Adverse Selection, Lemons Shocks and Business Cycles

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Abstract

Asymmetric information is crucial for understanding the disruption of the supply of credit. This paper studies a dynamic economy featuring asymmetric information and resulting adverse selection in credit markets. Entrepreneurs seek loans from banks for projects, but asymmetric information about entrepreneurs' riskiness causes a lemons problem: relatively safe entrepreneurs do not get funded. An increase in the riskiness of some entrepreneurs raises interest rate spreads, aggravates adverse selection, and shrinks the supply of bank credit. The model calibrated to the U.S. economy generates significant business fluctuations including severe recessions comparable to the Great Recession of 2007-09.

JEL Classifications: D82; E32; E44

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1 Introduction

In economics asymmetric information in financial markets has been central to understanding disruptions in the supply of credit, including those observed in financial crises. Yet, much of modern macroeconomics had paid less attention to the role of asymmetric information until the global financial crisis (GFC) of 2007-09. In the wake of the GFC a growing number of papers have incorporated asymmetric information into dynamic general equilibrium models. But, there remains a gap to be filled for such a macroeconomic program, given considerable knowledge accumulated in nearly a half century old literature on asymmetric information in financial markets.

This paper contributes to the macroeconomic program that emerged from the GFC by developing a dynamic general equilibrium model that features adverse selection in credit markets close in spirit to that of Stiglitz and Weiss (1981) and Mankiw (1986). The model articulates a view that an increase in the riskiness of some borrowers aggravates adverse selection in credit markets, causes a rise in interest rate spreads and a decrease in the supply of credit, and shrinks investment and output. The model calibrated to the U.S. economy generates significant business fluctuations including severe recessions comparable to the GFC.

Asymmetric information between entrepreneurs (borrowers) and banks (lenders) plays a central role in the model. Entrepreneurs have their own net worth, raise funds from banks, and invest in their project. Each project differs in its credit worthiness – riskiness, which is private information to each entrepreneur. Because banks cannot distinguish between risky and safe entrepreneurs, to compensate potential losses from lending to risky entrepreneurs they end up charging higher interest rates to safe entrepreneurs than those they would without asymmetric information. The high interest rates make safe entrepreneurs' expected debt burden heavier because they are more likely to repay. As a result, some of safe entrepreneurs are crowded out from the credit market, giving rise to so-called credit rationing. In addition, the pool of loans becomes riskier, which, in turn, makes the banks raise the interest rates and crowds out safe entrepreneurs further.

In addition to adverse selection, the model features entrepreneurs' limited pledgeability. With this agency problem a loan amount is constrained by entrepreneurs' net worth, which allows the model to preserve adverse selection in an environment where the scale of entrepreneurs' projects is not fixed. Moreover, it gives rise to a financial accelerator mechanism – a feedback loop through an interaction between an asset price and net worth.

A change in the price of capital affects entrepreneurs' net worth and thereby loans, which, in turn, affects demand for capital and its price

To understand the nature of a credit contract between entrepreneurs and banks under asymmetric information and limited pledgeability, the paper starts from considering a one-time financing problem between those agents in a partial equilibrium framework. The paper uses a mechanism design approach to solve the problem. The resulting solution – the optimal contract – features separation and heterogeneous credit spreads as well as adverse selection. In other words, each entrepreneur with different riskiness receives different amount of loan and faces different level of interest rates for repayment, while relatively safe entrepreneurs are cutting off from the credit market. In particular, a riskier entrepreneur borrows a higher loan amount and faces a higher interest rate. The paper then conducts a comparative statics analysis and shows that an increase in the riskiness of some entrepreneurs aggravates adverse selection in the form of credit rationing and decreases the supply of bank credit.

Next, the paper embeds the financing problem into a dynamic general equilibrium model, in a similar way as Bernanke, Gertler, and Gilchrist (1999) (BGG) embed the costly-state-verification (CSV) problem of Townsend (1983) into such a model. The paper then introduces a lemons shock – an exogenous shock that affects the riskiness of a subset of entrepreneurs in the mean-preserving spread sense – to study the impact of a change in the degree of adverse selection in credit markets on the real economy. From the viewpoint of banks, an increase in the riskiness of some entrepreneurs is equivalent to a deterioration in the quality of entrepreneurs as a whole because of asymmetric information. Such a deterioration aggravates adverse selection and decreases the supply of bank credit.

The simulation of the model, calibrated to the U.S. economy, shows that lemons shocks generate significant business fluctuations including severe recessions comparable to the GFC. A negative lemons shock increases the riskiness of some but not all entrepreneurs. Unable to distinguish entrepreneurs' credit worthiness, banks increase loan interest rates for all existing entrepreneurs. As a result, an increasing number of relatively safe entrepreneurs are cut off from bank lending, i.e., adverse selection worsens. Interest rate spreads rise and the supply of bank credit shrinks, consistent with the comparative statics results of the one-time financing problem. A decrease in bank lending disrupts entrepreneurs' activity, giving rise to a decrease in entrepreneurs' demand for capital. This causes a decrease in investment and a fall in the asset price – the price of capital, which damages entrepreneurs' net worth and, in turn, discourages entrepreneurs' activity further. Thus, an adverse-selection-led disruption in the supply of bank credit, accompanied by a rise in interest rate spreads, lies at the heart of the transmission mechanism of a lemons shock. A shrink in bank credit then causes investment to decrease, which eventually leads to a decrease in output.

A lemons shock, which disrupts the supply of bank credit, is reminiscent of a typical financial shock that changes a wedge between a return on capital and a risk-free interest rate. Indeed, the paper analytically shows that a lemons shock is identical to such a financial shock up to the first-order approximation of the model. In this sense, the model studied here provides a micro-foundation for the financial shock, which can explain key features of the GFC in the U.S. as argued by Hall (2011) and Gilchrist and Zakrajsek (2011). Also, the paper sheds light on a key distinction between a lemons shock and a risk shock studied by Christiano, Motto and Rostagno (2014) (CMR).

A driving force of a lemons shock is not an actual change in entrepreneurs' riskiness per se, but a change in banks' perception about such riskiness i.e., banks' lending stance that reflects their concern or fear about borrowers' riskiness. The paper shows that a shock to such perception has a greater impact on the economy than the same degree of a lemons shock, although such a shock does not affect the actual riskiness of entrepreneurs.

In the model asymmetric information not only gives rise to adverse selection and a lemons shock but also serves as an amplifier of other shocks such as a shock to the marginal efficiency of investment and a preference shock. The effects of these shocks on output are greater than those in the corresponding model with symmetric information. With asymmetric information the shocks affect the degree of adverse selection, amplifying their effects on output.

Related Literature

This paper contributes to a growing literature on adverse selection in dynamic general equilibrium models. Eisfeldt (2004), Kurlat (2013), and Bigio (2015) study a lemons problem in a dynamic framework, where entrepreneurs raise funds by selling assets whose value is subject to asymmetric information. Relatedly, Tirole (2012) studies public intervention in a partial equilibrium model in which the value of legacy assets is private information. While these papers focus on problems of liquidity caused by adverse selection in a buyer-seller setting á la Akerlof (1970), this paper focuses on a disruption in the supply of bank credit caused by adverse selection in a borrower-lender setting á la Stiglitz and Weiss (1981).

In a general equilibrium framework, there are only a few papers that adopt the Stiglitz and Weiss setting: House (2005) in an overlapping generations model and Christiano and

Ikeda (2013) in a two-period model. In a partial equilibrium framework, Mankiw (1986) and Minelli and Modica (2009) study government policies to address credit rationing. Phillippon and Skreta (2012) study public intervention in a partial equilibrium model in which the return of old project is private information. All the papers mentioned above fix a scale of investment, but this paper allows a variable scale of investment by introducing borrowers' limited pledgeability. It then embeds adverse selection into a standard dynamic general equilibrium model where a financial accelerator mechanism comes into play.

Broadly this paper contributes to the literature on financial frictions in dynamic general equilibrium models. The literature has studied various types of financial frictions. A selective list includes CSV problems (BGG 1999, Carlstrom and Fuerst 1997, CMR 2014), collateral constraints (Kiyotaki and Moore 1997, Iacoviello 2005, Jerman and Quadrini 2012), asset resaleability constraints (Kiyotaki and Moore 2008, Del Negro, Eggertsson, Ferrero and Kiyotaki 2011), moral hazard problems (Gertler and Kiyotaki 2010, Gertler and Karadi 2011), and adverse selection in a buyer-seller problem (Eisfeldt 2004, Kurlat 2013, Bigio 2015). This paper adds adverse selection in a borrower-lender problem to the literature.

The rest of the paper is organized as follows. Section 2 sets up a partial equilibrium model with asymmetric information, derives the optimal contract, and conducts a comparative statics analysis. Section 3 embeds the partial equilibrium model into a dynamic general equilibrium model. Section 4 conducts quantitative analyses and Section 5 studies the nature of a lemons shock and adverse selection. Section 6 concludes.

2 Adverse Selection: Partial Equilibrium

This section presents a static partial equilibrium model with adverse selection in credit markets. It builds on Stiglitz and Weiss (1981), extended to incorporate unlimited scale of investment and borrowers' limited pledgeability. A mechanism design approach is used to solve for an optimal contract. The solution features credit rationing – a situation in which some borrowers do not get funded – as in Stiglitz and Weiss. But, unlike Stiglitz and Weiss it also features separability – a situation in which different borrowers have a different loan arrangement in terms of the amounts of loans and repayment.

The rest of the section is organized as follows. First, the environment of the model is described. Next, to highlight the role of asymmetric information, a symmetric information version of the model – the model without adverse selection – is studied. Then, the model with adverse selection is studied and an optimal contract is derived using a mechanism design approach. Finally, a comparative statics analysis is conducted.

2.1 Model Environment

There are a large number of entrepreneurs and banks. Both entrepreneurs and banks are risk neutral and competitive. There is a single good. Each entrepreneur, indexed by n, has exogenous net worth N_n. Banks take in deposits from households at the risk-free interest rate R and offer entrepreneurs a credit contract, which can differ among banks. Entrepreneurs choose a contract among those offered by banks. After making the choice entrepreneurs receive private information regarding the success probability of the project, p, which is drawn from distribution function $F : [\underline{p}, \bar{p}] \to [0, 1]$ with $0 < \underline{p} < \bar{p} \leq 1$, independently and identically across entrepreneurs. It is assumed that $F(\cdot)$ has full support and its density $f(p) = F'(p)$ is continuous. Knowing the success probability p of the project, each entrepreneur takes out a loan from the chosen bank if doing so is profitable and invests the sum of the net worth and the loan in the project. In the case of success, the project yields gross return $\theta(p)R^k$ for each good invested. In the case of failure, the project yields nothing. After the project's outcome is realized, each entrepreneur repays to the bank in accordance with the contract.

The model has three key assumptions. First, banks observe only the success or the failure of an entrepreneur's project; they cannot observe the project's return. This assumption implies that banks cannot back up private information p ex post. Hence, repayments made by an entrepreneur to a bank can be contingent only on the success or the failure of the project. Second, entrepreneurs are protected by limited liability, so that entrepreneurs' repayments are zero in the case of the failure of their project. Third, the expected return of an entrepreneur's project $p\theta(p)R^k$ is assumed to be identical to R^k for all entrepreneurs i.e., $p\theta(p) = 1$ is assumed. In addition, the expected return is assumed to be greater than the deposit interest rate: $R^k > R$. The identical expected return makes the model tractable and helps the model provide a simple interpretation about a change in the distribution $F(\cdot)$: it means a change in the riskiness of some projects in the mean-preserving-spread sense. For example, if a project's success probability decreases from p to $p' < p$, the project has become riskier than before in the mean-preserving-spread sense.[1]

[1] Another assumption implicitly embedded in the model is the timing that entrepreneurs choose a bank before they receive private information. This assumption is made for simplicity and the model can be modified in a way that entrepreneurs choose a bank after they receive private information. In this version

Under these assumptions, credit contracts offered by banks specify loans $B_n(p) \geq 0$ and repayments $X_n(p) \geq 0$, both of which can depend on the entrepreneur's net worth and riskiness, indicated by n and p, respectively. Without loss of generality, a truth-telling contract is considered such that the type-(n,p) entrepreneur chooses $\{B_n(p), X_n(p)\}$ among the schedule $\{B_n(\tilde{p}), X_n(\tilde{p})\}_{\tilde{p}=\underline{p}}^{\bar{p}}$ offered by the bank, which the entrepreneur already chose before receiving private information. Because there are a large number of entrepreneurs with net worth N_n for each n, perfect competition among banks leads to the zero profit condition:

$$\int_{\underline{p}}^{\bar{p}} \left[pX_n(p) - RB_n(p)\right] dF(p) = 0, \tag{1}$$

where $pX_n(p)$ is the expected repayments from the type-(n,p) entrepreneur and $RB_n(p)$ is the costs of raising funds $B_n(p)$. As entrepreneurs can walk away by not taking out a loan from their bank, the schedule $\{B_n(p), X_n(p)\}_{p=\underline{p}}^{\bar{p}}$ has to satisfy their participation constraint:

$$p\theta(p)R^k B_n(p) - pX_n(p) \geq 0, \quad \forall p \in [\underline{p}, \bar{p}], \tag{2}$$

where $p\theta(p)R^k B_n(p)$ is the expected return from taking out loans with $p\theta(p) = 1$ by assumption and $pX_n(p)$ is the expected repayments. The net profits from borrowing – the left-hand-side of the inequality (2) – have to be non-negative for all entrepreneurs.

In addition to asymmetric information, the model has another friction: entrepreneurs can pledge at most a fraction, $0 < \phi < 1$, of their expected return to repay to a bank. This limited pledgeability gives rise to the following constraint on loans $B_n(p)$ and repayments $X_n(p)$:

$$pX_n(p) \leq \phi p\theta(p)R^k[N_n + B_n(p)], \quad \forall p \in [\underline{p}, \bar{p}], \tag{3}$$

where again $p\theta(p) = 1$ by assumption. The left-hand-side of (3) is the expected repayments to the bank and the right-hand-side is the maximum amount that the type-(n,p) entrepreneur can pledge to repay.[2] Given R and R^k, parameter ϕ is assumed to be low enough to satisfy $R > \phi R^k$. Otherwise the pledgeability constraint (3) becomes irrelevant.

of the model, however, without any modification, the model would not have a solution because the model suffers from a problem similar to that pointed out by Rothchild and Stiglitz (1976): both a pooling equilibrium and a separating equilibrium fail to exist in competitive markets with adverse selection. Hence, some modifications are needed for this version of the model to have the same solution as in the model in this section. Such modifications include those proposed by Wilson (1977) and Hellwig (1987).

[2] Constraint (3) can be derived from a moral hazard problem in which entrepreneurs can divert a fraction $1 - \phi$ of their return.

2.2 Model with Symmetric Information

To highlight the role of asymmetric information it is useful to consider a version of the model in which the riskiness of an entrepreneurial project is not private information. In this model with symmetric information, banks can observe an entrepreneur's riskiness p so that the banks' zero profit condition holds for each p:

$$pX_n(p) - RB_n(p) = 0. \tag{4}$$

The zero profit condition (4) implies that the participation constraint (2) is satisfied because $R^k > R$ and $B_n(p) \geq 0$. The contract schedule $\{B_n(p), X_n(p)\}_{p=\underline{p}}^{\bar{p}}$ offered by banks maximizes the expected profits for an entrepreneur with net worth N_n before p is realized:

$$\int_{\underline{p}}^{\bar{p}} \left[R^k(N_n + B_n(p)) - pX_n(p)\right] dF(p), \tag{5}$$

subject to the pledgeability constraint (3) and the zero profit condition (4). Substituting condition (4) into the problem yields:

$$\max_{\{B_n(p)\}_{p=\underline{p}}^{\bar{p}}} \int_{\underline{p}}^{\bar{p}} (R^k - R)B_n(p)dF(p), \quad s.t. \;\; B_n(p) \leq \frac{\phi(R^k/R)}{1-\phi(R^k/R)} N_n,$$

where constant $R^k N_n$ is omitted from the objective function. Because of the assumptions of $R^k > R$ and $R > \phi R^k$, a solution to this problem features the binding pledgeability constraint. Hence the solution $\{B_n(p), X_n(p)\}_{p=\underline{p}}^{\bar{p}}$ is given by: $\forall p \in [\underline{p}, \bar{p}]$,

$$B_n(p) = \frac{\phi(R^k/R)}{1-\phi(R^k/R)} N_n, \tag{6}$$

$$X_n(p) = \frac{R}{p} B_n(p). \tag{7}$$

The solution of the model with symmetric information has four features. First, all entrepreneurs receive a loan, irrespective of their riskiness p. Second, the amount of loans $B_n(p)$ is independent of p and linear in the net worth N_n. Hence, the aggregate loan B depends neither on the distribution of p nor the distribution of n, and thereby it is given by:

$$B = \frac{\phi(R^k/R)}{1-\phi(R^k/R)} N, \tag{8}$$

where N is the aggregate net worth. Third, the loan interest rate is given by $R^b(p) \equiv X_n(p)/B_n(p) = R/p$. Hence, entrepreneurs pay interest that purely reflects their risk of default. Fourth, the leverage, $[B_n(p) + N_n(p)]/N_n(p) = 1/[1 - \phi(R^k/R)]$, is identical for all entrepreneurs. It is increasing in the excess return R^k/R and a fraction ϕ that entrepreneurs can pledge to repay.

2.3 Model with Asymmetric Information

Now the model with asymmetric information is studied. In this model, banks cannot observe the riskiness of entrepreneurs' projects. Before p is realized, entrepreneurs choose a bank that offers the best schedule of contracts for them. The optimal contracting problem is thus to choose the schedule of contracts $\{B_n(p), X_n(p)\}_{p=\underline{p}}^{\bar{p}}$ that maximizes an entrepreneur's expected profits (5) subject to the zero profit condition (1), the participation constraint (2), the pledgeability constraint (3), and the following incentive constraint:

$$R^k B_n(p) - pX_n(p) \geq R^k B_n(\tilde{p}) - pX_n(\tilde{p}), \quad \forall p, \tilde{p} \in [\underline{p}, \bar{p}]. \tag{9}$$

Incentive constraint (9) ensures that the type-(n, p) entrepreneur chooses $\{B_n(p), X_n(p)\}$ voluntarily: it restraints the schedule $\{B_n(p), X_n(p)\}_{p=\underline{p}}^{\bar{p}}$ such that the expected profits by choosing $\{B_n(p), X_n(p)\}$ – the left-hand-side of (9) – are no less than the expected profits by picking up a different pair $\{B_n(\tilde{p}), X_n(\tilde{p})\}$ with $\tilde{p} \neq p$ – the right-hand-side of (9).

The optimal contracting problem is a standard mechanism design problem except for: the presence of pledgeability constraint (3) and the linearity of the type-(n, p) entrepreneur's expected profits – the term inside the integral of the objective function (5) – with respect to $B_n(p)$ and $X_n(p)$.[3] In spite of linearity, a solution to the problem can exist because of the pledgeability constraint. The problem can be solved by guessing and verifying that, as in Stiglitz and Weiss (1981), there exists a threshold p^* such that entrepreneurs with riskiness $p > p^*$ do not get a loan, and that the pledgeability constraint (3) is binding for entrepreneurs with $p \leq p^*$ who take out a loan. To ensure that there exists a unique solution consistent with these guesses, two assumptions are made.

Assumption 1: *Parameters R^k/R and ϕ and distribution $F : [\underline{p}, \bar{p}] \to [0, 1]$ are such that*

[3] See e.g. Section 2 of Bolton and Dewatripont (2005).

there exists a unique $p^* \in (\underline{p}, \bar{p})$ *that solves*

$$\int_{\underline{p}}^{p^*} \omega(p) \left(\frac{1}{p}\right)^{\frac{1}{1-\phi}} dp = 0. \tag{10}$$

where $\omega(p) \equiv pf(p) - (R/R^k)pf(p) - (R/R^k)F(p)$.

This assumption ensures that there exists a unique p^* such that the credit market features credit rationing where entrepreneurs with $p > p^*$ do not get a loan. To capture intuition about the assumption, consider a uniform distribution, $F(p) = (p - \underline{p})/(\bar{p} - \underline{p})$ with $\bar{p} = 1$. Then, as shown in the supplementary material, a sufficient condition for Assumption 1 is given by:

$$\frac{R^k}{R} < 2 - \underline{p}\frac{1-2\phi}{\phi}\frac{\underline{p}^{\frac{-\phi}{1-\phi}} - 1}{1 - \underline{p}^{\frac{1-2\phi}{1-\phi}}}. \tag{11}$$

Condition (11) states that the excess return, R^k/R, should not be too high. In the case of $\phi = 1/2$, condition (11) is reduced to $R^k/R < 1 + (1 - \underline{p})$. If condition (11) does not hold, the return from investing in the project is so high that even the safest entrepreneur would participate in the credit market, leading to no credit rationing.

The next assumption ensures that the pledgability constraint (3) is binding for entrepreneurs with $p \leq p^*$.

Assumption 2: *Parameters* R^k/R *and* ϕ *and distribution* $F : [\underline{p}, \bar{p}] \to [0, 1]$ *are such that* $\xi(p) > 0$ *for* $p < p^*$*, where*

$$\xi(p) = \frac{F(p) + \lambda\omega(p)}{p} + \frac{\phi}{(1-\phi)p}p^{\frac{\phi}{1-\phi}} \int_{\underline{p}}^{p} [F(x) + \lambda\omega(x)] \left(\frac{1}{x}\right)^{\frac{1}{1-\phi}} dx, \tag{12}$$

with λ *given by:*

$$\lambda = \frac{F(p^*) + \frac{\phi}{1-\phi}(p^*)^{\frac{\phi}{1-\phi}} \int_{\underline{p}}^{p^*} F(x) \left(\frac{1}{x}\right)^{\frac{1}{1-\phi}} dx}{-\omega(p^*)}.$$

and p^* *is a solution to (10).*

As shown in the supplementary material, λ and $\xi(p)$ in Assumption 2 correspond to Lagrange multipliers on the zero profit condition (1) and on the pledgeability constraint (3) in the optimal contracting problem, respectively. Hence, $\xi(p) > 0$ for $p < p^*$ ensures that the pledgeability constraint holds with equality for entrepreneurs with $p < p^*$.[4] Importantly, if

[4]For those with $p = p^*$, the pledgeability constraint also holds with equality by continuity. For the

$F(\cdot)$ is uniform over $[\underline{p}, \bar{p}]$, Assumption 1 is sufficient for Assumption 2.

To summarize, although Assumptions 1 and 2 look complicated, if $F(\cdot)$ is uniform over $[\underline{p}, 1]$, these assumptions can be replaced by the single sufficient condition (11), which simply states that R^k/R is not too high.

Now we are in a position to state a solution to the optimal contracting problem.

Proposition 1 (Optimal contracting problem): *Under Assumptions 1 and 2, a solution to the optimal contracting problem is given by: for* $p \in [\underline{p}, p^*]$,

$$B_n(p) = \left[\frac{1}{1-\phi} \left(\frac{p^*}{p} \right)^{\frac{\phi}{1-\phi}} - 1 \right] N_n, \tag{13}$$

$$X_n(p) = \left[\frac{\phi R^k}{1-\phi} (p^*)^{\frac{\phi}{1-\phi}} \right] \left(\frac{1}{p} \right)^{\frac{1}{1-\phi}} N_n, \tag{14}$$

and for $p \in (p^*, \bar{p}]$, $X_n(p) = B_n(p) = 0$, *where* p^* *is given by a solution to (10). In addition, the aggregate borrowing is given by:*

$$B = \frac{\phi(R^k/R)}{1-\phi(R^k/R)} F(p^*) N. \tag{15}$$

Proof: See Section A1 of the supplementary material.

Two features are worth noting. First, the optimal contract features credit rationing, i.e., entrepreneurs with $p > p^*$ do not get a loan. The credit rationing distinguishes this model from the model with symmetric information in which all entrepreneurs get a loan. In the symmetric-information model, risky entrepreneurs have to repay the amount that reflects their default risk as shown by equation (7). If such a repayment schedule were offered under asymmetric information, they would pretend to be a safe entrepreneur to reduce the expected repayment. To prevent such deception under asymmetric information, a bank has to provide a right incentive to risky entrepreneurs. Indeed, the incentive constraint (9) implies that the type-(n, p) entrepreneur's expected profits, after p is realized, are increasing in the repayment by safer entrepreneurs: $R^k B_n(p) - pX_n(p) = \int_p^{p^*} X_n(p)dp$.[5] Because this entrepreneurial rent is costly for banks, the cost should be covered by repayments from safer entrepreneurs who are more likely to repay. As a result, it becomes unprofitable for low-risk entrepreneurs with $p > p^*$ to take out a loan from the bank, giving rise to credit

detail, see the supplementary material.

[5] For the derivation of the entrepreneur's expected profits, see Step 2 of Section A1 of the supplementary material.

rationing. This adverse selection manifests itself to a decrease in the aggregate borrowing. The aggregate borrowing under asymmetric information, given by equation (15), is lower by $100\,[1 - F(p^*)]$ percent than that under symmetric information, given by equation (8).

The second feature of the optimal contract is its separability. In particular, both the loan schedule $B_n(p)$ and the repayment schedule $X_n(p)$ are decreasing in p. This separability arises from the pledgeability constraint (3). To see its role, consider a pooling contract, $\{\bar{B}_n, \bar{X}_n\}$ with threshold $\bar{p}^*$, which is independent of p. Then, the pledgeability constraint holds with equality only for the entrepreneurs with $p = \bar{p}^*$: $\bar{p}^* \bar{X}_n = \phi R^k (N_n + \bar{B}_n)$. For those with $p < \bar{p}^*$, the pledgeability constraint becomes slack: $p\bar{X}_n < \phi R^k (N_n + \bar{B}_n)$. Thus, if separability is allowed, there is room for increasing the expected profits of risker entrepreneurs by increasing both $B_n(p)$ and $X_n(p)$ in a way that the pledgeability constraint continues to be satisfied.[6]

The separability of the optimal contract leads to heterogeneous credit spreads, $\mathrm{CS}(p) \equiv R^b(p) - R$ for $p \in [\underline{p}, p^*]$, where $R^b(p)$ is the loan interest rate charged to the type-p entrepreneur, defined as $R^b(p) \equiv X_n(p)/B_n(p)$, which is independent of net worth. The credit spread $\mathrm{CS}(p)$ is decreasing in p so that a higher credit spread is charged to a risker entrepreneur. The heterogeneous credit spreads distinguish this model from others and it can characterize not only the mean but also the dispersion of credit spreads.

2.4 Comparative Statics

How do the degree of credit rationing, measured by $1 - F(p^*)$, and the aggregate borrowing under the optimal contract react to a change in key parameter values? The following proposition summarizes the result of a comparative statics analysis regarding the impact of the excess return R^k/R and distribution $F(p)$ on the threshold p^*, the degree of credit rationing $1 - F(p^*)$, and the aggregate borrowing B.

Proposition 2 (Comparative statics): *In the model with asymmetric information,*

(i) *An increase in the excess return R^k/R raises the threshold p^*, decreases the degree of credit rationing $1 - F(p^*)$, and increases the aggregate borrowing B.*

[6] Regarding the pooling contract, in addition to the pledgeability constraint (3), the participation constraint (2) holds with equality for the entrepreneurs with $p = \bar{p}^*$. As a result, the pooling contract is given by $\bar{B}_n = B_n(p^*)$ and $\bar{X}_n = X_n(p^*)$ where $B_n(\cdot)$ and $X_n(\cdot)$ are given by (13) and (14), respectively, and the threshold $\bar{p}^*$ is determined by the zero profit condition (1). Under the assumptions of unique p^*, it can be shown that $\bar{p}^* < p^*$ so that $X_n(p) > \bar{X}_n$ for all $p \leq \bar{p}^*$. Because an entrepreneur's profits before p is realized are given by $\int_{\underline{p}}^{p^*} X_n(p) F(p) dp$ as shown in the supplementary material, the optimal contract strictly dominates the pooling contract.

(ii) *Assume a uniform distribution over* $[\underline{p}, 1]$ *for* $F(p)$. *Then, an increase in the riskiness of some entrepreneurs in the mean-preserving-spread sense – a decrease in* $\underline{p}$ *– lowers the threshold* p^*, *increases the degree of credit rationing* $1 - F(p^*)$, *and decreases the aggregate borrowing* B.

Proof: Section A2 of the supplementary material.

Intuitively, an increase in the excess return R^k/R raises entrepreneurs' profitability, which allows them to borrow and repay more, leading to an increase in the number of those who take out a loan – increases in p^* and $F(p^*)$ – and an increase in the aggregate borrowing. Regarding entrepreneurs' riskiness, under the assumption of a uniform distribution for $F(p)$ a decrease in $\underline{p}$ implies that some entrepreneurs become more risky in the mean-preserving-spread sense. This leads to an increase in the number of entrepreneurs who fail in their project ex-post, although the project yields a higher return in the case of success. Because failed entrepreneurs repay nothing, banks have to charge higher interest rates on successful entrepreneurs. This makes relatively safe entrepreneurs less willing to take out a loan, causing a drop in the threshold p^*, an increase in the degree of credit rationing $1-F(p^*)$, and a decrease in the aggregate borrowing B. This result depends crucially on the presence of asymmetric information. Without it, there would be no credit rationing, i.e., the threshold is always unity: $p^* = 1$, and the aggregate borrowing would be independent of the degree of riskiness of entrepreneurial projects – the distribution $F(p)$ – as shown in Section 2.2.

3 General Equilibrium

In this section, the partial equilibrium model studied in the previous section is embedded into a dynamic general equilibrium model. In the following, four types of agents – households, producers, entrepreneurs, and banks – are described in turn. Then a lemons shock is introduced. Finally, four variants of the model are defined for disentangling the transmission mechanism of a lemons shock. The first two variants of the model have no nominal friction, while the last two feature nominal wage rigidity, which is introduced later in this section.

3.1 Households

There is a continuum of identical households of measure unity. Each household consists of a large number of family members who are either workers or entrepreneurs. The family members switch their occupation, either workers or entrepreneurs, randomly in a way that the proportions of workers and entrepreneurs stay constant over time. In period t, each household, as a representative agent of the family members, consumes C_t and saves B_t in bank deposits at the risk-free real interest rate R_t. The household provides perfect consumption insurance among the family members. Workers within the household supply labor h_t per household and earn the real wage w_t. The resulting flow budget constraint is given by:

$$C_t + B_t = R_{t-1}B_{t-1} + w_t h_t + \Theta_t, \tag{16}$$

where Θ_t is the sum of net transfers from entrepreneurs who belong to the household and the profits of producers who are owned by the household. Each household maximizes the utility, given by:

$$E_t \sum_{s=0}^{\infty} \beta^s b_t \left[\log(C_{t+s}) - \psi \frac{h_{t+s}^{1+1/\nu}}{1+1/\nu} \right], \qquad 0 < \beta < 1, \quad \psi, \nu > 0$$

subject to the flow budget constraint (16), where b_t is a preference shock. The assumption of a household as a large family members allows the model to keep a representative agent framework as in Gertler and Karadi (2011).

3.2 Producers

There are two types of producers: a consumption-good producer and a capital-good producer. Both types of producers are competitive. A representative consumption-good producer combines effective capital $\bar{K}_t$ and labor h_t, and produces output Y_t using the Cobb-Douglas technology:

$$Y_t = \bar{K}_t^{\alpha} h_t^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{17}$$

where the effective capital is given by the capital utilization rate u_t times the physical capital K_{t-1} installed in the beginning of period t: $\bar{K}_t = u_t K_{t-1}$. The producer maximizes the profits, $Y_t - r_t^k \bar{K}_t - w_t h_t$, taking as given the rental rate of capital r_t^k and the wage w_t.

A representative capital-good producer purchases I_t units of the consumption good and transforms them into $\bar{I}_t$ units of the capital good, in accordance with the following technology:

$$\bar{I}_t = \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}} \right) \right] I_t, \tag{18}$$

where μ_t is a shock to the marginal efficiency of investment (MEI) and $S(\cdot)$ is the investment adjustment cost function used by CEE (2005), which satisfies $S(1) = S'(1) = 0$ and $S''(1) \geq 0$. The case of $S''(1) = 0$ corresponds to no investment adjustment cost in the linearized version of the model.

The capital producer combines new capital goods $\bar{I}_t$ with the depreciated physical capital purchased from entrepreneurs, $(1-\delta)K_{t-1}$, and sells the combined capital goods to entrepreneurs, where $0 < \delta < 1$ is a capital depreciation rate. As a result, the law of motion for physical capital is given by:

$$K_t = (1-\delta)K_{t-1} + \bar{I}_t. \tag{19}$$

Given the price of capital q_t the producer chooses I_t to maximize the expected profits:

$$\max_{\{I_t\}} E_t \sum_{s=0}^{\infty} \beta^s \frac{b_{t+s}}{b_t} \frac{C_t}{C_{t+s}} \left(q_{t+s}\bar{I}_{t+s} - I_{t+s} \right),$$

subject to the investment technology (18). Because the producer is owned by households, the households' discount factor is applied to the profit maximization problem.

3.3 Entrepreneurs and Banks

There are a large number of entrepreneurs. Without loss of generality, there is a representative bank. Both entrepreneurs and the bank are competitive. As in BGG (1999) and CMR (2014), the role of entrepreneurs is to transform physical capital into capital readily usable for production using their risky technology (project) and provide such capital to producers; the role of banks is to channel funds from households to entrepreneurs. But, unlike BGG and CMR, a costly-state-verification technology is not available and thereby the credit market features "complete" asymmetric information, giving rise to adverse selection.

Entrepreneurs and a representative bank make a loan contract, where asymmetric information plays a critical role. Each entrepreneur runs a risky project that transforms one unit of the capital good into $\theta(p)$ units of capital readily usable for production with success probability p. If the project fails, it generates nothing. In the beginning of period t, success probability p is not realized yet, so that it is not known for both entrepreneurs and the bank. After making a loan contract with the bank, each entrepreneur receives private information p – the success probability of the project, which is drawn from distribution function

$F_t : [\underline{p}_t, 1] \rightarrow [0,1]$ with $0 < \underline{p}_t < 1$, independently and identically across entrepreneurs. The riskiness p is unobservable for the bank.

In addition to information asymmetry, entrepreneurs have an agency problem: they can pledge at most a fraction, $0 < \phi < 1$, of their expected return to repay to a bank.

Against this background, events are unfolded as follows. In the beginning of period t, entrepreneurs, indexed by n, have net worth $N_{n,t}$ in consumption-good units. A bank takes in deposits from households at the risk-free real interest rate R_t and offers a loan contract, taking into account that entrepreneurs will receive private information about the riskiness of their project and will be subject to the agency problem. The bank offers a truth telling contract $\{B_{n,t}(p), X_{n,t}(p)\}_{p=\underline{p}_t}^{\bar{p}}$ such that after receiving private information p an entrepreneur with net worth $N_{n,t}$ and riskiness p – the type-(n, p) entrepreneur – takes out loans $B_{n,t}(p)$ and repays $X_{n,t}(p)$ in the case of success. The type-(n, p) entrepreneur, who has made a loan contract with the bank, takes out a loan if doing so is profitable for the entrepreneur, and purchases physical capital $K_{n,t}(p)$ at price q_t by using the sum of the net worth and loans, $N_{n,t} + B_{n,t}(p)$. Thus, the balance sheet of the entrepreneur is given by $q_t K_{n,t}(p) = N_{n,t} + B_{n,t}(p)$. Aggregating it over n and p yields the balance sheet of the entrepreneurial sector as:

$$q_t K_t = N_t + B_t, \tag{20}$$

where N_t is the aggregate net worth. In aggregate, entrepreneurs who have succeeded in their project set the capital utilization rate u_{t+1}, rent out effective capital $\bar{K}_{t+1} = u_{t+1} K_t$ to the consumption-good producer, and earn the rental rate r_{t+1}^k per unit of the effective capital. In setting the capital utilization rate, the entrepreneurs incur the costs, $a(u_{t+1})$ units of the consumption good, per unit of the physical capital, where $a(\cdot)$ satisfies $a'(u_t), a''(u_t) > 0$ and $a(1) = 0$ as in CEE (2005). In particular, its functional form is given by:

$$a(u) = r^k \left[\frac{a_p}{2} u^2 + (1 - a_p) u + \frac{a_p}{2} - 1 \right], \quad a_p \geq 0, \tag{21}$$

where r^k is the rental rate in steady state. After renting out capital, the entrepreneurs sell depreciated capital to the capital-good producer at price q_{t+1}. Consequently, the type-(n, p) entrepreneur's expected return from investing one unit of the consumption good is given by $p\theta(p) E_t R_{t+1}^k$ where R_{t+1}^k is given by:

$$R_{t+1}^k = \frac{r_{t+1}^k u_{t+1} + q_{t+1}(1 - \delta) - a(u_{t+1})}{q_t}. \tag{22}$$

The capital utilization rate is set to maximize the return R^k_{t+1} so that it satisfies $r^k_{t+1} = a'(u_{t+1})$, or $u_{t+1} - 1 = a_p^{-1}(r^k_{t+1}/r^k - 1)$. That is, the capital utilization rate is increasing in the rental rate. The case of $a_p = \infty$ corresponds to a constant capital utilization rate at $u_{t+1} = 1$. As in Section 2, $p\theta(p) = 1$ is assumed so that the expected return of an entrepreneur's project is identical to $E_t R^k_{t+1}$ for all entrepreneurs.

As in CMR (2014), each household – a representative agent of its family members – instructs its entrepreneurs to maximize their expected period $t+1$ net worth. For each n, an entrepreneur chooses a schedule $\{B_{n,t}(p), X_{n,t}(p)\}_{p=\underline{p}_t}^{\bar{p}}$ to maximize the expected period $t+1$ profits, given by $\int_{\underline{p}_t}^{1} \left[E_t R^k_{t+1}(N_{n,t} + B_{n,t}(p)) - pX_{n,t}(p)\right] dF_t(p)$, which is essentially the same as the expected profits (5) in the partial equilibrium model. The entrepreneur does so subject to the bank's zero profit condition, the entrepreneur's participation constraint, pledgeability constraint, and incentive constraint, which correspond to (1), (2), (3), and (9), respectively, in the partial equilibrium model. This problem is essentially the same as that of the partial equilibrium model studied in Section 2.3. The returns R^k and R in the partial equilibrium model correspond to $E_t R^k_{t+1}$ and R_t, respectively, in this general equilibrium model.

Applying Proposition 1 to the contracting problem in this general equilibrium model, the aggregate borrowing is given by:

$$B_t = \frac{\phi E_t(R^k_{t+1}/R_t)}{1 - \phi(E_t R^k_{t+1}/R_t)} F_t(p^*_t) N_t. \tag{23}$$

Hence the aggregate balance sheet (20) can be written as:

$$q_t K_t = \left[1 + \frac{\phi\left(E_t R^k_{t+1}/R_t\right)}{1 - \phi\left(E_t R^k_{t+1}/R_t\right)} F_t(p^*_t)\right] N_t, \tag{24}$$

where p^*_t is a threshold such that entrepreneurs with $p > p^*_t$ do not get a loan. The threshold p^*_t is determined by (10) with R^k replaced by $E_t R^k_{t+1}$, i.e.,

$$\int_{\underline{p}_t}^{p^*_t} \omega_t(p) \left(\frac{1}{p}\right)^{\frac{1}{1-\phi}} dp = 0. \tag{25}$$

where $\omega_t(p) \equiv pf_t(p) - (R_t/E_t R^k_{t+1})pf_t(p) - (R_t/E_t R^k_{t+1})F_t(p)$.

In aggregate, after earning $R^k_{t+1}(N_t + B_t)$, entrepreneurs repay $R_t B_t$ to the bank because the bank earns zero profit. A fraction $1-\gamma$ of entrepreneurs then become workers randomly and bring their net worth back to the household they belong to. Consequently, the law of motion for the aggregate net worth is given by:

$$N_{t+1} = \gamma \left[R^k_{t+1}(N_t + B_t) - R_t B_t \right] + \xi Y_{t+1}, \tag{26}$$

where ξY_{t+1} with $0 < \xi < 1$ is the aggregate transfer from households to entrepreneurs who do not have any net worth.[7]

The economy is closed by the good-market clearing condition: $Y_t = C_t + I_t + a(u_t)K_{t-1}$. The GDP is defined as $GDP_t = C_t + I_t$. The complete list of the equilibrium conditions is relegated to the supplementary material.

Finally, to map the model to data, an average loan interest rate is defined as a ratio of the aggregate payment X_t in the beginning of period $t+1$ to the aggregate loan B_t made in period t: $R^b_t = X_t/B_t$, where X_t is derived by aggregating (14), and the average credit spread, CS_t, is defined as $\mathrm{CS}_t = R^b_t - R_t$. In addition, the heterogeneity of credit spreads in this model allows us to study its dispersion, defined by a difference between the credit spreads at the 10th percentile and at the 90th percentile: $\mathrm{Disp}_t = \mathrm{CS}_t(p_{10}) - \mathrm{CS}_t(p_{90})$, where $\mathrm{CS}_t(p_m)$ is the credit spread of a borrower whose private information p is at the m-th percentile of distribution $F_t(\cdot)$, i.e., $100 \times F(p_m) = m$.

3.4 Lemons Shocks

The distribution $F_t(p)$ affects the degree of credit rationing – adverse selection – in the credit market. To obtain a simple analytical solution, the distribution is assumed to be uniform over interval $[\underline{p}_t, 1]$:

$$F_t(p) = \frac{p - \underline{p}_t}{1 - \underline{p}_t}, \quad \underline{p}_t \equiv \underline{p} e^{\upsilon_t}, \quad 0 < \underline{p} < 1, \tag{27}$$

with $\upsilon_t = \rho_\upsilon \upsilon_{t-1} + \epsilon_{\upsilon,t}$, $0 \leq \rho_\upsilon < 1$, where $\epsilon_{\upsilon,t}$ is a lemons shock i.i.d. with mean zero. A negative lemons shock makes the distribution of private information more dispersed downward and makes the projects of some entrepreneurs become more risky in the mean-preserving spread sense. This exacerbates adverse selection and credit rationing.

A lemons shock υ_t plays the same role as a typical financial shock that affects the excess

[7] In a similar modeling framework, CMR (2014) assume that the transfer is lump sum and Gertler and Karadi (2011) assume that the transfer is proportional to $q_{t+1}K_{t+1}$. Both the assumptions and the assumption in this paper do not affect quantitative results because the amount of the transfer is tiny.

return on capital exogenously. Hall (2011) and Gilchrist and Zakrajsek (2011) argue that such a financial shock plays an important role in the U.S. Great Recession of 2007-09. Log-linearizing equations (24) and (25) and arranging them yield:

$$E_t \hat{R}^k_{t+1} - \hat{R}_t = -\chi_1 \left(\hat{N}_t - \hat{q}_t - \hat{K}_t \right) - \chi_2 \upsilon_t, \tag{28}$$

where $\hat{x}_t$ denotes the deviation of variable x_t from its steady state, and $\chi_1, \chi_2 > 0$ are given by the model's structural parameters. The derivation of equation (28) is relegated to the supplementary material.

Equation (28) shows that a lemons shock is identical to the financial shock studied by Gilchrist and Zakrajsek (2011) and is similar to that considered by Hall (2011). A negative lemons shock increases the excess return on capital through its effect on the degree of adverse selection. This effect is hidden in equation (28) because the threshold p_t^*, which summarizes the degree of adverse selection, in equation (24) is substituted out using equation (25). In this sense, the mode studied here provides a micro-foundation for the financial shock studied by Gilchrist and Zakrajsek (2011) and Hall (2011).

Equation (28) also points to a financial accelerator mechanism – a feedback loop between N_t and q_t. A negative lemons shock raises the excess return on capital $E_t R^k_{t+1}/R_t$ by decreasing the price of capital q_t, which at the same time decreases the current return on capital R^k_t and decreases the net worth N_t through the law of motion for the net worth (26). This, in turn, decreases the demand for capital and raises the excess return on capital further from equation (28).

3.5 Four Variants of the Model

To understand the transmission mechanism of a lemons shock – how it affects the economy, four variants of the model are considered. The first model is called as the *basic model*, which is identical to the model presented in Sections 3.1–3.4 but with no investment adjustment cost and no variable capital utilization, i.e., $S''(1) = 0$ and $a_p = \infty$. The basic model shuts down the impact of a lemons shock on the price of capital q_t because q_t is always unity in this model. The second model is called as the *Q-model* in which the investment adjustment cost $S'' > 0$ is activated in the basic model. The adjustment cost generates a feedback loop between the price of capital and the net worth, helping the model generate a co-movement between output and net worth.

The third model is called as the *W-model* in which nominal wage rigidity is added to the Q-model. As is well known, a standard real business cycle model with non-TFP shocks suffers from a co-movement problem between consumption and hours worked, as pointed by Barro and King (1984). In addition, such a co-movement problem dampens the effects of non-TFP shocks on output. The basic model and the Q-model are no exception. To overcome this problem, following Justiniano, Primiceri, and Tambalotti (2010), nominal wage rigidity á la Erceg, Henderson, and Levin (2000) is introduced. In this model, households are monopolistically competitive in the labor market and set their nominal wage with probability $1-\xi_w$ every period. This wage setting makes a wage markup move countercyclically around its steady state value of $\lambda_w - 1 > 0$ and thereby mitigates the co-movement problem.[8] In this version of the model, the nominal bond with zero net supply is available for households, so that the typical Euler equation holds: $1 = E_t\beta(C_t/C_{t+1})(R^n_t/\pi_{t+1})$, where R^n_t is the nominal interest rate and π_{t+1} is the inflation rate. A subsidy that offsets the steady state markup of $\lambda_w - 1$ is introduced so that the steady state remains the same as that of the basic model and the Q-model. The model is closed by a simple Taylor rule, $\log(R^n_t/R^n) = r_\pi \log(\pi_t)$. The detail description of the model is relegated to the supplementary material.

The final model is called as the *full model* in which variable capital utilization is activated in the W-model. This additional factor will be shown to amplify the effects of a lemons shock further and strengthen correlations between GDP and credit spreads.

As examined in the next section, considering these four variants of the model allows us to disentangle the roles of the key features of the full model, i.e., investment adjustment costs, nominal wage rigidity, and capital utilization rates, for the transmission mechanism of a lemons shock.

4 Quantitative Analyses

In this section, the effects of a lemons shock and its transmission mechanism in the dynamic model are examined quantitatively. To this end, the model parameter values are set in Section 4.1. In Sections 4.2 and 4.3, to disentangle the transmission mechanism, impulse responses to a white-noise lemons shock and a persistent lemons shock are studied for the

[8] What is important here for addressing the co-movement problem is not nominal wage rigidity per se, but a countercyclical wage markup. In the the supplementary material, it is shown that the full model in which nominal wage rigidity is replaced by an exogenous countercyclical wage markup shares similar quantitative features with the full model.

four variants of the model presented in Section 3.5. In Section 4.4, stochastic simulations are conducted for the full model to study its implications for business cycles including deep recessions.

4.1 Model Parameterization

The time periods are quarters and the full model is calibrated to the US economy.[9] First, regarding parameters pertaining to the real economy, the preference discount factor β is set at $\beta = 0.993$, implying the net risk-free interest rate of three percent annual rate in steady state. Conventional values are used for the labor supply elasticity ($\nu = 1$), the capital income share ($\alpha = 0.36$), and the capital depreciation rate ($\delta = 0.025$). The coefficient of the disutility of labor, ψ, is set by normalizing hours worked to unity in steady state. The curvature of investment adjustment costs is set at $S''(1) = 1.8$, based on the micro-evidence of Eberly, Rebelo, and Vincent (2012). The degree of capital utilization rates is set at $a_p = 0.5$, which lies between those estimated by CEE (2005) and CMR (2014). For the case of no variable capital utilization, $a_p = 1e{+}10$ is used, which makes capital utilization essentially constant.

Next, regarding parameters pertaining to a financial sector, the pledgeability parameter ϕ, the parameter of distribution $F(\cdot)$, $\underline{p}$, and the survival rate γ are jointly set for the model in steady state to match the following three objects: the leverage ratio qK/N of 2 as in BGG (1999)[10]; the credit spread CS of 1.88 percent, which is equal to the sample average of the GZ spread – the average of credit spreads of corporate bonds with various credit grades relative to hypothetical Treasury yields with the same maturity, constructed by Gilchrist and Zakrajsek (2012) – over the period of 1985Q1-2010Q3; and a fraction of entrepreneurs who do not get a loan, $1 - F(p^*)$, of 0.2. The resulting value of $\gamma = 0.986$ is fairly close to that used by BGG (1999) and CMR (2014). Admittedly, there is little empirical guidance about the value of the degree of credit rationing, $1 - F(p^*)$. But a robustness check conducted in the end of this section shows that quantitative results continue to hold as long as the degree of adverse selection, $1 - F(p^*)$, is not too high.

Regarding a lemons shock, its AR(1) coefficient is set at $\rho_v = 0.8$. As will be shown in Section 4.4, the auto-correlation of the credit spread calculated from simulated data for

[9]The full model shares the same steady state with the other three variants of the model, i.e., the basic model, the Q-model, and the W-model. Hence, the calibration, which mainly focuses on steady state, applies to all the four models.

[10]The model is not sensitive to the leverage ratio in steady state. For example, quantitative results barely change if the leverage ratio in steady state is set at 4 as in Gertler and Karadi (2011).

Table 1: Parameter values

		Real sector			
β	Discount factor	0.993	ν	Labor supply elasticity	1
α	Capital income share	0.36	δ	Depreciation rate	0.025
$S''(1)$	Adjustment costs	1.8 or 0	a_p	Capital utilization	0.5 or $1e{+}10$
		Financial sector			
ϕ	Moral hazard	0.554	$\underline{p}$	Parameter of $F(\cdot)$	0.992
γ	Survival rate	0.986	ξ	Transfers	0.0001
		Lemons shock			
ρ_v	AR(1) coefficient	0.8 or 0			
		Nominal wage rigidity (for the full model only)			
ξ_w	Wage rigidity	0.75	λ_w	Wage markup	1.05
r_π	Inflation coefficient	1.5			

the full model is 0.78, which is close to the auto-correlation of 0.81 in the recent period of 2000Q1-2010Q3 for the GZ spread. In addition, no persistence case of $\rho_v = 0$ is considered to clarify the transmission mechanism of a lemons shock. An i.i.d process for a lemons shock $\epsilon_{v,t}$ will be specified in business cycle simulations conducted in Section 4.4.

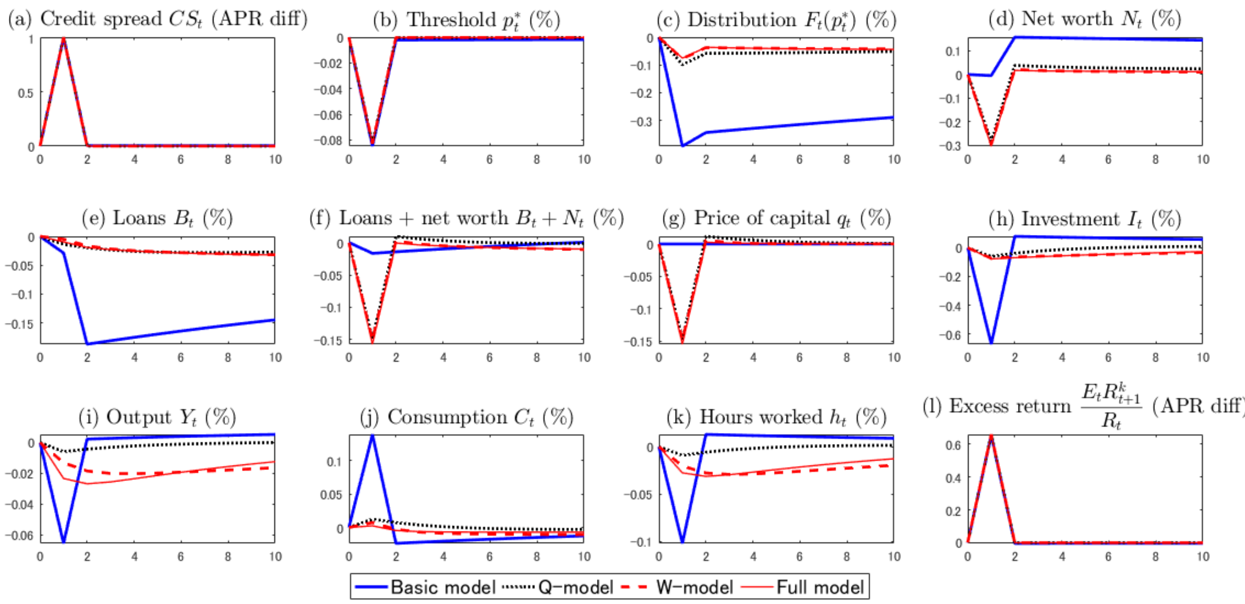
Finally, parameters pertaining to nominal wage rigidity in the full model are set following the literature on new Keynesian models such as CMR (2014). The parameter that governs the frequency of wage changes is set at $\xi_w = 0.75$. The steady state wage markup is set at $\xi_w = 1.05$ and the inflation coefficient in the Taylor rule is set at $r_\pi = 1.5$.

The resulting parameter values are summarized in Table 1.

4.2 Transmission Mechanism of Lemons Shocks

How does a lemons shock affect the economy? To get straight to the point, a negative lemons shock disrupts the credit market by aggravating credit rationing, i.e., by decreasing the threshold p_t^*, and decreases the supply of credit – entrepreneurs' funds for purchasing capital, which, in turn, decreases investment and eventually output. To disentangle this transmission mechanism, it is useful to start from the case of a lemons shock with no persistence i.e., $\rho_v = 0$. Figure 1 plots impulse responses to such a negative lemons shock for the four variants of the model presented in Section 3.5: the basic model, the Q-model, the W-model, and the full model, where the size of the shock is set so that the credit spread

Figure 1: Impulse responses to a white-noise lemons shock ($\rho_v = 0$)



Note: For each panel the unit of a vertical axis is either a percentage deviation from the steady state, denoted as (%), or an annual percentage difference, denoted as (APR diff).

CS_t rises by 1 annual percentage points at the impact of the shock.

Basic model The basic model (blue solid lines in Figure 1) makes clear how the negative lemons shock disrupts the economy. In response to such a shock – an increase in the number of entrepreneurs who are riskier in the mean-preserving spread sense – which hits at $t = 1$, the bank responds by raising the loan interest rate, which widens the credit spread CS_t at $t = 1$ (Panel (a)). The threshold p_t^* then drops (Panel (b)) and fewer and riskier entrepreneurs take out loans (Panel (c)), aggravating credit rationing – adverse selection – in the credit market, consistent with the comparative statics result in Proposition 2(ii). Because the price of capital q_t is constant in this model, the return on capital R_t^k is nearly constant at $t = 1$ as it is mainly determined by the pre-determined capital, and thereby the law of motion for the net worth (26) implies that the net worth N_t is also nearly constant at $t = 1$ (Panel (d)). Consequently, given the excess return $E_t R_{t+1}^k / R_t$, which will be mentioned later, equation (23) implies that the loans B_t decrease at $t = 1$ (Panel (e)), driven by a fall in the number of entrepreneurs who take out loans from the bank, $F_t(p_t^*)$. Putting together, the sum of the loans and net worth, $B_t + N_t$, decreases in the initial period (Panel (f)).

Since entrepreneurs use the sum, $B_t + N_t$, for purchasing capital, its decrease affects output through a decrease in investment. In this model, the price of capital q_t is constant (Panel (g)), so that the law of motion for capital (19) and the balance sheet of the entrepreneurial sector (20) imply that investment is given by:

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

Hence, a decrease in the sum of the loan and net worth causes investment to drop sharply (Panel (h)). Driven by this decrease in investment, output and hours worked decrease as well (Panel (i) and (k)). Because this model is built within a standard business cycle framework, consumption and hours worked move in different directions in response to non-TFP shocks. Indeed, the optimality conditions of the household's problem and the consumption-good producer's problem imply $MPL = MRS$ i.e., $(1-\alpha)K_{t-1}^{\alpha}h_t^{-\alpha} = \psi h_t^{1/\nu}C_t$, and thereby h_t and C_t inevitably move in opposite directions. Because of this, consumption increases at $t = 1$ (Panel (j)). In the next period consumption decreases from the high level at $t = 1$ as there is no shock anymore. Because the real interest rate R_t is proportional to the consumption growth rate, the real rate falls sharply at $t = 1$, raising the excess return on capital $E_t R_{t+1}^k / R_t$ at $t = 1$ (Panel (l)). According to Proposition 2(i), an increase in the excess return pushes up the threshold p_t^*, partially offsetting the direct impact of the lemons shock – a decrease in $\underline{p}_t$ – on the threshold. But the direct effect dominates the indirect effect that works through a change in the excess return, and therefore the threshold drops and affects the entire economy.

From period $t = 2$ onward, although output, consumption, investment, and hours worked almost return to zero, the loans B_t decrease further at $t = 2$ and stay low (Panel (e)). This is mainly driven by a fall in $F_t(p_t^*)$, the number of entrepreneurs who take out loans (Panel (c)). Because the lemons shock considered here has no persistence i.e., $\rho_\upsilon = 0$, $\underline{p}_t$ returns to $\underline{p}$ at $t = 2$ so that the decrease in $F_t(p_t^*)$ is purely driven by a fall in the threshold p_t^*. Although it is difficult to see such a drop in Panel (b), the threshold deviates from its steady state by -0.0022 percent in period $t = 2$ and this drives a decrease in $F_t(p_t^*)$ (Panel (c)).[11] In turn, again although it is difficult to see in Panel (l), it is a fall in the excess return $E_t R_{t+1}^k / R_t$ that drives a fall in p_t^* through equation (25). The excess return stays below zero as the real interest rate is slightly high in line with a recovery of consumption from period $t = 2$ onward (Panel (j)). The net worth increases at $t = 2$, driven by an increase in the marginal product of capital, which is caused by a fall in the

[11] A deviation of $F_t(p_t^*)$ from the steady state in period $t = 2$ is given by $p^*/(p^* - \underline{p}) \times \hat{p}_t^* = 158 \times (-0.0022) = 0.34$ percent, where $\hat{p}_t^*$ is a deviation of p_t^* from its steady state.

capital stock due to a decrease in investment at $t = 1$. But, such an increase in the net worth is dominated by a fall in $F_t(p_t^*)$ and thereby the loans decrease persistently. In spite of such a decrease in loans, investment, given by equation (29), does not decrease from $t = 2$ onward due to a fall in K_t at $t = 1$.

Q-model The basic model has two variables that have a co-movement problem with output: net worth and consumption. In particular, the net worth increases at $t = 2$ while output drops at $t = 1$. This is qualitatively problematic because in practice net worth, which can be approximated by stock prices as in CMR (2014), tends to co-move with output. To address this issue, the Q-model modifies the basic model to incorporate investment adjustment costs.

With this modification, in response to the negative lemons shock, the credit spread spikes, the threshold falls, and loans decrease (black dotted lines in Panel (a), (b), and (e)) similar to the basic model. Given the net worth, now with the amount of credit less available for purchasing capital, the price of capital falls sharply (Panel (g)) through the balance sheet equation (20). This, in turn, decreases the net worth (Panel (d)) and further decreases the sum of the loans and net worth (Panel (f)). Because such a decrease in funds for purchasing capital is mainly reflected in a drop in the price of capital, investment decreases moderately at $t = 1$ relative to the basic model (Panel (h)). But the presence of the adjustment cost makes the recovery of investment slow. Consequently, the responses of output and hours worked become more persistent than in the basis model (Panel (i) and (k)).[12]

W-model Although the Q-model cures the co-movement problem of net worth, it still suffers from the co-movement problem of consumption. In addition, although the Q-model adds persistence to output, output becomes less responsive relative to the basic model. To address these issues, the W-model modifies the Q-model to incorporate nominal wage rigidity.

With nominal wage rigidity put in place, in response to the negative lemons shock, real variables such as output and hours worked are significantly amplified relative to the

[12]The loans B_t also become less responsive in period $t = 2$ onward than that in the basic model (Panel (e)). This is driven by the number of entrepreneurs who take out loans, $F_t(p_t^*)$ (Panel (c)), which, in turn, is caused by the threshold p_t^* (Panel (b)). Although it is difficult to see in Figure 1, the threshold is slightly greater in the Q-model than in the basic model, which mirrors the development of the excess return. The excess return is slightly higher in the Q-model than in the basic model. Behind it lies in the persistent response of consumption in the Q-model: unlike the basic model, consumption decreases slowly back to its steady state from period $t = 1$.

Q-model as shown by red dashed lines in Figure 1. In addition, the co-movement problem of consumption is mitigated and consumption decreases below its steady state level from period $t = 2$, moving in the same direction with output. Since the nominal wage is less flexible, the real wage is kept high as inflation goes down. This pushes down both hours worked and consumption further. By making the wage markup countercyclical, i.e., by making the real wage higher than its frictionless level when output decreases, nominal wage rigidity greatly amplifies the effects of the lemons shock. This amplification mechanism is adopted in the literature that studies non-TFP shocks including risk shocks (CMR, 2014), investment shocks (Justiniano, Primiceri, and Tambalotti, 2010), and a shock to intermediation spreads (Ajello, 2016).

Full model Finally, the full model modifies the W-model to add variable capital utilization. As the marginal product of capital drops due to a decrease in hours worked, the capital utilization rate falls, which further decreases output relative to the W-model, as shown by a red thin line in Panel (i) of Figure 1. Although the variable capital utilization has little effects on financial variables such as loans and net worth, it amplifies the effect of the lemons shock on output, which decreases more and sharper than in the W-model (Panel (i)). This helps GDP co-move timely with the credit spread as will be discussed in business cycle simulations conduced in Section 4.4.

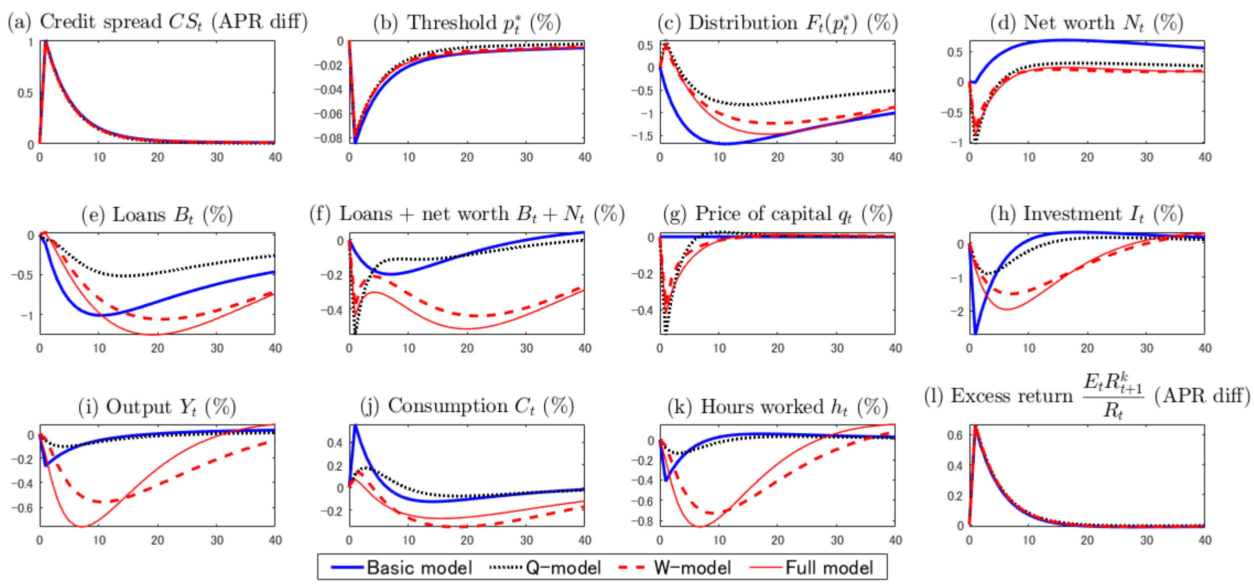
4.3 Impulse Responses to a Persistent Lemons Shock

Now consider a persistent lemons shock with $\rho_v = 0.8$. Figure 2 plots impulse responses to such a negative shock for the four variants of the model, where the size of the shock is the same as that in Figure 1.

The impulse responses become persistent for all variables for all the variants of the model due to the persistence of the shock itself, but the main observations about the transmission mechanism continue to hold. In the basic model, the negative lemons shock exacerbates adverse selection in the credit market, decreases the supply of bank credit, and dampens investment, driving the fluctuation of output, as shown by thick blue lines in Figure 2.[13] The Q-model, modified to add investment adjustment costs to the basic model, makes the price of capital fluctuate and adds a balance sheet channel, i.e., a channel through

[13] In the basic model the impulse responses of investment and the sum of loans and net worth do not necessarily coincide from period $t = 2$ onward (Panel (f) and (h)) because investment today depends on capital accumulated yesterday as it is given by $I_t = B_t + N_t - (1 - \delta)K_{t-1}$.

Figure 2: Impulse responses to a persistent lemons shock ($\rho_\upsilon = 0.8$)



Note: For each panel the unit of a vertical axis is either a percentage deviation from the steady state, denoted as (%), or an annual percentage difference, denoted as (APR diff).

which the price of capital affects net worth. In response to the negative lemons shock, the price of capital falls (Panel (g)) through such a channel and the net worth decreases (Panel (d)), amending the co-movement problem of the net worth in the basic model. The Q-model also adds further persistence to the responses of real variables such as investment and consumption. The W-model, modified to incorporate nominal wage rigidity into the Q-model, adds an amplification mechanism and mitigates the co-movement problem of consumption. Real variables such as output and hours worked show significantly greater responses relative to those of the Q-model, as shown by red dashed lines (Panel (i) and (k)). In addition, consumption decreases from period $t = 2$ in line with output. Finally, the full model, modified to add variable capital utilization to the W-model, further amplifies the effects of the lemons shock, as shown by red thin lines in Figure 2. In particular, the effect on output is greatly amplified and the output decreases more rapidly than in the W-model (Panel (i)).

4.4 Business Cycles and Deep Recessions

This section simulates the full model with persistent lemons shocks and studies its implications for business cycles and potential deep recessions. To this end, a stochastic process for a lemons shock $\epsilon_{\upsilon,t}$ is specified. Since a lemons shock drives credit spreads by directly affecting loan interest rates, its stochastic process is specified to match the standard deviation and skewness of the GZ spread in the period of 1985Q1-2010Q3, which are 1.12 and 2.40, respectively. The high skewness implies that the GZ spread occasionally spikes substantially. Indeed, in the global financial crisis of 2007-09, it jumped up from 1.4 percent to 7.6 percent. To match the high skewness in addition to the standard deviation, it is assumed that a lemons shock is given by $\epsilon_{v,t} = -(\epsilon_t - 1)\Delta$, where $\Delta > 0$ and ϵ_t follows a log normal distribution of $\ln \mathcal{N}(-\sigma^2/2, \sigma^2)$. Consequently, a lemons shock is i.i.d. with mean zero, but occasionally takes a large negative value. The parameter values that match the two statistics of the GZ spread are given by $\sigma = 2.05$ and $\Delta = 0.0065$, which mainly govern the skewness and standard deviation of the shock, respectively.

Table 2 reports summary statistics for simulated series from the model and U.S. data, where the latter is shown in parenthesis. The model is simulated for 1000 times with each sample size equal to that of U.S. data and its average statistics are reported.[14] The sample period is 1985Q1:2010Q2 in line with the availability of the data for the credit spread and the dispersion of credit spreads. The data corresponding to the credit spread CS_t and its dispersion Disp_t are the GZ spread and a difference between the 90th percentile and the 10th percentile of the distribution of credit spreads, constructed by Gilchrist, Sim, and Zakrajsek (2013), respectively.[15] The data corresponding to GDP_t, C_t, I_t, and h_t are per capita GDP, per capita consumption, per capita investment, and per capita hours worked, respectively.[16]

Table 2 reveals three features of the model, namely, volatility, persistence, and comovement. First, starting from volatility, lemons shocks generate significant fluctuations of GDP, consumption, investment, and hours worked. In particular, lemons shocks generate 44 percent (=0.49/1.11) of the actual standard deviation for GDP. The shocks match the volatility of the credit spread by construction. However, they generate only a small portion of volatility of the dispersion of credit spreads. This is because the dispersion is tiny in

[14] Each simulation starts from the model's steady state and the first 20 observations are discarded in obtaining simulated series. For each simulation it is highly unlikely but if $p_t^* > 1$ for some t, such a simulation is discarded. A next simulation is conducted until 1000 simulated series are obtained.

[15] Credit spreads used for calculating the GZ spread, constructed by Gilchrist and Zakrajsek (2012) and credit spreads constructed by Gilchrist, Sim, and Zakrajsek (2013) are similar, but the latter includes credit spreads for manufacturing firms only.

[16] The data for Y_t is nominal GDP divided by GDP deflator and population, where population is given by civilian non-institutional population with ages 16 and over. The data for C_t and I_t are constructed in the same manner, where nominal consumption is given by personal consumption expenditures for non-durables and services, and nominal investment is given by the sum of gross private domestic investment and personal consumption expenditures for durables. The data for h_t is given by hours of all persons in non-farm business sector divided by population. The data source is FRED, Federal Reserve Bank of St. Louis.

Table 2: Business cycle statistics for the model and data (in parenthesis) [a,b]

Variable x_t	$\mathrm{SD}(x_t)$	$\frac{\mathrm{SD}(x_t)}{\mathrm{SD}(GDP_t)}$	$\mathrm{Corr}(x_t, x_{t-1})$	$\mathrm{Corr}(x_{t-1}, GDP_t)$	$\mathrm{Corr}(x_t, GDP_t)$	$\mathrm{Corr}(x_{t+1}, GDP_t)$
GDP_t	0.49	1.00	0.94	0.94	1.00	0.94
	(1.11)	(1.00)	(0.87)	(0.87)	(1.00)	(0.87)
C_t	0.18	0.37	0.89	0.3	0.56	0.79
	(0.79)	(0.71)	(0.82)	(0.68)	(0.86)	(0.84)
I_t	1.95	3.62	0.92	0.97	0.96	0.82
	(4.42)	(4.00)	(0.89)	(0.87)	(0.93)	(0.81)
h_t	0.76	1.54	0.94	0.96	0.99	0.89
	(1.74)	(1.58)	(0.94)	(0.73)	(0.87)	(0.90)
CS_t	1.12	2.40	0.78	-0.47	-0.25	0.02
	(1.12)	(1.01)	(0.89)	(-0.36)	(-0.23)	(-0.04)
Disp_t	0.02	0.04	0.77	-0.46	-0.22	0.05
	(1.26)	(1.14)	(0.90)	(-0.43)	(-0.38)	(-0.31)

[a] The table shows population moments computed from the simulated data of the model and the U.S. data (in parenthesis). The sample period is 1985Q1-2010Q2. All variables are in logarithm, multiplied by 100, and have been detrended using the HP filter with the smoothing parameter value of $\lambda = 1600$ (with the exception for CS_t and Disp_t).

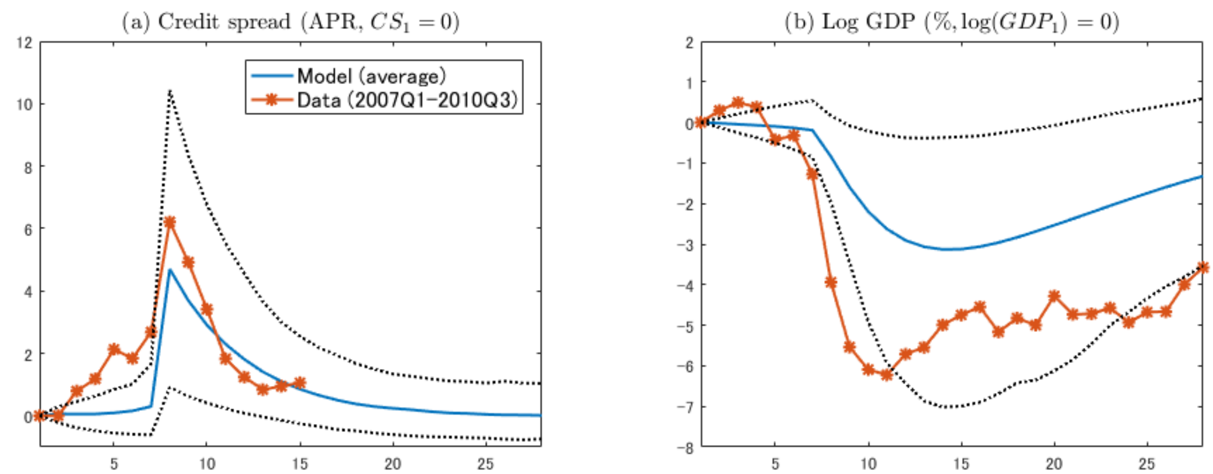
[b] $\mathrm{SD}(x_t)$ denotes a standard deviation of variable x_t and $\mathrm{Corr}(x_t, x_t')$ denotes a correlation coefficient between x_t and x_t'.

the model: Disp $= 0.02$ percent in steady state while the sample average of the dispersion in the data is 3.21 percent. This difference reflects the fact that the data include credit spreads in various grades from triple A to single D in the measure of the S&P credit ratings, while the model essentially has only one grade of credit spreads because lenders cannot distinguish the riskiness of borrowers. That said, relative to steady state, the model generates significant fluctuations of the dispersion, which is about 1 (=0.02/0.02), while the corresponding data is about 0.4 (=1.26/3.21).

Second, regarding persistence, the model generates a high auto-correlation of around 0.9 for GDP, consumption, investment, and hours worked, as observed in the data. The model generates an auto-correlation of about 0.8 for the credit spread, which is slightly less than that of the data of about 0.9. The relatively low auto-correlation is mainly attributable to the assumed AR(1) coefficient of lemons shocks of $\rho_v = 0.8$. But, as mentioned previously, the auto-correlation for the credit spread in the model is close to that of the recent data, 0.81, during the period of 2000Q1-2010Q3.

Third, regarding co-movement, the model generates a high co-movement with GDP for

Figure 3: Deep recessions from simulated data



Note: The two dotted lines represent the 10th and 90th percentile of a variable from 1000 simulated data. The data for CS_t and GDP_t are the GZ spread and per capita GDP, respectively, where per capita GDP is detrended by a linear trend in the period of 2000Q1-2007Q1. The data are normalized to zero in the initial period.

investment and hours worked, and to a lesser degree for consumption, as observed in the data. In addition, the model shows a negative correlation with GDP for the credit spread and the dispersion as in the data. Moreover, for these two financial variables, the model matches relative magnitudes of a correlation with GDP among lagged and current variables. In particular, an increase in the credit spread or the dispersion tends to be followed by a decrease in GDP in the next quarter. As mentioned previously, variable capital utilization plays a key role in this regard. Without it, a correlation with GDP for the current credit spread would be almost zero but slightly positive, although that for the lagged credit spread continues to be negative. By making GDP drop sharply, variable capital utilization helps generate a negative contemporaneous correlation between GDP and the credit spread as observed in the data.

The model generates not only business cycles but also deep recessions comparable to the U.S. Great Recession of 2007-09. For each sample of the 1000 simulated series, an event in which the credit spread is the highest in the sample is extracted. Figure 3 plots the average and [10, 90] percentile points of the credit spread and GDP in the period around such an event. In Panel (a) a deep recession occurs at $t = 8$ when the credit spread rises sharply by more than 4 percentage points on average. GDP drops substantially and persistently on average, as shown in Panel (b). Both the credit spread and GDP mimic those observed in the Great Recession. This deep recession is driven by a large negative lemons shock. Such a shock can occur in the model because the shock process is calibrated to match both the volatility and the skewness of the GZ spread.

These simulation results are robust to the target value of a fraction of entrepreneurs who do not get a loan in steady state, which has been set at $1 - F(p^*) = 0.2$, as long as it is not quite large. Even if the target value is set at 0.3 instead, lemons shocks still generate significant volatility of GDP of 0.43, albeit smaller than the volatility of 0.49, reported in Table 2. For the target value smaller than 0.2, the volatility of GDP increases. Hence, given a magnitude of a lemons shock, the economy would be more amplified by a lemons shock if the steady state has smaller degree of adverse selection, i.e., a smaller value of $1 - F(p^*)$. This is because a change in the degree of credit rationing – adverse selection – relative to its steady state level would become greater as the value of $1 - F(p^*)$ becomes smaller.

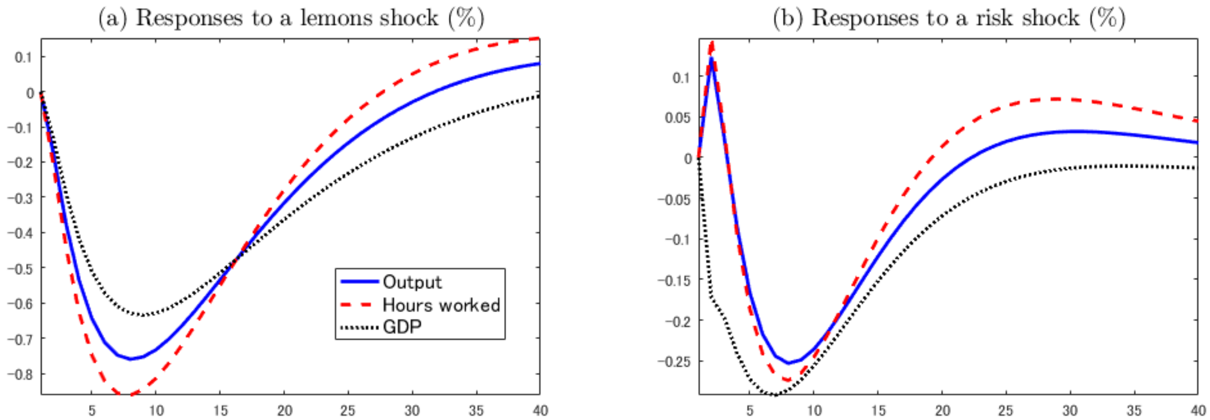
5 Features of Lemons Shocks and Adverse Selection

This section shines light on features of lemons shocks and adverse selection in the full model. It first provides a comparison between a lemons shock in this paper and a risk shock studied by CMR (2014). Next it studies the role of adverse selection in credit markets as an amplifier of other shocks. Finally, as an extension of a lemons shock, a shock to banks' perception of borrowers' riskiness is introduced and the effect of a change in such perception is studied.

5.1 Comparison with a Risk Shock

To highlight a unique feature of a lemons shock, it is useful to compare it with a risk shock studied by CMR (2014) – a shock to the riskiness of entrepreneurs' return in the framework of BGG (1999). A model of the version of CMR (2014), which is called as the risk-shock model, replaces equations pertaining to the credit friction and the good-market clearing condition in the full model presented in Section 3 with new equations related to costly state verification problems – a friction considered by BGG and CMR. In particular, a good-market clearing condition has an additional term, Mcost_t, that captures monitoring costs: $Y_t = C_t + I_t + a(u_t)K_{t-1} + \mathrm{Mcost}_t$. The values of parameters pertaining to financial frictions are set to hit the target value of $qK/N = 2$ and $\mathrm{CS} = 1.88$ as in the lemons-shock model. The detail of the risk-shock model is relegated to the supplementary material.

Figure 4: Comparison between lemons shocks and risk shocks



Figures 4(a) and (b) plot responses of output, GDP, and, hours worked to a lemons shock and to a risk shock, respectively, where the AR(1) coefficient of each shock is set at 0.8.[17] The responses in panel (a) correspond to those of the full model shown in Figure 2. All the three variables show a hump-shaped response. However, in response to the negative risk shock, output and hours worked increase initially although GDP decreases at the same time, as shown in panel (b). Such increases occur because an increase in the entrepreneurs' riskiness causes more defaults and increases the monitoring costs, Mcost_t. The increase in Mcost_t plays a role similar to expansionary government spending and thus stimulates output and hours worked in period $t = 1$.[18] Absent from such monitoring costs, the lemons-shock model features smooth hump-shaped responses for output and hours worked as well as GDP.

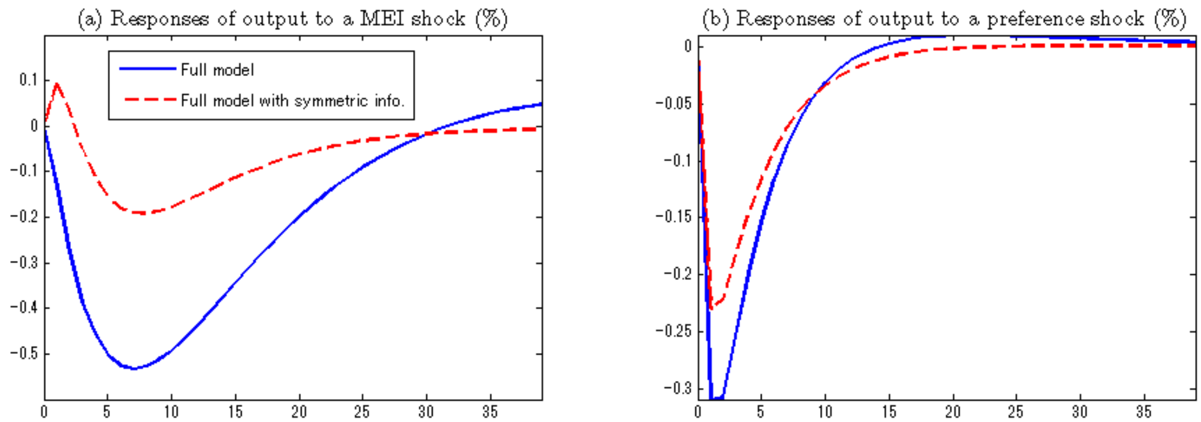
5.2 Adverse Selection: an Amplifier or a Dampener?

Adverse selection not only gives rise to a lemons shock but also could serve as an amplification mechanism of other shocks. As is clear from a comparison between he equations for the aggregate loan, (8) and (15), an only difference between the models with and without asymmetric information lies in the presence and variability of threshold p_t^*. From this observation, in this dynamic general equilibrium framework a model with symmetric infor-

[17]In panel (b) of Figure 4 the magnitude of the risk shock is set so that the risk-shock model generates the same excess return on capital – a measure of an inefficiency of the economy – initially as in the lemons-shock model.

[18]The feature of spikes in output and hours worked is also observed in the CMR (2014) model if an AR(1) coefficient of a risk shock is not too high as in this paper. In CMR a risk-shock in period t affects the volatility of entrepreneurial idiosyncratic returns in period $t + 1$, so that the responses of output and hours worked would exhibit a spike in the second period.

Figure 5: Adverse selection as an amplifier



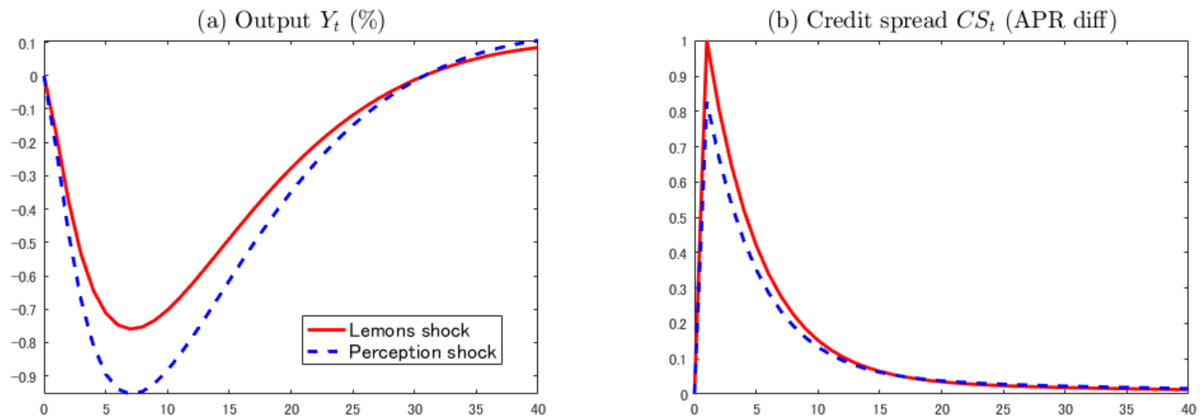
Note: "Full model" represents the model presented in Section 3 and "Full model with symmetric info." represents the same model but with symmetric information.

mation is defined as the full model presented in Section 3 in which threshold p_t^* is fixed at its steady state value. As a result, in a system of log-linearized equations, an only difference between the two models in considering non-lemons shocks lies in equation (28) in which $0 < \chi_1 < \chi_{1,\text{sym}}$, where $\chi_{1,\text{sym}}$ is a corresponding coefficient in the model with symmetric information.[19]

Figure 5 plots responses of output to a shock to the marginal efficiency of investment (MEI) of $\mu_1 = -0.005$ and a preference shock of $b_1 = -0.005$ for the full model (solid line) and the model with symmetric information (dashed line), where the two shocks are assumed to follow an AR(1) process with the coefficient of 0.8. The presence of adverse selection in the full model amplifies both the effects of the MEI shock and the preference shock. In particular, in response to the negative MEI shock, the full model shows a negative and hump-shaped response of output while output increases initially in the symmetric information model that has no adverse selection. To understand the amplified response in the full model, note that a negative MEI shock shifts the supply curve of investment inward so that it increases the price of capital and decreases the excess return on capital, $E_t R_{t+1}^k / R_t$. Such a fall in the excess return on capital causes the threshold p_t^* to drop, increasing the degree of credit rationing – adverse selection. The drop in p_t^* decreases borrowing, amplifying the negative effect of the MEI shock. In the model with symmetric information, such a mechanism through a change in the threshold p_t^* is absent, and an increase in the price of capital, caused by the negative MEI shock, expands the net worth

[19] In addition, in the model with symmetric information a lemons shock has no impact on the economy and thereby $\chi_{2,\text{sym}} = 0$ in equation (28).

Figure 6: Comparison between lemons shocks and perception shocks



and generates an initial increase in output. A similar mechanism works for the negative preference shock, which also generates an amplified response of output in the full model relative to the model with symmetric information.

5.3 Shocks to Lenders' Perception of Borrowers' Riskiness

In this section, a shock to lenders' perception of borrowers' riskiness is considered, which is similar to but different from a lemons shock. In practice a change in bankers' lending stance could affect the economy. Here, lending stance is captured by lenders' perception of borrowers' riskiness. In particular, if a negative perception shock hits banks, they perceive an increase in some borrowers' riskiness as in the case of a negative lemons shock, although such an increase does not actually occur. Banks make zero profit ex ante based on their perception of borrowers' riskiness and make positive profits ex post, which are transferred to households. The detail of equations pertaining to a perception shock is relegated to the supplementary material.

Figure 6 plots impulse responses of output to a lemons shock and to a perception shock, where the stochastic process and the magnitude of the perception shock is identical to those of the lemons shock. The figure shows that the perception shock generates a greater response of output and a smaller response of the credit spread than the lemons shock. The perception shock has a larger effect on output because banks earn positive profits ex post so that resources are drained from entrepreneurs, decreasing entrepreneurs' net worth. It has a smaller effect on the credit spread because the actual riskiness of entrepreneurs do not change and these entrepreneurs have a lower credit spread than those who actually become risky under a lemons shock. These observations suggest that business cycles and deep recessions simulated in Section 4.4 would become more volatile and severer if they are caused not only by a lemons shock but also by a perception shock.

6 Conclusion

Motivated by the global financial crisis of 2007-09 and the resulting need for new macro models with financial frictions, this paper has developed a dynamic general equilibrium model featuring adverse selection in credit markets. The model features a lemons shock – a shock that changes the riskiness of some entrepreneurs. The paper uses a mechanism design approach to characterize and solve for the optimal contract between entrepreneurs and banks under the assumption that entrepreneurs maximize their expected profits. A resulting solution features a separating equilibrium in which entrepreneurs with different riskiness receive a different amount of loans and repay a different level of interest rates. In the model calibrated to the U.S. economy, lemons shocks generate significant business fluctuations including deep recessions comparable to the Great Recession of 2007-09. Also, the paper analytically shows that a lemons shock is equivalent to a typical reduced-form financial shock that changes a wedge between a return on capital and a risk-free interest rate. Hence, the model with adverse selection in credit markets provides a micro-foundation for such a financial shock. In addition, the paper points out a key distinction regarding dynamic responses of output and hours worked between a lemons shock and a risk shock studied by CMR (2014).

This paper has shed light on mechanisms through which a change in riskiness for some borrowers could affect the entire economy through adverse selection in credit markets. Albeit a lemons shock is equivalent to a typical financial shock and is slightly different from a risk shock, it has yet to be determined whether adverse selection in credit markets with a lemons shock has a unique role to play in explaining some phenomena or the fluctuations of the economy. Various financial friction models have been developed since the global financial crisis. A next challenge would be to determine the empirical importance of financial imperfection among various financial friction models including the model proposed in this paper.

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