	0
-2.7027	-2.7027	-2.7027	-2.7027	0	0	0
-2.5278	-2.5278	-2.5278	-2.5278	0	0	0
-2.4358	-2.4358	-2.4358	-2.4358	0	0	0
-2.3922	-2.3922	-2.3922	-2.3922	0	0	0
-2.3439	-2.3439	-2.3439	-2.3439	0	0	0
-2.2926	-2.2926	-2.2926	-2.2926	0	0	0
-2.2398	-2.2398	-2.2398	-2.2398	0	0	0
-2.1864	-2.1864	-2.1864	-2.1864	0	0	0
-2.133	-2.133	-2.133	-2.133	0	0	0
-2.0799	-2.0799	-2.0799	-2.0799	0	0	0
-2.0274	-2.0274	-2.0274	-2.0274	0	0	0
-1.9758	-1.9758	-1.9758	-1.9758	0	0	0
-1.9251	-1.9251	-1.9251	-1.9251	0	0	0
-1.8755	-1.8755	-1.8755	-1.8755	0	0	0

Table 5: Robustness - 16 quarters of Output results for the IGE Model with intervention calibrated with different values of Alpha parameter and its differences relative to the calibration used for the analysis (o.1)

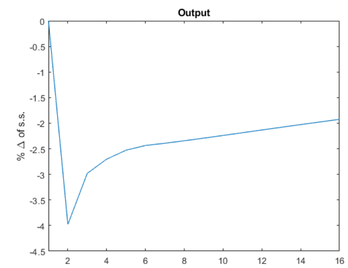
6.7 Complementary Charts for Section 4.1



(a) Data

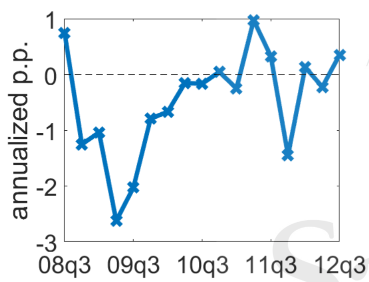


(b) IGE Model- Intervention in Assets Markets

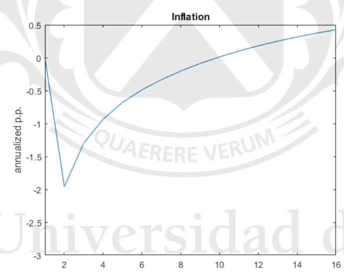


(c) IGE Model - Intervention in Liability Markets

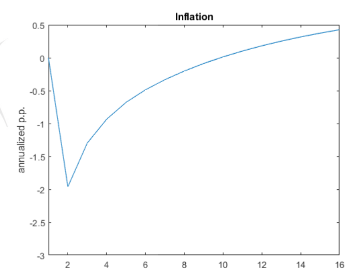
Figure 18: Output



(a) Data

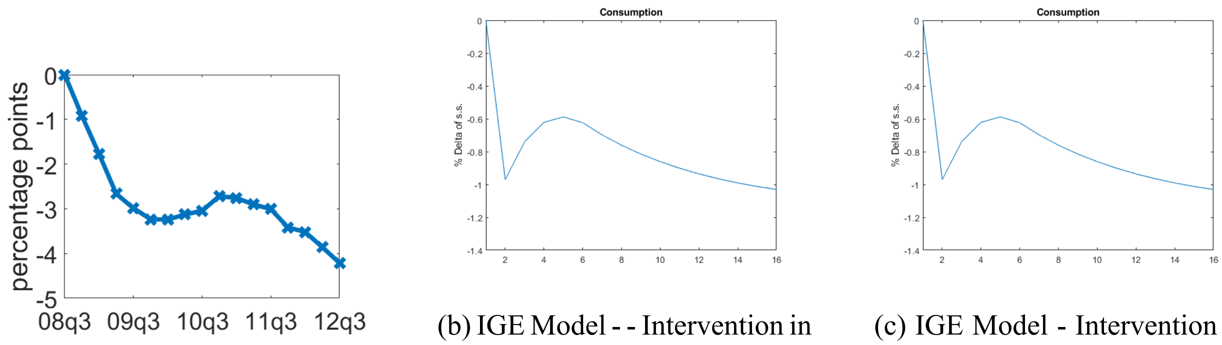


(b) IGE Model - - Intervention in Assets Markets



(c) IGE Model - Intervention in Liability Markets

Figure 19: Inflation

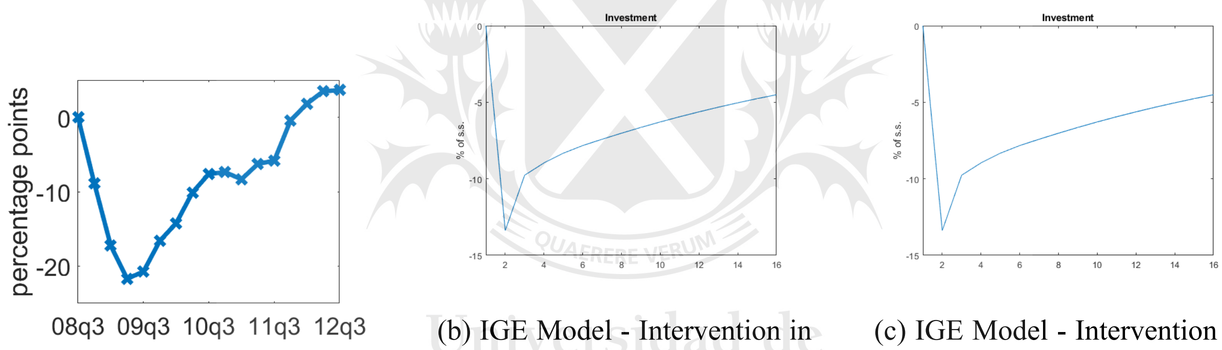


(a) Data

(b) IGE Model - - Intervention in Assets Markets

(c) IGE Model - Intervention in Liability Markets

Figure 20: Consumption

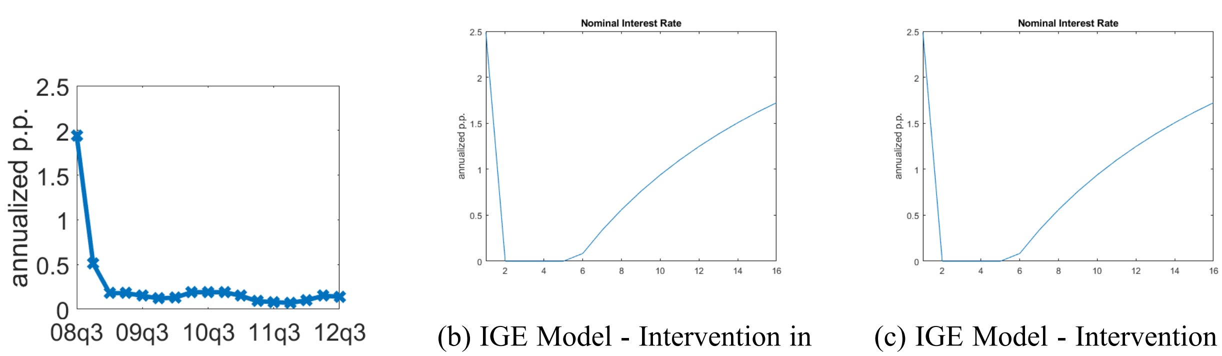


(a) Data

(b) IGE Model - Intervention in Assets Markets

(c) IGE Model - Intervention in Liability Markets

Figure 21: Investment

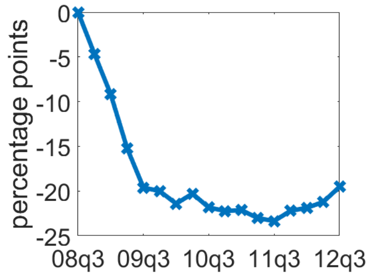


(a) Data

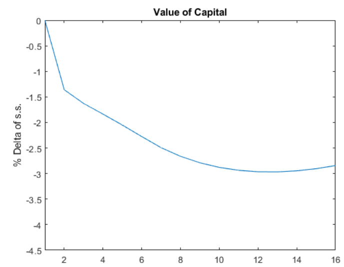
(b) IGE Model - Intervention in Assets Markets

(c) IGE Model - Intervention in Liability Markets

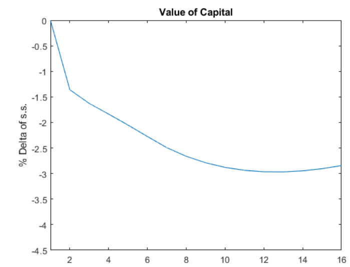
Figure 22: Nominal Interest Rate



(a) Data

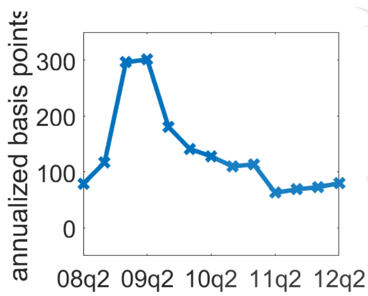


(b) IGE Model - Intervention in Assets Markets

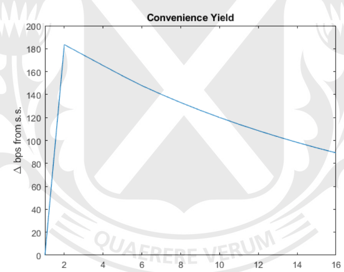


(c) IGE Model - Intervention in Liability Markets

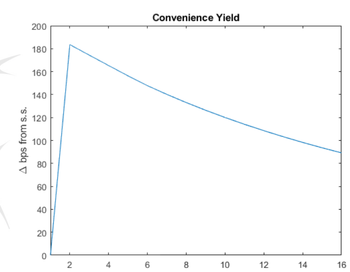
Figure 23: Value of Capital



(a) Data



(b) IGE Model - Intervention in Assets Markets



(c) IGE Model - Intervention in Liability Markets

Figure 24: Convenience Yield