Innovation-induced Bank Runs

Run in and Run out

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Abstract

This research illustrates a possible channel through which innovation financing can amplify the uncertainty of innovation and raise the probability of financial crises. Innovation can generate "public good" (i.e. productivity gain), as well as "public bad" (i.e. unexpected social hazards) which we call attention to in this research. Financial institutions (e.g. banks) try to finance a new type of projects with short-term debts. The parameters of this new financing technology are not perfectly known and require further experimentation and learning. The new projects are supplied in a limited quantity so banks have strong motive to compete for a larger share of it. This preemptive motive will distort their incentive for patient learning, encouraging banks to adopt the new financial technology in a premature stage. Therefore, banks "run in" to compete for limited number of new projects. Impatient learning and premature adoption of innovation will amplify the coordination problem of short-term debt financing by increasing the probability of bank run, i.e. "run out". We analyze the aforementioned mechanism by extending the Diamond-Dybvig model to a global game setup as well as allowing parameter uncertainty and learning. Market structure matters for the efficiency of innovation financing. We discuss several variants and conditions under which differences emerge between centralized (monopolistic case) and decentralized learning (duopoly and free-competition), as well as necessary conditions under which inefficiencies can occur. Some forms of monopolistic ownership can mitigate this distortion. In this sense, patent or some form of monopoly can not only help to internalize the benefit but also the potential social hazard of innovation.

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1 Introduction

New financial products have been widely blamed as an important cause of the 2008 financial crisis. Report issued by the FCIC (Financial Crisis Inquiry Commission) claims "there was an explosion in risky subprime lending and securitization". The subprime share of all mortgages rises sharply in the early 2000s. As early as 2007, the subprime sector started to experience serious delinquencies, triggering fire sales and a credit crunch eventually. Therefore, a central question we want to ask is whether, why, and how has financial innovation led to the Subprime Crisis 2008? In this paper, we propose a mechanism through which innovation financing can raise the risk in the financial system and increase the probability of a bank run. Intense competition between Financial Institutions (FIs) to enter the new financial product market is an important contributor to the systemic risk. As FCIC points out "The GSEs participated in the expansion of subprime and other risky mortgages, but they followed rather than led Wall Street and other lenders in the rush for fool’s gold."

For modeling purpose, we assume at the very beginning some FI invented a new type of financial contract, which can finance projects which can not be profitably financed by traditional contracts before. For simplicity, we call this a financial innovation because it can finance a new type of projects. However, the parameters of the new financing technology is not known perfectly: even the innovator will wrongly finance some bad projects. After this new financial contract is available, some FIs firstly enter this new market and start experimenting with the new products. Experimenting with the new financial product will generate more precise knowledge regarding the parameters so that early entrants and the rest of FIs can learn and update their beliefs about the parameters after observing these signals. On the other hand, the pool of projects that can be financed by the new financial contracts are supplied in a limited amount. Entering the new markets have two counteracting effects: the benefit of exploiting the limited number of new profitable opportunities, and the risk of ending up with a bad innovations.

A relevant recent research is Pastor and Veronesi (2009). An essential difference is that they assume the pure public good feature of the innovation and the number of projects that can be supported by the new technology is thus unlimited. Therefore, there will be no distorted incentives inducing early entry in their setup and competitive equilibrium of
learning delivers the same efficient outcome as a social planner. However, in reality, as revealed by the 2008 Subprime Crisis, FIs tend to enter a new market too early and massively than the social efficient level before the uncertainty of the new (financial) technology is sufficiently resolved. We will explicitly illuminate this type of inefficiency with our model.

Innovation is generally a good thing, which introduces new profitable opportunities. However, these new opportunities are oftentimes supplied only in a very limited number. Therefore, FIs have strong incentives to preempt the new market. Moreover, the effectiveness and parameters of these innovations are uncertain and thus risky to adopt prematurely. Therefore the new technology needs to be examined and refined patiently. Nevertheless, the limited new opportunities can distort the incentives for patient learning and generate inefficiency and extra risk. In this sense, this research is close to the innovation and preemption game literature started by Reinganum (1981) and Fudenberg and Tirole (1985).

In comparison to the innovation and preemption game literature, this research introduces another negative externality, systemic risk, which is defined as the probability of a bank run in this research. Banks usually finance projects with short-term debts. As pointed out by Gorton, Lewellen, and Metrick (2012), over the last decade the shadow banking sector (other financial institutions) has produced a large share of liquid assets by issuing short-term debts. Collective-action problem arises from the innate nature of decentralized short-term debts as shown by the Diamond-Dybvig model. Uncertainty (the probability of high default rate) can aggravate this collective-action problem and increase systemic risk. Moreover, this type of systemic risk is a "public bad", which the FIs will not fully internalize when calculating their own costs. The preemptive motive under uncertainty will induce premature massive entry and reduce FIs' learning efforts. This will result in a higher probability of bank run and inefficient liquidation of projects which is suboptimal in terms of social welfare.

Patent is rarely granted to financial innovations, but first movers of financial innovation usually can catch a larger market share, according to Tufano (1989). Financial institutions face a tradeoff between precision of learning and market share grabbing. This is an important reason why they will be inclined to deviate from the social efficient investment in learning of the new technology. For example, in the case of subprime issuers, the screening efforts spent on each project can not only guarantee a higher quality for the financed projects but also facilitate learning of the parameters of the new financial technology. Many current empirical research have shown lax screening was ubiquitous during the boom years of subprime lending. The competition for more financing opportunities for the new projects will discourage early entrants from exerting appropriate screening efforts. Reduced efforts will lower the effectiveness of learning.

Regarding modeling methodology, we embed uncertainty and learning into a Diamond-
Dybvig model under a global game setup. Investors perceive private information regarding the public information of project failure rates and decide whether to run. It results in a threshold equilibrium: there is a threshold of project failure rate above which the investors will run on the bank. The probability of bank run is endogenous and dependent on the banks’ decisions of investments on learning, and timing of entry into the new market. We firstly present the socially optimal equilibrium of experimenting, learning and entering. Then we analyze a general setup which allows banks to endogenously choose when and how to enter the market. It illustrates that suboptimal equilibria are always reached in which some banks will always enter the new market earlier, investing in more projects but with less efforts spent on each project. We also find under some conditions, waiting for and learning the signals released by early entrants can be a better decision than entering the market blindly in a massive fashion. This implies free-riding motive can somehow alleviate the negative effect of over-competition.

We integrate two types of strategic complementarities into one framework. Ex ante, investors are competing for a limited number of good new investment opportunities although the quality of these projects has not been fully understood. That is, they "run in" to finance a limited number of new projects in a similar pattern as depositors "run out" on bank deposits during an ordinary bank run. Ex post, they may run on their investments when they see a bad realization. Moreover, the ex an Run – in can worsen the interim signals about project quality and increase the probability of Run – out ex post.

This research have several contributions. This research intends to model a linkage between innovation and social risk of innovation, which the endogenous growth literature, the current experimentation and preemption game literature have missed. In addition to the well-known public good property of innovation, we emphasize innovation’s "public bad" property due to its innate uncertainty. The collective-action problem of financing innovations can be further worsened by FIs’ preemptive motive for a larger share of the new market. Therefore, this demonstrates another benefit that patent protection could have contributed implicitly: by granting Intellectual Property, it can give innovators’ enough incentives to patiently learn and reduce the potential risk of innovation to the society. That is, innovation always goes hand in hand with uncertainty, and better IP protection can encourage the innovator to internalize the potential hazard of innovation. As for modeling technique, we integrate uncertainty and learning with a Diamond-Dybvig bank run model. We also discuss four variants in terms of different information structure and exclusiveness, and analyze the necessary conditions that can result in inefficiencies.

A policy implication is that by granting some form of monopolistic power over the new technology to innovators (or earlier adopters) can not only internalize the positive side of
innovation but also the negative side: the innate uncertainty and risk of the new product. Particular attention should be paid to ways of mitigating the collective-action problem in financing innovations.

**Related Literature**

*Preemption game*

Reinganum (1981), and Fudenberg and Tirole (1985) apply preemption game to market entry and technology adoption. Firm will make a tradeoff between entering earlier with the possibility of acquiring a patent or a significant share of the new market and waiting for a reduced uncertainty and entry cost. Weeds (2002)

Hopenhayn and Squintani (2011) extend this line of research by adding heterogeneous information to each firm.

This research adds a systemic factor which is an additional cost that an individual firm will not take into consideration.

*Financial Fragility*

Allen and Gale have a series of research on financial fragility. This research contributes to the literature in that it focus on market structure and learning, and identify an amplification mechanism due to innovation and competition.

*Entry, Competition and Inefficiency*

Mankiw and Winston (1986) discuss the social inefficiency due to over-entry of firms. "Mankiw and Winston (1986): Economists typically presume that free entry is desirable for social efficiency. As several articles have shown, however, when firms must incur fixed set-up costs upon entry, the number of firms entering a market need not equal the socially desirable number. Spence (1976a) and Dixit and Stiglitz (1977), for example, demonstrate that in a monopolistically competitive market, free entry can result in too little entry relative to the social optimum. In more recent work von Weizsacker (1980) and Perry (1984) point to a tendency for excessive entry in homogeneous product markets. Nevertheless, despite these findings, many economists continue to hold the presumption that free entry is desirable, in part, it seems, because the fundamental economic forces underlying these various entry biases remain somewhat mysterious." Hsieh and Moretti (2003) provides empirical evidence on this channel.

*Experimentation and Learning*

Bolton and Harris (1999) extend the two-armed bandit problem to a multi-agents dynamic game, and show the coexistence of a discouraging free-rider effect and a counteracting encourage effect for experimentation. Pastor and Veronesi (2003, 2006, 2009) argue technology bubble may be efficient, and their analysis is under the assumption of social efficient
learning. This research focuses on decentralized learning and competition, and will show that decentralized learning can bring about inefficiencies under certain conditions.

Bank Run and Global Game


Information Acquisition and Crisis

Chari and Kehoe (2003) shows that information is important for financial crisis. They illustrate the herding effect on crisis.

Financial Innovation

Thakor (2012) discusses a channel of risk creation by modeling FIs’ motive to differentiate their financial products from the standard ones. Empirically, Seru et al (2010) shows that securitization is an important contributor to lax lending standard.

Innovation-induced Social Hazards

Xie (2015b) examine the social hazards related to innovation. Jones (2014) is also a relevant paper.

The paper proceeds as follows. Section 2 describe the environment and model. Section 3 derives the social optimum of learning and entering. Section 4 discusses ownership and market structure for new projects, and how they are related to inefficiency. Section 5 discusses a suboptimal case in which a free-rider will enter later. Section 6 analyzes a general setup in which FIs can endogenously choose when and how to enter the new market. Section 7 extends the setup to many banks. Section 8 discusses several variants. Section 9 provides some empirical evidence and application. Finally Section 10 concludes the paper and provide some policy suggestions.
2 The Model

To model parameter uncertainty and learning, we overlap two three-period Diamond-Dybvig bank run models to make a four-period model as illustrated by Figure (??): $t = 0, 1, 2, 3$.

Investors deposit their funds into banks, which will invest in projects on behalf of the investors.

2.1 Projects

There are two types of projects that can be financed: the traditional type, and the new type. A bank can choose to finance projects at date 0 or 1.

**Traditional type of projects**

There is a measure one of traditional safe projects always available for financing. Bank chooses the amount of traditional projects to finance at date 1, and get return $(1 + r)$ at time 3.

**New type of projects**

With the new financial technology, there will be a measure $N$ of new projects available for financing. Each project needs one unit of initial investment.

Good project will mature after 2 periods, and produce an output $R$ after maturity. If a project is liquidated at date 1, it can only generate one unit of output. $R$ is unknown with prior $R \sim N(R_0, \sigma_0^{-1})$. We assume,

**Assumption 1** $E_0[R] > 1 + r$, where $r \geq 0$.

This assumption implies the new financial technology has been revealed to be good in general. Financing these new projects will generate a higher return than the traditional ones. However, there is still uncertainty about its real return.

2.1.1 Ownership of Projects

Because the new projects just emerge due to innovation, there is no clear ownership assignment to these projects. They looks like a common pool to the banks.

2.2 Investors

We adopt a standard Diamond-Dybvig setup for consumer preference and types. There is a measure one of consumers, indexed by $i$. Each consumer has one unit of endowment at
date 0 and can deposit it into a bank. Therefore the total fund available at date 0 is 1. All consumers have perfect storage technology to store the goods with no cost.

There are two types of consumers: type 1 are unlucky ones and care only about consumption in period 1; type 2 care about consumption in period 1 and 2. Consumers do not know their types at date 0. At date 1, their types are (privately) known to themselves. There will be a fraction $\lambda$ of consumers being type 1. Information regarding consumer’s type is revealed at time 1.

If a type 2 consumer withdraws the consumption goods at date 1, she can store them until date 2 and then consume. We use $c_1$ and $c_2$ to denote the goods withdrawn (therefore publicly observable) at $T = 1, 2$ respectively. Hence a type 2 agent will consume $c_1 + c_2$ units of goods at date 2.

Therefore each agent has a utility function which is dependent on the realization of state.

\[
U(c_{i,1}, c_{i,2}) = \begin{cases} 
  u_1(c_{i,1}) = \begin{cases} 
  c_{i,1} & \text{if } c_{i,1} \geq \eta \\
  -\infty & \text{if } c_{i,1} < \eta 
  \end{cases} & \text{if } i \text{ is type 1} \\
  u_2(c_{i,1} + c_{i,2}) = c_{i,1} + c_{i,2} & \text{if } i \text{ is type 2} 
\end{cases}
\]

where $\eta = 1 + \xi; \xi > 0$.

At date 0, the consumer’s expected utility is,

\[
\lambda \cdot u(c_{i,1}) + [1 - \lambda] \cdot u(c_{i,1} + c_{i,2})
\]

In this way, we will be able to derive the optimal demand contract as follows,

\[
\tau = \eta
\]

2.3 Banks

Banks invest for depositors, and give all investment returns back to depositors. Banks are risk-neutral. Banks choose to invest in either traditional safe project or new projects.

Banks can choose to finance new projects at two dates: either $t = 0$ or $t = 1$, or both dates. Banks can only invest in traditional safe projects at date $t=1$. After making decision on how many new projects to invest in at $t = 0$ and $t = 1$, banks will invest the rest of their fund in traditional projects at $t = 1$.

For the analysis of social optimum, we use a single representative bank.

For the analysis of decentralized learning and investment, we will model banks’ endogenous choice of entry into the market of new projects.
2.3.1 Market Structure of banks

Banks are competitive and return all profits to consumers.

2.4 Timing

Timing is described in Figure 1. Banks can choose to invest in new project either at \( t = 0 \) or \( t = 1 \). A project will mature after two periods, if there is no bank run in between.

![Figure 1: Timing](image)

2.5 Contracts

Investors’ type uncertainty renders type-contingent contract impossible to implement. Then we assume banks use demand-deposit contracts as in Diamond and Dybvig (1983). Investors can withdraw their deposits in the middle.

If an investor wants to withdraw their deposit in the middle at time \( t \), they will be paid \( \tau_u \). If investors start to withdraw their deposits at \( t \), banks need to liquidate their asset; each unit of investment at \( t - 1 \) can be liquidated and return one unit of output at \( t \).

Banks follow a sequential service rule: early withdrawer can get a output \( \tau_u \) if the number of withdrawer \( m_t \) is smaller than \( \frac{1}{\tau_u} \); otherwise, they can receive \( \tau_u \) with probability \( \frac{1}{m_t \tau_u} \), and 0 with probability \( 1 - \frac{1}{m_t \tau_u} \).
Later we will prove the optimal contract is $\tau_t = \eta$, which has the feature of risk-sharing.

### 2.6 Information Structure

#### 2.6.1 Banks’ information

At time $t$, failure rate $d_t$ ($t = 1, 2$) will realize for the projects that banks financed at time $t - 1$,

$$d_t = R + \epsilon_t$$

(2)

where $\epsilon_t$ is a stochastic process following a normal distribution $\epsilon_t \sim N(0, \frac{1}{g(\epsilon_{t-1})})$.

Effort level of last period will affect the precision of signal of next period. Higher effort $\epsilon_{t-1}$ spent on each project last period can help to reduce the variance of $\epsilon_t$ further.

**Assumption 2** $g(\cdot) > 0, g'(\cdot) > 0, g''(\cdot) < 0$.

**The Mechanism of Experimenting and Learning**

Banks perceive project failure rates $d_1$ and $d_2$, and update their belief $R$ at $t$ according to $d_t$ following the Bayesian rule.

#### 2.6.2 Investors’ information

At time $t$, investor $i$ receives a private signal of the aggregate project failure rates $d_{i,t} = d_t + \nu_{i,t}$, where $\nu_{i,t} \sim Unif(-\nu, \nu)$, a uniform distribution, and $d_t$ follows the aggregate stochastic process (2). The realization of $d_t$ implies the total return at $t + 1$, equal to $(1 - d_t) \cdot R$. A low realization of $d_t$ will induce investors to withdraw at $t$, and the probability of a bank run thus increases. Later we will prove there will be an endogenous threshold $D$ above which investors will run.

If the bank financed new projects at time $t$, investors will perceive a signal at $t + 1$ about the health of the financed projects. They can choose to withdraw their funds at $t + 1$ if the signal is too low.

We assume after $t = 2$ all projects are good projects, but investors can run and stop financing any new projects for ever at $t = 1, 2$ if they observe a high enough default rate.
3 Monopoly: Pre-assigned Ownership of New Projects

This is the benchmark case. We assume the ownership of new projects are all pre-assigned to every banks. Each bank can only invest in the preassigned new projects.

In this section, we model and analyze the optimal solution from the perspective of a monopolistic bank. It chooses how many new projects to invest at time $0$ and $1$ respectively. Early investment will function as an experiment to learn more precisely about the parameters of the financial innovation.

Optimally, during the learning stage, the bank should experiment some projects very carefully and patiently to learn the real $\gamma$. The learning result is useful for deciding the optimal effort of screening at time $1$.

3.1 Systemic Risk and the Probability of bank run

According to the previous setup, we know the realization of $d_t$ will act as a coordination device for investors to decide to withdraw or not at time $t$. This setup is similar to that in Goldstein and Pauzner (2005).

Because $\gamma|d_{t-1} \sim N(\gamma_0, \alpha_{t-1}^{-1})$, and $\epsilon_t \sim N(0, g(e_{t-1})^{-1})$, we have $d_t = \gamma + \epsilon_t$:

$$d_t \sim N(\gamma_0, \alpha_{t-1}^{-1} + g(e_0)^{-1}) \quad (3)$$

At date 1 and 2, investors perceive private signals $d_{i,t}$, and decide whether to run or not. In fact, the aggregate signal $d_t$, will determine whether a bank run will occur.

According to Goldstein and Pauzner (2005), we have the following theorem,

Proposition 1 There exists a unique threshold equilibrium in which patient investors decide to run if they receive a signal $d_{i,t} \geq D$, and not to run if $d_{i,t} < D$. Each investor will withdraw deposit if her private signal $d_{i,1} < D_1$ where $D_1(n_0)$ is solution to $\left[\frac{\alpha_0^{-1} + g(n_0)^{-1}}{\alpha_0^{-1} + g(n_0)^{-1}}\right]^{-1} + \beta.D_1 = \beta\left[\frac{\alpha_0^{-1} + g(n_0)^{-1}}{\alpha_0^{-1} + g(n_0)^{-1}}\right]^{-1} + \beta.$

Proof. Details are provided in the Appendix. ■

Then we can define systemic risk as follows,

Definition 1 Systemic risk $P_t(\cdot)$ is defined as the probability of a bank run occurring at time $t$.

$$P_t(\cdot) = \Pr(d_t \geq D) \quad (4)$$
Therefore, plus (3), we can calculate Systemic Risk at $t$ as follows,

$$P_t(\cdot) = 1 - \Phi\left(\frac{\gamma_0 - D}{\sqrt{\alpha_{t-1}^{-1} + g(e_0)^{-1}}}\right)$$

We have $P'(e_0) < 0, P''(e_0) > 0$.

We can calculate the systemic risk at date 1, as shown in (6),

$$P(e_0) = 1 - \Phi\left(\frac{\gamma_0 - D}{\sqrt{\alpha_0^{-1} + g(e_0)^{-1}}}\right)$$

3.2 Bayesian updating

At $t = 1$, the bank receives signal $d_1$, about the default rate of the projects financed at $t = 0$. The bank will update their belief about $\gamma$ according to the Bayesian rule. We want to calculate $\gamma|d_1 \sim N(\gamma_1, \alpha_1^{-1})$. According to the Bayesian rule, we will have,

$$\alpha_1 = \alpha + g(e_0)$$

$$\gamma_1 = \gamma_0$$

We want to calculate the systemic risk at $t = 2 : P(e_0, e_1) = Pr(\gamma + \epsilon_2 \geq D)$.

Because $\gamma_0 = \gamma_1$, and $\epsilon_2 \sim N(0, g(e_1)^{-1})$, we will have $\gamma + \epsilon_2 \sim N(\gamma_0, [\alpha + g(e_0)]^{-1} + g(e_1)^{-1})$.

Then we can derive the systemic risk at $t = 2$ as in (9),

$$P(e_0, e_1) = 1 - \Phi\left(\frac{\gamma_0 - D}{[\alpha_0 + g(e_0)]^{-1} + g(e_1)^{-1}}\right)$$

In addition, we impose the following assumptions:

**Assumption 3** (i). Monotonicity: $P_1(e_0, e_1) < 0, P_2(e_0, e_1) < 0$; (ii). Convexity: $P_{11}(e_0, e_1) > 0$; (iii). Substitutability: $P_{12}(e_0, e_1) < 0$.

3.3 Bank Run at $t = 2$

Similarly, we can prove there is a unique threshold equilibrium at $t=2$

**Corollary 2** There is a unique threshold equilibrium. Each investor will withdraw deposit if her private signal $d_{i,2} < D_2$. 
Corollary 3  The higher the precision of the fundamental, the lower the probability of bank run.

Proposition 2  Due to learning, we have $D_2 < D_1$. The threshold of bank run is lower in the later period(s).

Proof. This is because new information can reduce the variance of $R$. ■

3.4 One Representative Bank

In this section, we assume there is only one bank, who owns all new projects. The bank needs to make decisions according to its prior $\gamma \sim N(\gamma_0, \alpha^{-1})$, by choosing $\{e_0, n_0, \tau_0]\}$ and $\{e_1, n_1, \tau_1\}$, where $e_0, e_1$ are the efforts spent on screening each project at time 0 and 1 respectively; $n_0, n_1$ are the number of projects financed at time 0 and 1, and we have

$$n_0 + n_1 \leq N \quad (10)$$

$\tau_0, \tau_1$ are the payments to early bank withdrawals.

Two budget constraints need to be satisfied,

$$e_0 \cdot n_0 \leq B_0 \quad (11)$$

$$e_1 \cdot n_1 \leq B_1 \quad (12)$$

where $B_0, B_1$ are the budget constraints at time 0 and 1.

To help make optimal investment decision on the overall projects, a bank will firstly experiment on a small number of them and acquire better information about the real $\gamma$, the fraction of good ones in the pool.

Screening efforts will be crucial for learning precision. Conditional on the prior belief on $\gamma \sim N(\gamma_0, \alpha^{-1})$, the bank will screen $n_0$ projects at $t = 0$.

The bank’s overall optimization problem is formulated as (13),

$$\max_{\{e_0, n_0, \tau_0\}} E_0 \left\{ n_0 \cdot \left[ (1 - P(e_0)) (1 - \lambda \tau_0) [(1 - \gamma) R - 1] - e_0 \right] + \max_{\{e_1, n_1, \tau_1\}} n_1 \cdot E_1 \left[ (1 - P(e_0, e_1)) (1 - \lambda \tau_1) [(1 - \gamma) R - 1] - e_1 \right] \right\} \quad (13)$$

$$s.t. (11), (12), (10)$$
3.5 Solving by Backward Induction

We use backward induction to solve planner’s optimization problem. There are two stages. The planner firstly solve the problem for time \( t = 1 \), and then solve the overall problem at \( t = 0 \).

3.5.1 Step 1: Solve the optimization problem at \( t = 1 \)

The choice variables are \( \{e_1, n_1, \tau_1\} \), where \( e_1 \) is the effort as well as cost spent on screening each project. It subjects to the budget constraint (12).

Bank’s optimization problem at time \( t = 1 \) is specified and simplified to (14),

\[
\max_{\{e_1, n_1, \tau_1\}} n_1 \cdot E_1 \left\{ \frac{[1 - P(e_0, e_1)] (1 - \lambda \tau_1) [(1 - \gamma) R - 1 - e_1]}{(1 - \lambda \tau_1)} \right\}
\]

s.t. (12)

Firstly, we want to solve for the optimal contract so as to simplify the problem. We can easily see the optimal contract in fact is \( \tau_1 = \eta \).

Proposition 3 Optimal contract: payment \( \tau_t = \eta \).

Proof. We can easily see from the optimization problem (14), the only item involving \( \tau \) is \( (1 - \lambda \tau) \), which is decreasing in \( \tau \). Lower \( \tau \) can increase efficiency. On the other hand, according to the preference structure (1), \( c_t = \tau_t = \eta - c \) is the smallest consumption for impatient investors that can avoid extreme negative utility for them.

This optimal payment will satisfy the risk sharing demand of impatient investors with the least total social welfare reduction. This contract is optimal to investors ex ante. This optimal contract applies to both periods \( \tau_0 = \tau_1 = \eta \).

Then the optimization problem is now simplified to (15),

\[
\max_{\{e_1, n_1\}} n_1 \cdot E_1 \left\{ [1 - P(e_0, e_1)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1 \right\}
\]

s.t. (12)

The solution for this problem is derived in Appendix 1. The solution \( \{e_0^*, n_0^*\} \) is characterized by (17) and (18),

\[
P_2(e_0, e_1^*) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]}
\]
\[
\begin{align*}
    n_1^* = \begin{cases} 
    0 & \text{if } [1 - P(e_0, e_1^*)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^* < 0 \\
    N - n_0 & \text{if } [1 - P(e_0, e_1^*)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^* \geq 0 
    \end{cases}
\end{align*}
\] (18)

### 3.5.2 Step 2: Solve the optimization problem at \( t = 0 \)

Similarly we know \( \tau_0 = \eta \).

Given the solution \( \{e_1^*, n_1^*, \tau_1^*\} \) at time \( t = 1 \), bank’s optimization problem at \( t = 0 \) is,

\[
\max_{\{e_0, n_0\}} E_0 \left\{ n_0 \cdot \{[1 - P(e_0)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_0\} 
+ n_1^* \cdot E_1 \{[1 - P(e_0, e_1^*)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^*\} \right\}
\] (19)

s.t. (11), (10)

The solution to optimization problem (19) is derived in Appendix 2.

The full solution without budget constraint binding is characterized by (20), (21), (22), (23):

\[
\begin{align*}
    n_0^* \cdot \{P_1(e_0^*) (1 - \gamma_0) R + 1\} + (N - n_0^*) \cdot P_1(e_0^*, e_1^*) (1 - \gamma_0) R &= 0 \\
    [1 - P(e_0^*)] (1 - \gamma_0) R - (1 + e_0^*) &= [1 - P(e_0^*, e_1^*)] \cdot (1 - \gamma_0) R - (1 + e_1^*)
\end{align*}
\] (20), (21)

\[
P_2(e_0^*, e_1^*) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]}
\] (22)

\[
n_1^* = N - n_0^*
\] (23)

We can see from (22) that \( e_0^* \) are substitute.

**An Intuitive Solution**

An intuitive solution is when \( n_0^* = 1 \):

\[
\begin{align*}
    n_0^* = 1; n_1^* = N - 1 \\
    P_2(e_0^*, e_1^*) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]}
\end{align*}
\]

\[
P_1(e_0^*) \cdot (1 - \lambda \eta) [(1 - \gamma_0) R - 1] + 1 + (N - 1)P_1(e_0^*, e_1^*) (1 - \lambda \eta) [(1 - \gamma) R - 1] = 0
\]

The reasoning for this solution

- \( t = 0 \): Under our setup, investing in accurate learning (\( e_0 \uparrow \)), and less projects (\( n_0 \downarrow \))
is optimal

- under high uncertainty, less projects \((n_0 = 1)\) is optimal

- Public good feature of learning at \(t = 0\)
  - learning at \(t = 0\) can be applied to all the rest of projects left for \(t = 1\)

### 3.6 Budget constraint matters

When budget constraints are binding, there are *Special Solution*:

\[
\begin{align*}
  n_0^* &= 1; \quad n_1^* = N - 1 \\
  e_0^* &= B; \quad e_1^* = \frac{B}{N - 1}
\end{align*}
\]

**Proposition 4** More stringent budget constraint at \(t = 0, 1\) can increase systemic risk at both \(P(e_0)\) and \(P(e_0, e_1)\).

**Proof.** From the definition of systemic risk, we know \(P_1(e_0) < 0; \quad P_1(e_0, e_1) < 0, \quad P_2(e_0, e_1) < 0\). \(e_0^* = B; \quad e_1^* = \frac{B}{N - 1}\), then more stringent budget constraint will increase systemic risk.

This is an additional channel that can potentially result in higher systemic risk. The budget constraint that banks face can worsen the quality of screening and subsequently the quality of the financed new projects.

Budget constraints matter in the sense that the incentive to occupy a larger market share reduces the effort spent on each project, which renders learning ineffective. This research emphasizes learning effect under uncertainty of new technology. Naturally, if we assume away uncertainty, the tradeoff between market share and screening effort when budget constraint binds can also increase the project failure rates.

### 3.7 Simulation for a Simple Example

In this example, we set effort level \(e\) as constant and only use \(n_0\) as a choice variable. As shown in Figure 2, the y-axis represents welfare and the x-axis denotes \(n_0\). The upper curve illustrates the total welfare of the two wave of investments. The upslope line shows
the welfare of first wave of financing as a function of $n_0$, while the middle curve shows the welfare from the second wave of investment.

We can see from the figure that the optimal $n_0 = 28$.

![Optimal choice of $n_0$ and welfare](image)

Figure 2. The Benchmark

4 Ownership and Market Structure for New Projects

IPR (Intellectual Property Rights) i.e. patent, assign exclusive property rights to the inventor of new technologies. Traditionally, patent is argued to provide incentives for innovators to invest on $R$&$D$, although it also imposes a social cost due to its deterence of technology adoption. In this research, we argue that the exclusive ownership of new technology can encourage additional learning of the new technology and reduce potential hazards to the society under uncertainty. Imperfect IPR protection can aggravate the coordination failure of financing these new projects.

4.1 Nonpatentability

Property rights for new projects are oftentimes imperfectly defined. According to the Patent Law, "abstract idea" and "obvious idea" are not patentable. For example, the business method of Uber is largely not patentable: "This application is really seeking to claim the basic idea of pricing and service, which is a concept Adam Smith discussed 200 years ago." It is very difficult for Uber to discourage other competitors to copy its business model.
In general, financial innovations are also not eligible for IPR (Intellectual Property Rights). In a recent case, Alice Corp. v. CLS Bank (2014), the U.S. Supreme Court made a final decision that "a computer-implemented, electronic escrow service for facilitating financial transactions covered abstract ideas ineligible for patent protection. The patents were held to be invalid because the claims were drawn to an abstract idea, and implementing those claims on a computer was not enough to transform that idea into patentable subject matter."

4.2 Complementarity and Coordination Game

With imperfect IPR protection, banks can finance new projects too quickly even when there are still a lot of uncertainties left. Knowing there are limited supply of the new projects, banks would preempt other competitors to finance them. This creates a strategic complementarity between banks for entering the new market, which is very comparable to the complementarity between depositors during a bank run.

Therefore, the emergence of new projects induces a coordination game between banks: higher action by a bank increases the incentive for other banks to choose a higher action. This means "overentry" of banks and can lead to a kind of the "Tragedy of the Commons".
5 Inefficiency: Allowing Free Entry at $t = 1$

As discussed in the last section, without properly assigned ownership, complementarity can lead to overentry and inefficiency. In this section we start from a simple market structure and game with a leader and a follower. Assume there are two types of banks. Type 1 banks are called innovator banks and can exclusively finance new projects at $t = 0$; however, innovator banks will lose their monopolistic power at $t = 1$. Type 2 banks, abbr. copycat banks can enter and finance new projects only at $t = 1$. Due to symmetry, each type of banks will be treated as one representative bank of that type.

We assume at $t = 1$ the copycat bank can perfectly share the knowledge from the innovator about the new projects’ return $R$. We use superscript $i$ to denote the innovator, and $c$ to denote the copycat. Additionally, we assume away bank run contagion between banks.

5.1 The copycat bank

The copycat’s problem at time $t = 1$,

$$\max_{n_1^c \cdot E_1} \left\{ \begin{array}{c} [1 - P(e_0^i, e_1^c)] (1 - \lambda \eta) [(1 - \gamma) R - 1] \\ -e_1^c \end{array} \right\}$$  \hspace{1cm} (24)

where the new systemic risk is,

$$P(e_0^i, e_1^c) = 1 - \Phi \left( \frac{\gamma_0 - D}{\alpha_0 + g(e_0^i)^{-1} + g(e_1^c)^{-1}} \right)$$  \hspace{1cm} (25)

This problem is similar to the innovator’s at $t = 1$.

The solution is prescribed by (26),

$$P_2(e_0^i, e_1^{c*}) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]}$$  \hspace{1cm} (26)

Notice (26) indicates the public good feature of innovator’s learning in the last period, and there is no bank run contagion between the innovator and copycat.

5.2 The Innovator bank

The Innovator’s problem at time $t = 0$ is similar to the copycat’s, i.e. (24) and (26).
The Innovator’s optimization problem at time $t = 0$:

$$
\max_{\{e_0,n_0\}} E_0 \left\{ \begin{array}{cc}
n_0 \cdot \left\{ [1 - P(e_0)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_0^i \right\} \\
+ \max_{\{e_1^i,n_1^i\}} (N - n_0 - n_1^i) \cdot E_1 \left\{ [1 - P(e_0^i,e_1^i)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^i \right\}
\end{array} \right\}
$$

(27)

subject to:

$$
e_0 \cdot n_0 \leq B; e_1 \cdot n_1 \leq B; n_0, n_1 \leq N
$$

$$
P(e_0^i) = 1 - \Phi \left( \frac{\gamma_0 - D}{\sqrt{\alpha_0^{-1} + g(e_0^i)^{-1}}} \right)
$$

5.3 The Equilibrium and Inefficiency

We assume at $t = 1$ the two banks will enter symmetrically and thus split the market evenly, that is,

$$
n_1^c = n_1^i = \frac{N - n_0}{2}
$$

Moreover, the innovator has expected this to happen at time $t = 0$.

We can further prove the following proposition,

**Proposition 5** Allowing imitator(s) to enter at $t = 1$ will,

(i) discourage the innovator’s effort $e_0$ at $t = 0$;
(ii) encourage the innovator’s market expansion $n_0$ at $t = 0$;
(iii) increase systemic risk at $t = 0$.

Intuitively, by allowing imitation and entry at $t = 1$, innovator bank will be left a smaller market share at $t = 1$, relative to the social optimal senario. Inefficiency will emerge due to the following reasons:

1. The innovator cannot fully internalize the benefit of its own learning by investing to the efficient level in experimenting at $t = 0$.
2. The innovator makes a tradeoff between market share grabbing and precision of learning.
3. The innovator will try to grab a higher market share as early as $t = 0$ rather than learning more patiently.
Allowing entry at \( t = 1 \) will increase systemic risk at both periods.

At \( t = 0 \): innovator will choose \( e_0 \) lower than the social optimal, because,

1. she needs to conserve the cost on screening each project due to the need of financing a massive number of projects from \( t = 0 \)

2. the bank will finance less projects at time \( t = 1 \), it also has incentive to reduce learning at \( t = 0 \).

Therefore the systemic risk \( P(e_0) = 1 - \Phi \left( \frac{\gamma_0 - D}{\sqrt{\alpha_0^{-1} + g(e_0)^{-1}}} \right) \) will increase with a reduced effort level \( e_0 \).

At \( t = 1 \), \( P(e_0, e_1) = 1 - \Phi \left( \frac{\gamma_0 - D}{[\alpha_0 + g(e_0)]^{-1} + g(e_1)^{-1}} \right) \). With entry at \( t=1 \), \( e_0 \) has been cut down. To compensate the effect of a reduced \( e_0 \), \( e_1 \) must be increased. However, \( e_1 \) will not be increased to the level that reduces the systemic risk \( P(e_0, e_1) \) lower to that in the social optimum.

Under the social optimum, a higher \( e_0 \) is spent on very small number \( (n_0) \) of experimental projects at \( t = 0 \). The knowledge derived from the experiment will work as public knowledge for time \( t = 1 \). This public knowledge can save a lot of future resources: because cost \( e_1 \) applies to every project invested at \( t = 1 \) (and the total cost will be \( n_1 \times e_1 \)). Due to entry threat, the innovator tends to invest on a larger number of projects and grab a larger share at an earlier time. Therefore, the knowledge learned through experimenting at \( t = 0 \) can only be applied to a smaller pool of remaining projects left for \( t = 1 \). The smaller pool of projects left for this bank at \( t = 1 \) will also reduce its incentive to learn at \( t = 0 \). This is an important source of efficiency loss.

5.4 Simulation: the Benchmark (Monopoly) and the Duopoly

In this subsection, we want to simulate a scenario with imperfect property rights for new projects and make an efficiency comparison with the benchmark case (as in Figure 2). As shown by Figure 3, Bank 1 is the innovator, and Bank 2 is the imitator. The top curve represents the total social welfare in Duopoly as well as the welfare of bank 1 in the former Benchmark case.
The innovator, bank 1 will choose $n_0 = 28$ under monopoly as in the benchmark case, and choose $n_0 = 85$ under duopoly. Total social welfare is reduced under duopoly because bank 1 tends to invest on more new projects, knowing bank 2 will seize some market share at $t = 1$.

5.5 Imperfect IPR and Financial Fragility

Allowing copycat banks to finance new projects at a later stage will make the innovator less patient in learning at the beginning. Preemptive intention dilutes the innovator’s motivation for learning and waiting.

Moreover, the inefficiency comes from a higher probability of bank run at $t = 1$ relative to $t = 2$. The innovator bank will invest on a larger number of new projects ($n_0$) at $t = 0$ than the social optimal level (see Figure 3). This will amplify the coordination problem of depositors. Because the probability of bank run is higher at an early stage, the innovator’s overinvestment at $t = 0$ will reduce social welfare.

Therefore, imperfect IPR will eventually increase financial fragility through the above-mentioned mechanism.
6 Coordination Game: Allowing Free Entry at $t = 0$

Now we will discuss a more general case when banks are allowed to enter the new financial market as early as $t = 0$. We assume two symmetric banks can endogenously choose when to enter the new market (i.e. $t = 0$ or $1$) and decide on the number of projects to invest and corresponding screen efforts for each project.

There will be mixed incentives in this general setup. Two major incentives deviating from the social optimal:

1. Earlier massive entry: Bank wants to catch a larger market share, and might invest inefficiently on a larger number $n_0$ of new projects.

2. Delayed entry and reduced experimenting efforts: Due to knowledge sharing regarding the financial innovation, it can lead to under-investment (lower $e_0$) and free-ride behavior (postponed entry from $t = 0$ to $t = 1$).

6.1 The Game and Strategies

In the following game, strategy $(a)$ for column player (bank 2) denotes at time $t = 0$, bank 2 chooses project number $n_0^2 = a$. We assume the two banks always split market share at time $t = 1$, so the project numbers for the two banks at $t = 1$ are $n_1^1 = n_2^1 = \frac{N - n_0^1 - n_0^2}{2}$.

We list 3 strategies for each bank:

1. $(0)$: no investment and experiment at $t=0$. This is due to free-rider motivation.

2. $(1)$: optimal experimenting at $t=0$.

3. $(\hat{n}_0)$: massive investments at $t=0$. This is illustrated in Section 4: the response of innovator at $t=0$ to the entry of another bank at $t=1$.

The payoffs are illustrated in Table 1. The payoffs are generally determined by the market share at $t = 0$ and $1$, and the cost of experimenting with new projects. Here we use $M - \varepsilon$ to denote the total Social optimal payoff, where $\varepsilon$ is the cost of experimenting. So a benchmark case is a strategy pair $[(1), (1)]$: both banks behaves as a social planner; because the two banks duplicatively invest in experiment project at $t=0$, each of them will face a cost $\varepsilon$, and the individual payoff is $\frac{M}{2} - \varepsilon$.

According to the analysis in Section 4, we know bank 1 will get a higher payoff $\frac{M-H}{2} + x$ than splitting the social optimal payoff with the other bank (payoff $\frac{M}{2} - \varepsilon$), by choosing a larger number of projects $(\hat{n}_0)$ at $t = 0$. There will be a social welfare loss $H = \left(\frac{M-H}{2} + x\right) +$
\[(M - H - x) - M, \] due to the distorted incentive to enter the market earlier without patient experimenting. The following condition should be satisfied: \[\frac{M - H}{2} + x > \frac{M}{2} - \varepsilon,\] which is equivalent to condition (28),

\[x + \varepsilon > \frac{H}{2}\]  

which means that individual gain by entering earlier massively should be large enough.

In addition, when both banks choose to enter massively at \(t = 0\), each of them gets a worse payoff \(\frac{m}{2}\).

### Table 1. The Game of Entry

<table>
<thead>
<tr>
<th>Bank 1</th>
<th>(0)</th>
<th>(1)</th>
<th>((\hat{n}_0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0)</td>
<td>(\frac{m}{2}, \frac{m}{2})</td>
<td>(\frac{M - H}{2} - \varepsilon), (\frac{M}{2})</td>
<td>(\frac{M - H}{2} - x, \frac{M - H}{2} + x)</td>
</tr>
<tr>
<td>(1)</td>
<td>(\frac{M - \varepsilon}{2}, \frac{M}{2})</td>
<td>(\frac{M - \varepsilon}{2}, \frac{M}{2} - \varepsilon)</td>
<td>(\frac{M - \varepsilon}{2} - x, \frac{M - H}{2} + x)</td>
</tr>
<tr>
<td>(\hat{n}_0)</td>
<td>(\frac{M - H}{2} + x, \frac{M - H}{2} - x)</td>
<td>(\frac{M - H}{2} + x, \frac{M - H}{2} - x - \varepsilon)</td>
<td>(\frac{m}{2}, \frac{m}{2})**</td>
</tr>
</tbody>
</table>

#### 6.2 The Equilibria

According to the above setup, the game can deliver two types of equilibria,

- If \(\frac{m}{2} > \frac{M - H}{2} - x\) : Symmetric equilibrium:
  \([\hat{n}_0], (0)]\). Both banks enter massively at \(t = 0\)

- If \(\frac{m}{2} < \frac{M - H}{2} - x\) : Asymmetric equilibria
  \([\hat{n}_0], (0)]\), \([0], \hat{n}_0\)] and a half-half mixed strategy between them. One bank enters massively at \(t = 0\), and the other bank just wait to free-ride at \(t = 1\).

In terms of social welfare, the asymmetric equilibria \([\hat{n}_0], (0)]\) or \([0], \hat{n}_0\)] is indeed better than the symmetric equilibrium \([\hat{n}_0], \hat{n}_0\)]. Because in the asymmetric equilibria, at least \(n_0\) projects are postponed to be able to benefit from the knowledge learned from the last period. Neither type of equilibria is efficient.

The socially optimal equilibria are \([1], (0)\], \([0], (1)\] or an equilibrium close to the social optimum \([1], (1)\].

The strong incentive to grab a larger share of the new market will distort experimenting and learning decisions. In the two possible types of equilibria, at least one bank will enter massively at \(t = 0\) and reduces its learning efforts.

An interesting type of equilibria are the asymmetric ones \([\hat{n}_0], (0)]\) and \([0], \hat{n}_0\)] . They give higher total social welfare than the symmetric one symmetric equilibrium \([\hat{n}_0], \hat{n}_0\)].

\[\text{24}\]
This is because the free—riding Incentives which postpones one bank’s entry in fact mitigates the negative effect of entering earlier to catch higher market share. In this sense, free—riding can increase efficiency by encouraging waiting.

### 6.3 Complementarity and Coordination Game

The parameters will determine whether there are aggregate complementarity or substitution.

Under condition \( \bar{m} < M - H \), the game in fact becomes a Coordination game with symmetric equilibrium strategies \( [\hat{n}_0, (\hat{n}_0)] \). This is because the preemptive motive dominates the free—riding plus learning motive.

### 7 Many Banks with Free Entry at \( t = 0 \)

Now we assume there are a measure of banks and the market for innovation financing are competitive.

We assume banks have heterogenous information \( d_{j,t} = \gamma + \epsilon_{j,t} \).

The number of new projects are limited as before.

Similar to a bank run model under a global game setup. We can prove the following result,

**Proposition 6** (Run — in Threshold Equilibrium) There exists a unique threshold equilibrium in which banks decide to invest in new projects if they receive a signal \( d_{j,t} \geq \bar{D} \), and not to invest if \( d_{i,t} < \bar{D} \).

We can generalize to \( M \) symmetric banks and prove the following,

**Proposition 7** \( \hat{n}_0(M) \), the total number of new projects invested at \( t=0 \), is an increasing function of \( M \).

We will conduct further analysis under various conditions, e.g. different learning curves, and imperfect learning spillover between banks.

---

1Note: \( \bar{m} = \frac{\bar{m}}{2} + \frac{\bar{m}}{2} < M - H = \left( \frac{M-H}{2} + x \right) + \left( \frac{M-H}{2} - x \right) \).
8 Variants and Necessary conditions for Inefficiency

An important aim of this research is to investigate the possible channels through which financial innovations can result in bank run. We try to explore several setups to derive the necessary conditions. Here we assume the measure of available funds is 1. In this section we will discuss the necessary conditions for financial innovation to induce a bank run with increased inefficiency.

8.1 Case 1: $N \geq 1, \gamma = \gamma_0$

In this case the measure of new projects $N$ are greater than the available funds (measure 1). We assume the parameters of this new financial technology are perfectly known. The new technology is essentially a nonexclusive public good. There is no learning needed because all parameters are known.

Do banks have incentive to reduce effort level on each project?
They have if there is externality, i.e. contagion on other banks. If investors run on systemic default rates, individual bank has incentive to reduce effort level.

Do banks have incentive to finance the new projects earlier?
No. There is no uncertainty and the new projects are oversupplied. The investors will be indifferent to financing it earlier or later.

Budget constraint matters?
No. Because new projects are oversupplied, banks do not need to finance projects too early and do not need to make a tradeoff between quality and quantity.

8.2 Case II: $N \geq 1, \gamma \sim N(\gamma_0, \alpha^{-1})$

We still assume the new projects are available unlimitedly. However, the technological parameters are unknown and need to be learned by experimenting. This setup is very close to the situation specified in Pastor and Veronesi (2009). The new technology is still a nonexclusive public good.

Do banks have incentive to reduce effort level on each project?
This is similar to Case I.

Do banks have incentive to finance the new projects earlier?
No. They will learn patiently and optimally about the project and finance in large scale later, as in Pastor and Veronesi (2009). The new projects are oversupplied relative to the available funds, so investors have no need to compete for the new projects.

Budget constraint matters?
No. Analysis is similar to Case I.

8.3 Case III: $N < 1, \gamma = \gamma_0$

In this case, we assume the number of new projects are scarce relative to available funds. New type of projects are now exclusive. However, parameters are perfectly known. We want to see whether the exclusiveness of new technology can be a root of over-competition and inefficiency.

Do banks have incentive to reduce effort level on each project? They have if there is externality on other banks. If investors run on systemic default rates, then individual bank has incentive to reduce effort level inferior to social optimal.

Do banks have incentive to finance the new projects earlier, and inefficiency? Yes. They want to compete for limited supply of new projects and enter early

Budget constraint matters? Budget constraint is essential to generate inefficiency. There is no learning because of certainty of technology. There is no inefficiency generated for the next period. If a bank has stringent budget constraint, it will make a tradeoff between screening efforts and market share.

8.4 Case IV: $N < 1, \gamma \sim N(\gamma_0, \alpha^{-1})$

Now we assume not only limited number of projects, but also imperfect knowledge of parameters. In contrast to Case II (as in Pastor and Veronesi (2009)), we barely require that new projects are limitedly supplied relative to available funds. This is the case that we have been examining throughout this research.

Do banks have incentive to finance the new projects earlier? Yes. They need to compete for limited number of new projects and prefer to enter early massively; otherwise, other banks will grab it.

Do banks have incentive to reduce effort level on each project? They will reduce effort level in the early stage because they need to invest in many projects early and because their knowledge from learning will be public good for other banks.

Budget constraint matters? Budget constraint matters but it is not a necessary condition to generate inefficiency as in Case III.

Claim 4 Parameters uncertainty together with the competition for limited supply of new projects is necessary to generate inefficiency.
9 Applications and Empirical Evidence

9.1 The History of Financial Crisis

Kindleberger (1978) cites Minsky’s argument that any speculative bubble and crisis starts with a "displacement" or innovation, some exogenous macroeconomic shock. This will grow to be a speculative bubble, overinvestment, and eventual crash.

The model of this paper is consistent with the empirical description of Kindleberger and Minsky.

9.2 2008 Subprime Crisis

Subprime lending as a financial innovation, which is not patentable. The Subprime projects were largely funded by short-term debts. Bank run happened eventually after some delinquencies.

10 Conclusions

We have illustrated a channel through which innovation financing and preemptive incentives can increase the probability of bank run. Innovation creates better financing opportunities and potential productivity gains as well as uncertainties. The innovation uncertainty can aggravate the collective-action problems for financing these new projects. Patient experimentation and learning are necessary to reach social optimum. However, this can be distorted by individual bank’ incentive to grab a larger share of the new market. This distortion will further amplify the innovation uncertainty through the collective-action problem of financing.

The social optimum demands early experimentation on a small number of new projects but with great efforts invested in each project. The knowledge from experiment has public good feature and can improve efficiency of later investments. Facing a limited supply of new projects, banks prefer to enter the market prematurely. This preemptive motive will increase the probability of bank run, imposing a negative externality on the society.

We analyze the baseline case that an early entrant faces the entry of the other bank at a later stage. Then we discuss a more general setup which allows banks to endogenously choose when to enter the market. An important conclusion is that suboptimal equilibria are always selected due to the preemptive motive. Interestingly, the incentive for free-riding the knowledge learned by others can mitigate some negative effect of over-entry. Under some
conditions, waiting for more public knowledge released from early entrants can be a better
decision than entering the market blindly.

Our findings imply that granting some monopolistic ownership can help to correct in-
efficiencies in decentralized learning. Financial innovations usually are not protected by
patent laws. The traditional literature of innovation and patent assumes the pure public
good characteristics of innovation. This research calls attention to the other side of inno-
vation: uncertainty and potential social hazard. Premature diffusion of an innovation can
bring about significant and unexpected "public bad". Appropriate mechanism needs to be
designed to motivate banks to internalize this negative externality.
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Appendix

11 Derivation for Backward Induction stage 2

we can derive the foc: $P_2(e_0, e_1) (1 - \lambda \eta) [(1 - \gamma) R - 1] = -1$

$$P_2(e_0, e_1^*) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma) R - 1]} \quad (29)$$

$$n_1^* = \begin{cases} 
0 & \text{if } [1 - P(e_0, e_1^*)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^* < 0 \\
N - n_0 & \text{if } [1 - P(e_0, e_1^*)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^* \geq 0 
\end{cases} \quad (30)$$

12 Derivation for Backward Induction stage 1

Bank’s optimization problem at time $t = 0$:

$$\max_{\{e_0, n_0\}} E_0 \left\{ n_0 \cdot \{ [1 - P(e_0)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_0 \} + \max_{\{e_1, n_1\}} E_1 \{ [1 - P(e_0, e_1)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1 \} \right\} \quad (31)$$

s.t. \quad (11) \text{ and } (12)

Given the solution $\{e_1^*, n_1^*\}$ at $t = 1$, Bank’s optimization problem at time $t = 0$:

foce:

$[e_0] \quad n_0^* \cdot \{ P_1(e_0^* ) (1 - \lambda \eta) [(1 - \gamma) R - 1] + 1 \} + (N - n_0^*) \cdot P_1(e_0^*, e_1^* ) (1 - \lambda \eta) [(1 - \gamma) R - 1] = 0$

$[n_0] \quad \{ [1 - P(e_0^* )] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_0^* \} = [1 - P(e_0^*, e_1^* )] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1^* \quad (33)$

The full solution without budget constraint binding is characterized by (32), (33), (34), (35):

$$n_0^* \cdot \{ P_1(e_0^* ) (1 - \gamma_0) R + 1 \} + (N - n_0^*) \cdot P_1(e_0^*, e_1^* ) (1 - \gamma_0) R = 0 \quad (32)$$

$$[1 - P(e_0^* )] (1 - \gamma_0) R - (1 + e_0^* ) = [1 - P(e_0^*, e_1^* )] \cdot (1 - \gamma_0) R - (1 + e_1^*) \quad (33)$$

$$P_2(e_0^*, e_1^* ) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]} \quad (34)$$

$$n_1^* = N - n_0^* \quad (35)$$
13 Derivation of General Corner Solution

Intuitive (corner) solution

should be

\[ n_0^* = 1; \quad n_1^* = N - 1 \]

\[ P_2(e_0^*, e_1^*) = \frac{-1}{(1 - \lambda \eta) [(1 - \gamma_0) R - 1]} \]

the new problem

\[
\max_{\{e_0, n_0\}} E_0 \left\{ \frac{[1 - P(e_0)] (1 - \lambda \eta) [(1 - \gamma \eta) R - 1] - e_0}{(N - 1) n_1 \cdot E_1 \left\{ [1 - P(e_0, e_1)] (1 - \lambda \eta) [(1 - \gamma) R - 1] - e_1 \right\}} \right. 
\]

\[ \text{ foc : } \left[ e_0 \right] \]

\[ P_1(e_0^*) \cdot (1 - \lambda \eta) [(1 - \gamma \eta) R - 1] + 1 + (N - 1) P_1(e_0^*, e_1^*) (1 - \lambda \eta) [(1 - \gamma) R - 1] = 0 \]