Unemployment and credit constraints in a heterogeneous agent model

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Abstract

What is the link between the drop in consumer credit during the Great Recession and increased unemployment? I build a heterogeneous household model with endogenous idiosyncratic risk of unemployment, incomplete insurance, sticky wages, and a central bank that follows a predetermined interest rate rule. After a shock to their credit constraints, households try to save more and thereby reduce their spending. This results in increased unemployment. With a typical interest rate rule, I find that a tightening in credit constraints that matches the decline in consumer credit between 2008:Q2 and 2010:Q3 can explain about a 1 percentage point increase in unemployment. Without an interest rate decrease, my model exhibits a 5.36 percentage point increase in unemployment.

1 Introduction

In the years prior to the U.S. recession in 2008-09, households had been steadily taking on more and more debt. When the recession hit, this trend was abruptly broken, and

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households began to reduce their debt levels very quickly over the next several quarters. Real consumer credit per capita declined to 2002 levels over the course of nine quarters. From its peak in 2008:Q2, real consumer credit per capita fell 9.65% to a trough in 2010:Q3. Additionally, this time period was also marked by a significant increase in the unemployment rate. Prior to the crisis, the unemployment rate was around 5%. During the recession, it rose to a peak of 10%.

At the core of the common narrative offered for this severe recession, households reduced their demand for consumption goods and chose to save more of their income. This caused employment and output to fall, lowering income and further reducing the demand for consumption goods. The initial shock that precipitates the decrease in demand is different for different stories. Explanations for this initial shock include popping asset bubbles (and the resulting wealth effect), confidence shocks, inflation expectations shocks, preference shocks, and credit constraint shocks.

The purpose of this paper is to present a simple model that captures the common element of these popular stories. In the model, a tightening of credit constraints reduces consumer credit. As a consequence, households face increased incentive to save and decrease demand for consumption, resulting in an increase in unemployment. The main question that I address is a quantitative one: What portion of the observed increase in unemployment during the recession can be attributed to the tightening of households’ credit constraints and the consequent fall in consumer credit?

My model is built on four components: heterogeneous households, a credit constraint shock, nominal wage rigidity and an interest rate rule. I require heterogeneous households because an economic model with one representative household generally cannot describe debt. Some households must have positive asset holdings and some must have negative asset holdings (debt). I introduce heterogeneity by assuming binary employment outcomes and incomplete insurance. A household is either employed or unemployed. There is no intensive margin for labor such as hours. This is the starting point for creating differences between households. Employed households earn a wage, and unemployed households earn an unemployment benefit which is less than the wage. Therefore, households will differ by their employment history.

Incomplete insurance is required to maintain these differences between households. Otherwise, households would agree to an income-sharing arrangement which would make their employment histories irrelevant to their budget constraint.
With these two assumptions, households will differ by their levels of wealth. Households that have been employed for a while will generally have higher wealth than households that are in a spell of unemployment. These two assumptions make for a heterogeneous agent model that I have to solve computationally.

The next component is an exogenous credit constraint for all households. The economy will initially be in a steady state with loose credit and some small amount of unemployment. The credit constraint is then tightened by an unanticipated and permanent shock.

After the credit constraint shock, households will increase demand for saving for two reasons. First, a fraction of households will be below the new credit constraint and will have to save more to be in compliance with the new, tighter constraint. Second, all households now have a smaller wealth buffer to draw down in case they are unemployed, and they will want to save more to restore that buffer.

This increase in demand for saving could be negated by an appropriate decrease in the real interest rate. While those households below the new credit constraint still need to save more, a decrease in the real interest rate will cause wealthier households to reduce saving. If the real interest rate falls sufficiently, the total effect on demand for saving would be nullified. Therefore, in order to get a decrease in demand for saving after the credit constraint shock, I need to restrict the movement of the real interest rate.

The real interest rate is a function of the inflation rate and the nominal interest rate. This leads me to the last two components of the model: nominal wage rigidity and an interest rate rule for the central bank. Wage rigidity is a common assumption in New Keynesian models. In my model, nominal wage rigidity restricts the inflation rate, and the central bank’s interest rate rule determines the nominal interest rate. After the credit constraint shock, the real interest rate will not decrease enough to negate the shock’s effect, and there will be an increase in demand for saving.

As households try to save more and the demand for consumption goods falls, firms will lay off workers, and the unemployment rate will rise. In this way, my model captures the paradox of thrift. There are two channels through which unemployment will continue to rise. The first is the typical Keynesian multiplier effect, or income effect. Diminished output implies diminished household income which causes demand for consumption goods to fall even further. The second is a precautionary saving effect. The rise in the unemployment rate implies that the probability of a household losing its job has increased, and the
expected duration of an unemployment spell has lengthened. In light of this heightened risk of unemployment, households will increase demand for saving even further.

My model allows me to quantify how much the increase in unemployment can be attributed to the households’ response to the credit constraint shock. If I calibrate the shock to match the fall in consumer credit between 2008:Q2 and 2010:Q3, the model can explain approximately a 1 percentage point increase in the unemployment rate. Adjusting for the upward trend in consumer credit prior to the shock, I can explain a 1.38 percentage point increase in the unemployment rate. This is in light of the fact that consumer credit makes up only 17.9% of household liabilities. Furthermore, in the model, the central bank responds in the same quarter as the shock by lowering the interest rate: there are no delays.

Moreover, my quantitative model can demonstrate the importance of the interest rate responding to changes in unemployment through the interest rate rule. I consider a situation where the interest rate does not fall after the credit constraint shock. This is to proxy for the case wherein the interest rate is at the zero lower bound. Alternatively, it could be that the central bank is simply unresponsive. Either way, after the credit constraint shock, the unemployment response is much greater when the interest rate is unable to fall. In this situation, after an identical shock to credit constraints, the unemployment rate will rise 5.36 percentage points.

These two results lead me to conclude that it is unlikely that the rapid drop in consumer credit alone explains the levels of unemployment observed in the U.S. during the Great Recession. While the unemployment rate increased about 5 percentage points, consumer credit alone explains only 1 to 1.38 percentage points. There must have been other factors at work: these factors likely brought the nominal interest rate to the zero lower bound. In which case, the shock to consumer credit can explain the 5 percentage point increase in the unemployment rate.

**Related work**

Since my model is a heterogeneous agent model, I have solved it using the computational method illustrated in Krusell and Smith (1998). In their model, households differ by their level of capital holdings, and employment outcomes are determined by an exogenous one
period Markov chain. Like their model, in mine, households will differ in their wealth levels. However, in my model, the probability of a household being employed is based on their employment state in the previous period and the employment rate as determined by aggregate demand. Thus, in this paper, employment is endogenously determined.

Eggertsson and Krugman (2012) build a model with patient and impatient agents. That is, some of their agents have high time discount factors ($\beta$'s) and some have low. All impatient agents are exactly at their credit constraint: the credit constraint binds with equality for them. Given this, they explore how a credit constraint shock would affect the economy. All impatient agents are forced to move, in one period, out of violation of the new tighter credit constraint. My model differs in that all households have identical preferences. Furthermore, in my model, only a small fraction of households will ever be in direct violation of the credit constraint after it is shocked. Additionally, I allow those households to gradually come into compliance with the new credit constraint, instead of forcing them to do so in one period. That said, Eggertsson and Krugman’s model is analytically solvable due to the fact that there are just two types of households.

Guerrieri and Lorenzoni (2011) also explore tightening credit constraints in a heterogeneous agent model. The decrease in output following a tightened credit constraint in that model is due to low productivity workers working more, while high productivity workers work less. They also extend their model to include sticky prices, and consider different paths for the interest rate after the shock. Since they explain the decrease in output due to a fall in average productivity, they provide more of a supply-side explanation for the recession than a demand-side one as told in the aforementioned story. In my model, all workers have identical productivity, and the decrease in output will be due to diminished demand for consumption goods.

Hall (2011) illustrates how a fixed interest rate can lead to unemployment. He shows that inflation is mostly exogenous over time: that prices do not necessarily fall when there is high unemployment. Given this, when the nominal interest rate is bound by the zero lower bound, the real interest rate is also constrained. And if this bound real interest rate does not match the real interest rate that would be implied by inter-temporal preferences and production technology, there will be unemployment. Like Eggertsson and Krugman (2012), he has two types of households: some households are always at their credit constraint and others are not. Among other components, his model features sticky real wages and exogenous inflation. He demonstrates that when the interest rate is pinned, there is unemployment.
My model is similar in its assumptions about wages and inflation. In my model though, I do not have a fixed fraction of agents at the credit constraint. Also, his experiment, at the core, is about a pinned versus unpinned interest rate. My model takes a step back from that and is about a credit constraint shock which will endogenously affect the interest rate.

Michaillat (2012) lays down a framework for discussing job rationing and demonstrates how rationing can occur when wages are rigid and marginal product of labor is decreasing. My model features fixed wages, and in effect, diminishing marginal product of labor. While the production function has constant marginal product of labor, the marginal revenue product of labor is decreasing. Past a point, while a firm could hire another worker to produce another unit of output, the firm would be unable to sell that unit of production, even for its marginal cost. My model has no matching frictions (and so no frictional unemployment): all unemployment will be rationing unemployment.

Ravn and Sterk (2013) feature a model with heterogeneous households that save for precautionary reasons. They include a job matching aspect with two pools of unemployed workers: the short-term unemployed and the long-term unemployed. They then shock the job matching component of the model and consider the effects. While the setup of the model is similar, the questions I consider are different. Whereas they are focused on shocks to the job matching aspect of the model, I study a change in credit constraints and do not need to include job matching.

Schmitt-Grohé and Uribe (2012) create a representative agent model to explain the recession, and in particular, the jobless recovery. They shock inflation expectations, and this causes the economy to fall into a liquidity trap, that is, a period where the zero lower bound on the nominal interest rate binds. Similar to my model, they assume households supply labor perfectly inelastically and include downward nominal wage rigidity. There are some differences in just these two assumptions though. In their model, the representative household can work for some or all of its time endowment. If the household does not work all its hours, they call that unemployment. In my model, households either work or do not, and the fraction of households that do not work is unemployment. Also, my nominal wage rigidity assumption is technically stronger than theirs.

There are two key differences between this model and mine. First, they shock inflation expectations, and I shock the credit constraint. Second, in their model, in order to get unemployment, the nominal interest rate must hit the zero lower bound. In my model,
I can get a response of increased unemployment after the shock without the zero lower bound binding.

The rest of this paper is in five sections. I set up the assumptions and equations of the model in Section 2. In Section 3, I calibrate most of the parameters for the model and examine the baseline case where the credit constraint is constant over time. Section 4 features the main experiment of the paper. I calibrate the shock to the credit constraint and present a number of figures as to the shock’s effects on the economy. In Section 5, I provide a set of alternative calibrations and experiments, including my proxy for an economy with the nominal interest rate at the zero lower bound. Section 6 concludes.

2 Model

Households

This is a quarterly model, and there are three types of actors: households, firms, and the government.

In the model, there is a continuum of households of measure $I = 1$, indexed by $i$. Households are infinitely-lived and risk averse. There is only one type of consumption good and households value it using an isoelastic (constant relative risk aversion) utility function. Households gain no utility from leisure and suffer no disutility from working. Therefore, their utility function, with coefficient of risk aversion $\gamma$, is as follows:

$$u(c_{i,t}) = \frac{c_{i,t}^{1-\gamma} - 1}{1 - \gamma}$$

A household $i$ starts any given period $t$ with some level of bonds $b_{i,t-1}$, which it chose in the previous period. Households are permitted to hold negative levels of bonds, which represents debt. If a household is employed, it will earn a wage $w_t$, which is taxed at a rate $\tau_t$. If a household is unemployed, it collects an unemployment benefit from the government $\eta_t$ and is not taxed. These things make up a household’s budget, as shown in Equation 2.2.

A household will spend its entire budget on purchasing consumption goods, $c_{i,t}$, or bonds, $b_{i,t}$. Consumption goods are purchased at price $p_t$, and bonds are purchased at price $q_t$. 
All households are bound by a credit constraint $\bar{b}_t$: all households must hold at least $\bar{b}_t$ bonds, where $\bar{b}_t$ is a negative number. This is the source of the aggregate shock to the economy.

Given all this, each household solves a recursive maximization problem, discounting utility across time by discount factor $\beta$.

$$V(e_{i,t}, b_{i,t-1}; \Gamma_t) = \max_{c_{i,t}, b_{i,t}} u(c_{i,t}) + \beta E_t V(e_{i,t+1}, b_{i,t}; \Gamma_{t+1})$$

subject to:

$$p_t c_{i,t} + q_t b_{i,t} = w_t (1 - \tau_t) e_{i,t} + \eta_t (1 - e_{i,t}) + b_{i,t-1}$$

$$b_{i,t} \geq \bar{b}_t$$

In period $t$, household $i$’s idiosyncratic state variables are $e_{i,t}$, the employment state of the household, and $b_{i,t-1}$, the quantity of bonds purchased by the household last period. For any period $t$, the household is either employed, $e_{i,t} = 1$, or unemployed, $e_{i,t} = 0$. A household’s employment status is not chosen by the household, but rather, is determined by demand for consumption goods.

Since households are idiosyncratically employed or unemployed, they will vary in their employment histories. Furthermore, since there is incomplete insurance as in Bewley (1977), households hold bonds, not just to earn a rate of return, but as a precaution against unemployment. Therefore, the idiosyncrasy in employment outcomes causes households to be heterogeneous in their levels of bond holdings. The joint distribution of employment states, $e_{i,t}$, and bond holdings $b_{i,t-1}$, is represented by the term $\Gamma_t$. In particular, note that households observe the current level of employment when they make their decisions.

**Firms**

There is an infinite number of perfectly competitive firms. Firms employ a measure of households $L_t$ and produce consumption goods $C_t$ according to a linear production function.

$$C_t = AL_t$$
Firms maximize profits according to the following optimization problem.

\[
\max_{L_t} p_t AL_t - w_t L_t
\]

The first order condition implies a simple relationship between the price of the consumption good and the wage. Furthermore, firms earn zero profits.

\[
w_t = p_t A
\]

**Employment dynamics**

At the start of the period, a fraction \( \lambda \) of employed households are separated from their jobs. Those employed households who avoid this separation will have jobs this period, assuming firms terminate no jobs. In this way, a household’s employment state is somewhat persistent. Households employed in the previous period have a higher chance of employment than those unemployed in the previous period.

These factors combine to give the following probabilities, where \( L_t \in [0, 1] \) represents the fraction of households employed in period \( t \), and \( \tilde{L}_t = (1 - \lambda)L_{t-1} \) represents the fraction of the households that survive the separation shock in period \( t \).

\[
\begin{align*}
\Pr(e_{i,t} = 1 | e_{i,t-1} = 1) &= \\
&= \begin{cases} 
(1 - \lambda) \frac{L_t}{L_t} & L_t < \tilde{L}_t \\
(1 - \lambda) + \lambda \frac{L_t - \tilde{L}_t}{1 - L_t} & L_t \geq \tilde{L}_t
\end{cases} \\
\Pr(e_{i,t} = 1 | e_{i,t-1} = 0) &= \\
&= \begin{cases} 
0 & L_t < \tilde{L}_t \\
\frac{L_t - \tilde{L}_t}{1 - L_t} & L_t \geq \tilde{L}_t
\end{cases}
\end{align*}
\]

For example, if \( L_t < \tilde{L}_t \), then firms want to further reduce their number of employees beyond those removed by the \( \lambda \) shock. The probability of a previously employed worker having a job then is the probability they survive the \( \lambda \) separation shock times the probability that they are of the \( L_t \) chosen among all of the workers in \( \tilde{L}_t \).
Model assumptions

At this point, it is worthwhile to talk about why there is unemployment. Recall that households have no disutility from working and supply labor perfectly inelastically. Consider a situation in which some households are employed and others are unemployed but want to work at the current wage. The classical response is to predict that the real wage, $w_t/p_t$, must fall until there are no unemployed households.

Since this is a model for recessions, and during the recession there is greater than normal unemployment, the nominal wage would only have a tendency to fall. However, many macroeconomic models assume that wages have nominal downward rigidities, such as Schmitt-Grohé and Uribe (2012). In the United States, this assumption is supported by survey data examined by Barattieri, Basu, and Gottschalk (2010). In my model, I assume that the nominal wage cannot decrease. And since the nominal wage would only decrease in the model, this implies that the nominal wage is constant. I normalize the nominal wage to $w_t = 1$ for all $t$. Despite fixing the nominal wage, the classical response could still work: the real wage, $w_t/p_t$, can be made to fall by increasing $p_t$.

However, since firms are perfectly competitive, we know they will price the consumption good at $p_t = \frac{w_t}{A}$. Therefore, with a fixed nominal wage and perfectly competitive firms, the real wage is fixed at $\frac{w_t}{p_t} = A$.

Note that there are three markets: labor, consumption goods, and bonds; and therefore, there are three prices: $w_t$, $p_t$, and $q_t$. I have discussed how nominal wages and the price of consumption goods are set and are incapable of adjusting to bring the economy from a state with unemployed households to a state of full employment.

The last hope for full employment is in the price of bonds, $q_t$. By lowering the bond price, a benevolent social planner can encourage saving, and inversely, discourage consumption. If the bond price can take on any value, then by adjusting the bond price appropriately, the planner can target the level of consumption corresponding to full employment $C_t = A$. However, the government will follow an interest rate rule, and this determines the bond price exactly. Because the bond price is constrained, the model can exhibit unemployment.

Throughout the rest of the paper, I drop the subscripts on wage, $w$, and the price of the consumption good, $p$, since they are constant over time.
**Government**

The government taxes wages and sets unemployment benefits according to some ratio $\rho$, which is the ratio between employed households’ after-tax wages and unemployed households’ benefits. For example, when $\rho = 0.4$, the unemployed have 40% the after-tax income of the employed (excluding interest income).

$$\rho = \frac{\eta_t}{w(1 - \tau_t)} \quad (2.4)$$

The government maintains a fixed level of debt. Thus, households as a group always have positive net assets (bonds). Let $B > 0$ represent this fixed level of government held debt per capita. The government always runs a balanced budget: tax revenue equals transfer payments plus service on the debt.

$$w\tau_t L_t = \eta_t (1 - L_t) + (1 - q_t)B \quad (2.5)$$

By way of Equations 2.4 and 2.5, the unemployment benefit, $\eta_t$, and the wage tax, $\tau_t$, are functions of $L_t$ alone.

The government also sets the nominal interest rate according to an interest rate rule involving the level of employment. Since inflation is zero, as discussed above, no inflation term appears in this interest rate rule. Furthermore, since inflation is zero, the real interest rate, $r_t$, is the same as the nominal interest rate.

$$r_t = \max \left( r^* + \psi(L_t - L^*), 0 \right) \quad (2.6)$$

The term $r^*$ is the target real interest rate. The term $L^*$ is the target employment rate, and $\psi$ is the government’s responsiveness to the employment gap. In the real world, households can always hold money and earn a nominal rate of return of zero. Therefore, the nominal interest rate cannot fall below zero and so neither can the real interest rate.

Again, this is a quarterly model, and I specify interest rates in annual terms. Therefore, the bond price $q_t$ is related to the interest rate according to the following equation.

$$q_t = \frac{1}{(1 + r_t)^{1/4}}$$
Equilibrium

For any given period $t$, an intra-temporal equilibrium is defined by a joint distribution of saving decisions and employment outcomes, $\Gamma_t$, where all of the above equations hold and the three markets are cleared:

- Total production equals total consumption: $C_t = \sum_i c_{i,t}$
- Total net quantity of bonds saved equals the number of bonds sold by the government: $B = \sum_i b_{i,t}$
- The number of households working equals the households employed: $L_t = \sum_i e_{i,t}$

Equilibrium is defined as sequence of intra-temporal equilibria where the evolution of $\Gamma_t$, the joint distribution of saving decisions and employment outcomes is consistent with the household policy function. The economy is in steady state in period $t$ if $\Gamma_t = \Gamma_{t+1}$.

Solution method

My solution method is similar to Krusell and Smith (1998). To briefly summarize it, the first step is to guess laws of motion for various moments of the household’s wealth distribution. Given these laws of motion, I estimate the households’ value and policy functions by value function iteration. I then simulate the economy given the households’ policy function. After that, I estimate new laws of motion for the moments of the wealth distribution based on the simulation’s results. If the estimated laws of motion are similar to the guessed ones, then I have found valid laws of motion and policy functions. If the estimated laws of motion differ from the guessed ones, then I repeat the process with new laws of motion estimates serving as the guessed laws of motion.

Computationally, only the current employment rate is necessary for households to make their consumption/saving decisions. That is, I require only the mean of the employment distribution. This is similar to a result in Krusell and Smith (1998), where only the mean of the capital distribution is required, while the variance and other statistics are extraneous.
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<th>Name</th>
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<th>Value</th>
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<td>Constant of relative risk aversion</td>
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<td>Total factor productivity</td>
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<td>Household credit constraint</td>
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Table 1: Parameter values

3 Baseline calibration and results

I first calibrate the model without the credit constraint shock and examine the steady state.

Calibration

Table 1 describes the values of the parameters in the baseline calibration.

I want the household discount rate, $\beta$, to correspond to an annual interest rate of 2.5% if this was a model with perfect insurance (a representative agent model). Note that $\beta$ is provided in quarterly terms by the formula in the table. The nominal wage is fixed by assumption. The choice of $w$ is a decision as to how to scale other variables. So I set $w = 1$. Similarly, total factor productivity just scales things, so I set $A = 1$. Shimer (2005) determines the quarterly job separation rate to be $\lambda = 0.1$ and has the unemployed earn 40% of what the employed earn, so $\rho = 0.4$.

I set $\psi = 0.5$, which is a typical coefficient for the output gap. Note, however, that it is actually being applied to a difference in employment rates or output, and not an output gap percentage. Of course, this is a fairly trivial distinction to make. I set $L^* = 0.95$ and $r^* = 0.025$. This will imply the unemployment rate is about 5%. Of course, these two parameters are not uniquely determined: any $L^*$ and $r^*$ satisfying the following equation
would be equivalent.

\[ r^\ast - 0.5L^\ast = 0.025 - 0.5(0.95) = -0.45 \]

However, setting \( r^\ast = 0.025 = \left( \frac{1}{\beta} \right)^4 - 1 \) is convenient, based on how \( \beta \) was chosen. In steady state, we should expect to see the steady state interest rate less than \( r^\ast \) and the steady state employment rate less than \( L^\ast \). Why? In a world with perfect insurance, we would expect the annual interest rate to equal \( r = r^\ast = \left( \frac{1}{\beta} \right)^4 - 1 \). However, without perfect insurance, saving provides not only a rate of return from interest, but also insurance against unemployment. The required rate of return on saving then is going to be less than \( \left( \frac{1}{\beta} \right)^4 - 1 \). Therefore, by way of Equation 2.6, we would expect \( L_t < L^\ast \). Of course, this should not be alarming: there is an equivalent \( r^\ast \) and \( L^\ast \) where they are equal to their steady state values.

Targeting around 5% unemployment is, of course, a bit wasteful; there is nothing in the model to prevent the government from targeting 0% unemployment. I chose the 5% unemployment target since there is some frictional/structural unemployment in the world, and this just models that. In fact, an earlier specification of the model included a reduced form of frictional unemployment, where a random 5% of households were made unemployed and unemployable for the period, and thus the maximum employment rate was 95%. That feature was dropped for simplicity’s sake, since, for the most part, it only justified targeting 5% unemployment.

To calibrate \( B \) and \( \bar{b} \), I chose to look at U.S. consumer credit and exclude other household liabilities. Naturally, home mortgages make up the majority of household liabilities. However, I suspect that the model would need to be expanded to include homes and mortgages explicitly if I wanted to properly include home mortgages.

Similarly, from the balance sheet for U.S. households, I chose to examine only the most liquid assets: currency, deposits and money market funds, to the exclusion of other household assets. Again, real estate makes up a large portion of household assets, but I have excluded it for reasons mentioned. I have also excluded corporate equity holdings, savings bonds, and other financial instruments. I believe that these types of assets are saved mostly to fund college education or retirement. Since the model does not emulate either college expenses or retirement, to include those assets would require that model households hold a relatively large amount of assets for precautionary saving motives.
Furthermore, with such high levels of mean asset holding, it is very hard to have indebted households.

Explained another way, when the household wealth distribution’s mean is so far to the right, it is very hard to get the left tail of the distribution left of zero such as to have sufficient household debt compared to the consumer credit data. The only way to increase the variance of the distribution is to lower the wealth floor $\bar{b}$, but that ceases being effective at increasing variance past a point. The idiosyncratic unemployment shocks only provide so much variance to household wealth. When the economy has so much in assets, households never have to enter debt.

The consumer credit series and the “currency, deposits, and money market funds” series were drawn from Table B-100 of the Federal Reserve’s Z.1 report, March 6, 2014. I seasonally adjusted the series using X-13ARIMA-SEATS. (I also tried other methods of seasonal adjustment with similar results.) I combined this with the seasonally adjusted GDP series from the BEA’s million-dollar NIPA tables to get debt-to-GDP and assets-to-GDP.

The variables $B$ and $\bar{b}$ are calibrated such that debt-to-GDP ($= 0.1785$) and assets-to-GDP ($= 0.5214$) match 2008:Q2, the quarter before the noticeable drop in consumer credit.

**Results**

In this baseline model without a credit constraint shock, let us consider the policies of households. In steady state, the economy has an unemployment rate of 5.1%, so I will examine how much households want to save at this level of employment. Figure 3.1 shows net bond accumulation for employed and unemployed households at various bond holding levels.

The horizontal axis corresponds to the household’s wealth or bond holdings. Very poor households are to the left, and rich households are to the right. Close to the credit constraint, households save a lot, and this decreases as household wealth increases. As expected, employed households save, increasing their bond holdings over time, and unemployed households dissave.
Intra-temporal equilibrium is found by looking for a fixed point of $L$, the measure of households employed. First I suppose some level of $L^1$ (the superscript here does not indicate an exponent). By way of the central bank’s interest rate rule, this provides $r^1$. Furthermore, with this $L^1$, I can determine which households are employed and which are unemployed based on the previous employment distribution. At this point, households have all the information they need to use their policy rule and report how many bonds they want to buy. They know the wage, the price of output, and the price of bonds (by way of $r^1$). They know their current wealth and whether they are employed or not. They finally know what the employment rate is today, which informs them as to what the employment rate is likely to be tomorrow through an estimated law of motion for employment rates. With this information, they indicate how many bonds they are willing to buy, or equivalently, how much output they want to buy, $C^1$. If $C^1 \neq AL^1$, then this is not an intra-temporal equilibrium. If $C^1 \neq AL^1$, then I can find a new $L^2 = C^1/A$, and repeat this process until $L^{k+1} = L^k$.

The solution method helps explain how Figure 3.2 is constructed. On the horizontal axis is output $AL$. On the vertical axis is aggregate demand/consumption, $C$. The vertical
Figure 3.2: Modified Keynesian cross for the baseline model

line at 0.949 is the intra-temporal equilibrium level of output, which corresponds to the unemployment rate 5.1%. The 45 degree line represents the firm’s side of the economy, $C = AL$. The consumption demand line represents the household and government’s side. This is not a typical Keynesian cross: consumption demand begins to decrease around 0.9 output (or 90% employment). This is due to the interest rate rule of the central bank. To the left of 90% employment, the interest rate is zero. To the right, however, the interest rate is increasing. This causes households to divert from spending to saving. Since the interest rate is not constant, I call this a modified Keynesian cross.

If the interest rate was constant at zero throughout, then consumption demand would continue its mostly linear trend and intersect the 45 degree line beyond output = 1. That is, there would be no intra-temporal equilibrium. There is excess demand for consumption goods and excess supply of bonds. At very high levels of employment, the precautionary motive to save is small, and households must earn a positive interest rate (near $1/\beta - 1$) in order to be enticed to buy all the bonds the government supplies.
4 Main experiment

Credit constraint shock

In the model presented in the previous section, the credit constraint faced by households, \( \bar{b} \), had been constant over time. As an experiment, I now introduce a permanent, unforeseen shock to it. That is, at some point, all households’ credit constraints will simultaneously become permanently tighter. Prior to the shock, households assign probability zero to the possibility that the credit constraint will change.

With this new feature, I have to deal with the possibility that households near the credit constraint prior the shock will find themselves in violation of it after the shock. To force such households to come into immediate compliance with the new, tighter credit constraint would force them to make a large cut to consumption. In fact, some households will have insufficient income to save to come into compliance even if they cut consumption to zero. To avoid complicating the model with the possibility that households go bankrupt, I need to permit these households to gradually come into compliance with the tighter credit constraint. Additionally, some consumer credit instruments have a longer term than one quarter, and a gradual adjustment to the credit constraint will better reflect this fact.

Guerrieri and Lorenzoni (2011) tighten the credit constraint linearly over the course of six quarters. There are seven different consumer credit constraint states: loose, tight, and five intermediate states. Since the credit constraint changes gradually, forcing households into compliance each period is not that harsh, and households never can go bankrupt. However, for computational reasons, I prefer just two consumer credit constraint states: loose and tight.

For households in violation of the new tight credit constraint, they are required to devote a fraction \( \phi \) of their income to saving or come into immediate compliance with the new constraint. For these households with \( b_{i,t-1} < \bar{b}_t \), that choose to save \( b_{i,t} < \bar{b}_t \), they are required to save according to the following inequality.

\[
q_t b_{i,t} - b_{i,t-1} \geq \phi \left( w_t (1 - \tau_t) e_{i,t} + \eta_t (1 - e_{i,t}) \right)
\]

As such, Inequality 2.3 is replaced by a new credit constraint where households can buy
and hold fewer bonds than $\bar{b}_t$. The household problem is now described by Equations 2.1, 2.2, and Inequality 4.1.

$$b_{i,t} \geq \min \left( \bar{b}_t, \frac{\phi(w_t(1-\tau_t)e_{i,t} + \eta_t(1-e_{i,t})) + b_{i,t-1}}{q_t} \right) \tag{4.1}$$

**Calibration**

Let $\bar{b}^L = -6.374$, the loose credit constraint from the previous section. There are two new variables to calibrate: $\bar{b}^T$, the tightened credit constraint, and $\phi$, the fraction of income that a household must save if $b_{i,t} < \bar{b}^T$.

I am interested in the period 2008:Q2 through 2010:Q3, where consumer credit decreased. However, during this period, GDP slightly increased in 2008:Q3, but then fell and then rose, with a trough in 2009:Q2. This makes debt-to-GDP an unsatisfactory variable to use in calibration. Therefore, I calibrate $\bar{b}^T$ and $\phi$ using real consumer credit per capita.

I took the seasonally adjusted consumer credit series discussed earlier, and converted to real 2009 dollars using a chained GDP deflator. To find per-capita amounts, I simply divided by U.S. population in the middle of the quarter. Throughout, I will call this just debt per capita.

In 2010:Q4, debt per capita experienced a large increase of 4.35% (not annualized), breaking the decreasing trend from 2008:Q3 to 2010:Q3. Past that point, the series is increasing. I believe this suggests that the economy saw another aggregate shock at that point, bringing it out of the decreasing consumer credit phase. I have not explored or calibrated the model for a subsequent shock. That said, a permanent tightening shock is prevalent in the literature, such as in Guerrieri and Lorenzoni (2011) and Eggertsson and Krugman (2012).

The term $\phi$ affects how quickly the debt per capita levels fall. The higher $\phi$, the quicker debt per capita falls. In other words, as $\phi$ increases, the impulse response of debt per capita becomes more convex. For 2008:Q2 through 2010:Q3, though, debt per capita falls fairly linearly. As such, I choose $\phi$ to be fairly small: $\phi = 0.1$. Given this parameter, I choose $\bar{b}^T = -4.2$ to match the relative decrease in debt per capita from 2008:Q2 through 2010:Q3.
Figure 4.1: Calibrating the credit constraint shock. Note that the vertical axis is scaled by dividing by 2008:Q2 GDP.

In the model, since the credit constraint shock is permanent, the economy will converge to some new steady state levels of employment and debt per capita. However, this steady state level of debt per capita will be much smaller than debt per capita in 2010:Q3. This can be seen in Figure 4.1. In the calibration with the parameters, $\phi = 0.1$ and $\bar{b}^r = -4.2$ (shown by the red line with square markers), debt continues to decrease after 2010:Q3. Note that in this figure, I have scaled the vertical axis by dividing by 2008:Q2 GDP to make the numbers a bit more meaningful than just real consumer credit per capita.

If instead I targeted a steady state value of debt to match the debt in 2010:Q3, then the shock would have to be miniscule. If $\bar{b}^r = -6$, then steady state debt after the shock would match the debt observed in the data in 2010:Q3. However, such a calibration cannot replicate the rapid drop in debt seen in the data. I show such a calibration with $\phi = 0.1$ and $\bar{b}^r = -6$ in the figure.

Therefore, in order to replicate the rapid decrease in debt per capita the U.S. economy experienced between 2008:Q2 and 2010:Q3, steady state debt per capita has to be much less than 2010:Q3’s debt per capita. Again, I think there was another shock in 2010:Q4 to break the decline in debt and expectations about future consumer credit levels. However,
I also think that the financial crisis and the aftermath was such a surprise and rarity that it is plausible that during the crisis, people thought consumer credit was going fall a lot more than it did and possibly reach a steady state below the 2010:Q3 trough.

I could consider an alternative calibration: what happens if I raise $\phi$ above 0.1 and choose to make the magnitude of the shock smaller, that is, choose a smaller $\bar{b}_T$? This will raise the steady state level of debt. However, things change very little. Very few households are affected by the $\phi$ in the credit constraint, and so raising $\phi$ does not allow me to decrease the magnitude of the shock much. In Figure 4.1, I show what happens when I raise $\phi$ to 0.9. If I keep $\bar{b}_T = -4.2$, then I miss my target in 2010:Q3 by a little. This is shown by the green line with triangle markers. If I then reduce $\bar{b}_T$ to -4.28, then I hit the target. However, as can be inferred from the orange line with square markers, steady state debt per capita does not change much at all. In fact, if I select $\phi = 0.9$ and $\bar{b}_T = -4.28$ as my chosen parametrization, then that actually slightly increases the effect on unemployment; my selected parameters ($\phi = 0.1$ and $\bar{b}_T = -4.2$) are more conservative.

In conclusion, the only way to replicate such a drop in debt over just 9 quarters is to have a shock of the magnitude I have calibrated. If I target a steady state debt per capita value equal to debt per capita in 2010:Q3, then the shock must be minute and debt per capita will decrease very slowly. If I try to raise $\phi$, that permits a shock of only slightly smaller magnitude and does not change the unemployment response or the debt per capita steady state much at all.

Results

After the credit constraint shock, households want to save more, and there are two immediate effects. The direct effect is that households below the credit constraint are forced to move away from it by way of Inequality 4.1. The indirect effect is that all households are now closer to their credit constraint, which means that their buffer against unemployment has shrunk. To rebuild their buffers, all households will want to save more. This is illustrated in the Figure 4.2.

This figure illustrates a cross section of the household policy functions at an employment rate of 94.9%, or equivalently, an unemployment rate of 5.1%. For the most part, the curves shift to the right after the shock because the minimum level of bond holdings
Figure 4.2: Net bond accumulation for 94.9% employment in the credit constraint shock model

(the credit constraint) has shifted to the right. The increasing sections of the post-shock curves correspond to households in violation of the new credit constraint. They are required to save a fraction $\phi$ of their income.

You may note that in Figure 4.2, for high levels of bond holding (greater than 5 or so), the post-shock curves are very slightly less than the pre-shock curves. This is because 94.9% employment is not a steady state level of employment for the economy with tightened credit constraints. Households perceive that employment will fall (by way of the estimated law of motion for employment). Therefore, they understand that interest rates will fall in the future, and choose to save a bit less than if they knew employment was going to stay at 94.9%.

There is a slight dip in the bond accumulation line for the employed post-shock for wealth levels around -4.5. This is an artifact of the solution method. During the value function iteration, for these wealth levels, the program identifies that either the minimum wealth should be saved (as determined by Inequality 4.1) or something a bit more. As more value function iterations occur, households “discover” that they should save more
than this minimum level of wealth, with the wealthier households discovering it first. This jump in their saving decision introduces a kink (a non-differentiable but continuous point) in the value function. A kink in the value function can cause the objective function to be bimodal in the subsequent iteration, which is ultimately responsible for this dip. I am unconcerned about this though: the number of households that are affected is very small.

As all households seek to save less and spend more, this pulls down the consumption demand line in the modified Keynesian cross diagram, Figure 4.3. The red solid line, representing consumption pre-shock, is steady state consumption demand with the loose credit constraint. The green dashed line represents consumption demand in the one period following the credit constraint shock. As the economy adjusts to the newer tighter credit constraint, the consumption demand line gradually rises.

Figure 4.4 illustrates the effects of this permanent, unanticipated credit constraint shock on employment, debt to GDP and assets to GDP. The initial level is marked by the circle: the fraction of households employed prior to the shock is 94.90%. While this model is calibrated only to correspond to the nine quarter drop in U.S. consumer credit,
I have included 100 quarters in the graph. Even after the nine quarters have passed, employment continues to improve, and debt and asset levels continue to drop. I have provided some key numbers in Table 2.

I compare the wealth (or bond-holdings) distribution of households before the credit constraint shock, and nine quarters following the shock in Figure 4.5, which illustrates the wealth distribution using a 20-bin histogram. The vertical lines represent the credit constraint values at $\bar{b}_L = -6.374$ and $\bar{b}_T = -4.2$. Prior to the shock, 39.70% of households are in debt, and 1.18% of households hold less than $\bar{b}_T = -4.2$ bonds. That is, only 1.18% of households are going to be in violation of the credit constraint after the shock and will have to consider the $\phi$ saving constraint.

<table>
<thead>
<tr>
<th></th>
<th>Fraction employed</th>
<th>Interest rate</th>
<th>Debt to GDP</th>
<th>Assets to GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-shock steady state</td>
<td>94.90%</td>
<td>2.45%</td>
<td>0.1785</td>
<td>0.5214</td>
</tr>
<tr>
<td>Post-shock 1 quarter</td>
<td>93.90%</td>
<td>1.95%</td>
<td>0.1777</td>
<td>0.6778</td>
</tr>
<tr>
<td>Post-shock 9 quarters</td>
<td>94.22%</td>
<td>2.11%</td>
<td>0.1625</td>
<td>0.5078</td>
</tr>
<tr>
<td>Post-shock steady state</td>
<td>94.80%</td>
<td>2.44%</td>
<td>0.0623</td>
<td>0.4055</td>
</tr>
</tbody>
</table>

Table 2: Credit constraint shock model
Figure 4.5: Wealth histograms

After nine quarters, 40.46% of households are in debt, and 0.04% hold less than -4.2 bonds. Additionally, the variance of the distribution decreases: households that are near the old credit constraint save more to move away from the new tighter credit constraint. Since the total number of bonds supplied by the government is fixed, this means that wealthier households reduce their bond holdings as the interest rate falls.

5 Alternative experiments

Detrended calibration

From 2002 through 2008:Q2, real debt per capita had been increasing linearly. In the above section, I calibrated the shock’s size using the difference between real debt per capita in 2010:Q3 and 2008:Q2. An alternative calibration could be considered where I calibrate the shock’s size using the difference between real debt per capita in 2010:Q3 and what real debt per capita would have been in 2010:Q3 had the linear trend continued. I show this in Figure 5.1. I keep $\phi = 0.1$ and set the new $\bar{b}^T$ to -3.9.
This does not affect employment much. With the original calibration and $\bar{b}_T = -4.2$, unemployment increased from 5.10% to 6.10%, or 1 percentage point. With this detrended calibration and $\bar{b}_T = -3.9$, unemployment increased from 5.10% to 6.48%, or 1.38 percentage points. The unemployment rates for this calibration are summarized in Table 4. Prior to the shock, the interest rate is 2.45%. Immediately after the shock, it fell to 1.76%, or 0.69 percentage points.

Less responsive interest rate experiment

In a nominal interest rate rule, a typical coefficient for the output gap is around $\psi = 0.5$, which is what I studied in the previous sections. However, a typical coefficient for the employment gap is around $\psi = 0.25$. In my model, employment and output are linearly related, so either $\psi$ could be a plausible coefficient, worthy of study. For this experiment, I keep $L^* = 0.95$ and $r^* = 0.025$ unchanged from the baseline parameters. Then, I set $\psi$ to 0.25 and recalibrate government bonds, $B$; the loose credit constraint, $\bar{b}_L$; and the tight credit constraint, $\bar{b}_T$. Table 3 provides their new calibrated values.
In the previous calibration, where \( \psi = 0.5 \), before the shock, the steady state employment rate was 94.9\%, and the steady state interest rate was 2.45\% by way of Equation 2.6. In this calibration, the steady state employment rate and interest rate are going to be a bit less. Suppose the steady state interest rate when \( \psi = 0.25 \) was 2.45\%. Then that would imply the steady state employment rate should be 94.8\% by Equation 2.6. However, this employment rate is slightly lower than the 94.9\%, which means there is a slightly greater precautionary motive to save for this \( \psi = 0.25 \) calibration in steady state. Therefore, we should expect the steady state interest rate to be slightly less than 2.45\% because of the increased precautionary motive and the employment rate to be slightly less than 94.8\%.

In this calibration, the pre-shock steady state employment rate is 94.78\%. Following the credit constraint shock, employment falls to 93.4\%, or 1.38 percentage points. The interest rate fell from 2.445\% to 2.1\%, or 0.345 percentage points. Table 4 provides the unemployment rates for this experiment.

**Unresponsive interest rate experiment**

I have demonstrated the effect of changing \( \psi \) from 0.5 to 0.25 on unemployment. If the interest is less responsive to changes in unemployment, then unemployment will be greater after the credit constraint shock. What is the effect on unemployment if the interest rate does not or can not fall at all after the shock? For example, what if the central bank’s only mandate was to control inflation? If full employment is not a goal for the central bank, then \( \psi = 0 \), and the interest rate would remain unchanged after an increase in unemployment.

Alternatively, consider an economy at steady state with 94.9\% employment, matching the original \( \psi = 0.5 \) calibration in Section 4. The steady state interest rate is 2.45\%
Table 4: Results summary

(see Equation 2.6). Next, suppose there is some unspecified shock to the economy that causes the nominal interest rate to fall to zero or some value near zero. Now the nominal interest rate cannot fall any further. The real rate cannot fall any further either, assuming inflation is constant. Suppose a credit constraint shock hit the economy in this state. The interest rate would be unresponsive to any subsequent increase in unemployment.

I am not going to model this unspecified shock that puts the economy at or near the zero lower bound on the nominal interest rate. However, as a proxy for this situation, I consider an interest rate floor at 2.45%. This will change the interest rate rule to Equation 5.1.

$$ r_t = \max \left( r^* + \psi (L_t - L^*), 0.0245 \right) $$

As a final note, I would suggest that the zero lower bound on the nominal interest rate applies to riskless overnight lending. For loans of a longer duration, like consumer credit instruments, if the yield curve is normal, a term premium is applied to the interest rate. Furthermore, this is a model of consumer credit. While default risk is not explicitly in my model, in reality, consumer credit is subject to default risk. Creditors would demand a default risk premium applied to the interest rate. So these two premia, when added to the zero lower bound for riskless overnight lending, could lead to a positive lower bound for consumer credit.

I wish to keep things comparable with the $\psi = 0.5$ calibration, where the steady state
interest rate is 2.45%. If I keep the tightened credit constraint the same at $\bar{b}^T = -4.2$, debt per capita falls a bit more than it did before. However, it misses its target by only 1.76%. Smaller values (more negative values) for $\bar{b}^T$, do not change the results much. Thus, for comparison purposes, I keep the tightened credit constraint the same as in Section 4: $\bar{b}^T = -4.2$.

For computational purposes, when $\bar{b}_t = \bar{b}^L$, the model uses Equation 2.6, with the interest rate floor at 0%. When $\bar{b}_t = \bar{b}^T$, the model uses Equation 5.1, with the interest rate floor at 2.45%. If there was an infinite number of households in my program, then I could use the 2.45% interest rate floor for all $\bar{b}_t$. However, the number of households I simulate is finite, and the exact fraction employed at any given period can vary slightly, or jitter, around the steady state value for the loose credit constraint state.

If the interest rate can fall below 2.45% in the loose credit constraint state, then the jittering might make the employment rate for that period 94.88%. It would then recover to 94.9% in subsequent periods. However, if the interest rate has a floor at 2.45% in the loose credit constraint state, then the jittering might make the employment rate for that period 94.68%. Since the interest rate rule is flat in that region, the employment rate will not return to 94.9%.

It might be helpful to think of the jittering as miniature demand shocks. As we expect, and will see, the effect of the demand shock on the employment rate increases in magnitude when the interest rate is constant.

Additionally, I have tested the model with an interest rate floor at 2.4% for all $\bar{b}_t$ versus the model with an interest rate floor at 0% when $\bar{b}_t = \bar{b}^L$ and 2.45% when $\bar{b}_t = \bar{b}^T$. The formulations behave absolutely identically. This is because in both formulations, the interest rate will fall in response to the negative miniature demand shock, and so the employment rate only falls 94.88%.

Thus, to keep this model’s pre-shock employment rate comparable with the previous model’s, I have the interest rate floor at 2.45% only after the shock.

Table 4 shows the unemployment rates observed when the interest rate does not fall below 2.45%. As can be seen, the effect on unemployment is greatly magnified. Whereas the unemployment rate rose from 5.1% to 6.1% in the previous parametrization, here, it rises from 5.1% to 10.46% after the shock.
6 Conclusion

I have examined this model in four different parametrizations, summarized in Table 4. In the first three parametrizations, the unemployment rate increased 1 to 1.38 percentage points in response to the credit constraint shock. In the fourth parametrization, the unemployment rate increased 5.36 percentage points. To frame these numbers, during the Great Recession, the U.S. unemployment rate rose from about 5.3% to a peak of 10%, which corresponds to a 4.7 percentage point increase.

In 2008:Q2, consumer credit was only 17.9% of U.S. household liabilities: home loans make up most of household liabilities. However, this model is calibrated using consumer credit alone. Since consumer credit is a small fraction of household liabilities, a 1 to 1.38 percentage point increase in the unemployment rate is fairly reasonable if the interest rate is able to adjust. Since the unemployment rate rose by 4.7 percentage points in the data, consumer credit alone cannot explain the observed increase in unemployment.

For further evidence, consider the fall in interest rates during the recession. In August 2008, the U.S. federal funds rate was 2.00%. At its lowest during the recession, the federal funds rate was 0.11%. Therefore, before the shock, the interest rate had at least 1.89 percentage points worth of room to fall. Of the three parametrizations where the interest rate could fall, the interest rate fell the most in the detrended calibration. In that calibration, the interest rate fell 0.69 percentage points. If the U.S. was subject to only a consumer credit shock, then the interest rate would have had enough room to adjust without reaching the zero lower bound.

If the interest rate cannot decrease after a credit constraint shock, then my model predicts a large increase in the unemployment rate: 5.36 percentage points. This increase in unemployment is much closer to what was observed during the recession. I conclude that there must have been some other factor that pushed the nominal interest rate down to zero or near zero. According to Hall (2011), inflation was nearly exogenous. Thus, neither the nominal nor real interest rate would have been able to fall further. With the interest rate unable to respond, the shock to consumer credit can explain the observed increase in the unemployment rate. Of course, the order of the two shocks does not matter: the unspecified shock could have occurred after the consumer credit shock or concurrent with it.

One of the key things that could be responsible for this unspecified shock is the asset
price bubble. Households lost a lot of net worth in their homes and retirement accounts. Given this loss of wealth, households wanted to save more and spend (consume) less, due to a precautionary motive to save against the risk of unemployment and a desire to rebuild their portfolios for retirement. The subsequent effects would continue from there as I have explained above. My model could be extended to incorporate households owning homes which are subject to price bubbles.

I am actively extending the model in two different ways. First, the distribution of wealth in my model is a bit too uniform. One way to introduce more variance in the current version of the model would be to decrease the degree of unemployment insurance $\rho$. Another way would be to make the employed more likely to keep jobs and the unemployed less likely to find them by decreasing the probability of separation $\lambda$. However to alter these variables would run counter to Shimer’s observations (2005). Thus, I am interested in following the method used by Krusell and Smith (1998) to change the shape of their wealth distribution. I will give households idiosyncratic discount rates, $\beta$’s, which will evolve according to a one period Markov chain. Then by altering the transition probabilities and discount rates, I can match the wealth distribution to what is observed in the data.

The second extension is to give households an age. Households would be available to work for 45 years, and then would be retired, unable to work, for 20 years. This would cause households to save not only for precautionary reasons but also for retirement. Calibrating the model with this extension, I could include stocks, corporate and government bonds, etc. as household assets. Since households would have another reason to save, shocking their credit constraint could result in a stronger effect on unemployment. This extension will also allow me to study the disparate impact of the credit constraint shock on households far from retirement, households near retirement, and households in retirement.

References


