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Intellectual Property Protection: Prevention in Advance or Punishment Afterward*

Qi Duan

Institute for Advanced Studies in Humanities and Social Sciences, Beihang University, China

Yupeng Shi

School of Economics, Central University of Finance and Economics, China
E-mail: shiyupeng@cufe.edu.cn

and

Jingwei Sun

School of Economics, Central University of Finance and Economics, China

This paper compares two types of Intellectual Property Protection policies, prevention in advance versus punishment afterward, based on a multi-stage duopoly model. We find (i) for advance prevention measures, it is optimal to make only one firm innovate and the other succeed in imitating; (ii) for punishment afterward measures, the optimal policy is to prevent imitation exhaustively; and (iii) prevention in advance is superior to punishment afterward if the latter cannot guarantee an equilibrium in which only one firm innovates; if both measures yield single-firm-innovation, the consequence depends on how imitation affects social welfare.

Key Words: Intellectual property protection; Prevention in advance; Punishment afterward.

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1. INTRODUCTION

Innovation, by providing firms with substantial advantages in competition and spurring the technological progress of the whole society, plays a pivotal role in modern economies. One of the key issues on protecting and motivating innovation is constructing an appropriate intellectual property protection (IPP) system composed of a series of policies and measures primarily to protect innovators' legal rights.

According to the specific patterns of enforcement, all IPP measures can be divided into two categories: prevention in advance and punishment afterward. Prevention in advance refers to measures that aim at reducing opportunities of intellectual property infringement, by spreading knowledge on IPP to the public conducting protection registration for possible-faking technology and products, and promulgating laws or formulate regulation rules for preventing commercial secrets from being illegally usurped, etc. In sum, the primary purpose of this type of measures is to reduce the possibility of infringement. Punishment afterward refers to the punishment on the infringement of the intellectual property rights which has already occurred, including imposing penalty on the individuals or firms who have implemented the violations. Although policies regarding punishment afterward have been commonly adopted all through the world, preventing infringement in advance is attracting greater attention and widely believed to be a more ideal way to protect intellectual properties. Policies or agreements to prevent infringement in advance are numerous, and here we only list a few of them. According to the 1994 GATT (WTO) Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS), "The judicial authorities shall have the authority to order a party to desist from an infringement, inter alia to prevent the entry into the channels of commerce in their jurisdiction of imported goods that involve the infringement of an intellectual property right, immediately after customs clearance of such goods..." (Article 44), "The judicial authorities shall have the authority to order prompt and effective provisional measures: (a) to prevent an infringement of any intellectual property right from occurring, and in particular to prevent the entry into the channels of commerce in their jurisdiction of goods, including imported goods immediately after customs clearance..." (Article 50). IPP in China, although was somehow delayed compared to the developed countries, has made great progress in the recent decades, and been developed following a similar pattern as the others do. In June 2008, the State Council of China issued The Outline of National Intellectual Property Strategy, served "to encourage and support the market entities to improve the management system of technical information and commercial secret, and to formulate intellectual property information retrieval system and the early-warning system of important issues, ..., to establish the early-warning and emergency-response mechanism of intellectual property, . . . , in order to control the damage, to present report about situations of intellectual property development in key fields, . . . , to deal with the potential intellectual property disputes and conflicts that cover a wide range and have great influence." In 2011, the Ministry of Commerce of China established the Assistance Center of Chinese Firms Intellectual Property Rights Overseas, to construct the beforehand protection system of oversea intellectual property and promote Chinese firms' innovation.

Numerous studies have been proposed on IPP during the past decades,[1] among which most employed perfectly competitive market structure by assuming that all firms in the market are price takers with the same production technology.[2] Such models suffer limitations in several aspects, such as being not appropriate in analyzing the dynamic process of the economy or the strategic interdependence between new technology's developer and imitator. In the 1980s, the limitations of the perfectly competitive models became spurs to motivate the rapid development of imperfectly competitive models. These models included dynamic general equilibrium models that took forward earnings and recent costs as the basic trade-off to consider the consequences of the IPP policies, and further analyzed the optimal patent length and patent breadth of patent protection.[3] In particular, some monopolistic competition general equilibrium models are used to discuss how the IPP policies in the southern countries affected the technological innovation of the northern countries (which has advanced technology) and welfare of both sides.[4]

Meanwhile, there is a substantial amount of studies on firms' R&D strategies and IPP policies using oligopoly models. Such models typically analyze firms' optimal R&D strategies under the conditions of rivalrous competition (see Kamien and Schwartz (1972), Reinganum (1981), Messica and David (2000), Druehl, Schmidt and Souza (2009), Hur (2010) for instance), oligopoly firms' R&D competition vs. joint venture (see Kamien, Muller and Zang (1992), D' Aspremont and Jacquemin (1988, 1990), Amir and Wooders (1998), Cellini and Lambertini (2003) for instance), R&D compe-

[1]The economic analysis on Intellectual Property Protection issues can at least be traced back to Arrow (1962). Arrow (1962) analyzed the information as a commodity in the meaning of innovation activities, and the influence that market structure may have on firms' innovation motivation.

[2]The representative studies include Nordhaus (1969, 1972), and Scherer (1972). Under these conditions, during the patent protection duration period, a firm which has successfully innovated would either become a monopolist and gain monopoly profits, or sell its patent and gain the economic rent as large as monopoly profits.

[3]See Judd (1985), Gilbert and Shapiro (1990), Mukoyama (2003), O'Donoghue and Zweimüller (2004), Acemoglu and Akcigit (2006), Okawa (2010) for instance.

[4]See Chin and Grossman (1988), Grossman and Helpman (1991), Helpman (1993), Lai (1998), Markusen (2001), Yang and Maskus (2003) for instance.

tition and industrial structure (see Fudenberg, Stiglitz and Tirole (1988), Kyung and Shogren (1992), Baye and Shin (1999), Colombo and Labrecciosa (2008) for instance). In the studies of these fields, attentions have been paid on not only the IPP polices but also those related to IPP, including industrial and antitrust policies (such as R&D taxes and subsidies) for supporting R&D investment and innovation, stimulating competition (see Jorde and Teece (1990) for instance), and cross border rent-shifting (see Brander and Spencer (1983), Wang and Blomström (1992), Salant and Shaffer (1999) for instance) and new technology seeking (see Deardorff (1992), Zigic (1998), Kim and Lapan (2008) for instance).

Besides the abundant literature on IPP policies, studies that rigorously discuss the prevention mechanism in IPP or the welfare contrast of the two types of IPP measures are rarely seen. In this paper, we distinguish two types of protection mechanisms, prevention in advance and punishment afterward, and discuss their different effects on firms' innovation strategies and social welfare. Specifically, we construct a Cournot duopoly model and discuss for a social welfare maximizing government:[5] (1) Within each type of measures, what is the optimal policy choice? (2) Within each type of measures, what are the firms' optimal R&D strategies? (3) What will be the welfare consequence of two types of policies, and which yields higher social welfare? The analysis shows that: (1) If the government adopts advance prevention measures to restrict technology imitation, the optimal policy (represented by the probability of successful imitation, p^*) must lead to an equilibrium in which only one firm invests in R&D, while the others obtain the new technology by imitating with the probability of success p^*; (2) If the government intends to punish technology imitation afterword, the optimal punishment (represented by the amount of fine, T^*) must be prohibitive, that is, it must be great enough that no imitation will occur. In this case, both firms invest in R&D (and obtain the new technology), or only one firm engages in R&D (and the other does not obtain the new technology); (3) In the circumstance that afterword punishment does not lead to equilibrium in which only one firm invest in R&D, prevention in advance is superior to punishment afterward. When both types of policies lead to the equilibrium in which only one firm invests in R&D, which type is more favorable depends on whether the non-innovation firm's technology imitation is beneficial or harmful to the social welfare: advance prevention

[5]We conduct our discussions in a duopoly model both for the issue we consider in the current paper and for the consistency with realities. First, in the current paper we discuss the effects of different types of IPP policy measures on firms' innovation incentives and R&D strategies, which will in turn affect the equilibrium outcomes and social welfare. Second, the market structures of the industries where IPP issues attract most attentions, for example cars, personal computer chips, mobile phones, electronic business, and civil aviation, etc, are close to oligopoly.

is superior to punishment afterward if imitation is beneficial, while advance prevention is inferior otherwise.

The following part of this paper is organized as follows. Section 2 introduces the theoretical framework in a multi-stage duopoly model. Section 3 solves the equilibrium without policy intervention. Analyses on the optimal actions taken by the government under the circumstances of prevention in advance and the punishment afterword are presented in Section 4 and 5, respectively. Section 6 concludes and provides policy implications.

2. THE MODEL

2.1. Preference and Demand

The utility function of the representative consumer can be expressed in a quasi-linear utility function as follows:

$$u(q_1, q_2, z) = q_1 + q_2 - \frac{1}{2}(q_1 + q_2)^2 + z \tag{1}$$

where q_1 and q_2 denote the quantity of product 1 and product 2, respectively, and z is the numeraire goods whose price is normalized to 1. Suppose that product z is supplied by a perfectly competitive sector with linear production technology: each unit of labour produces w units of z. In the labor market, the representative consumer inelastically provides one unit of labor and get the unit wage, which equals w. When take government tax and transfer payments into consideration, each consumer should also pay a lump-sum tax to the government (if the tax is negative, it could be considered as subsidy). Therefore, the total expenditure of the representative consumer should not exceed the wage income minus the tax paid (or plus the subsidy).

From equation (1) we can easily get the inversed demand function of product 1 and product 2:

$$p_1 = p_2 = 1 - q_1 - q_2$$

where p_1 and p_2 denote the price of product 1 and product 2, respectively.

2.2. R&D and Production

Two firms, firm 1 and firm 2, produce product 1 and product 2, respectively. If a firm does not invest in R&D before production, its unit costs is $c \in (0, 1)$.[6] Meanwhile, a firm could pay for a fixed innovation costs $F > 0$, to improve its production technology and reduce the unit costs of production to some lower level $c' \in (0, c)$.

[6] $c < 1$ ensures that under any condition, the supplies of product 1 and product 2 are above zero.

We denote the behavior of "invest in R&D" by r and "do not invest in R&D" by n. Hence, the R&D strategy combination of two firms can be expressed as a vector $\omega = (i, j)$, where $i, j \in \{r, n\}$, which means firm 1 chooses strategy i and firm 2 would chooses strategy j. Therefore, in the set of R&D strategy profile of the two firms, expressed by Ω, there are four elements: $\omega \in \Omega \equiv \{(r, r), (r, n), (n, r), (n, n)\}$. Due to the symmetry of two firms, of the two combinations $\omega = (r, n)$ and $\omega = (n, r)$, without loss of generality, we merely consider the former $\omega = (r, n)$.

For simplicity, we suppose that the fixed production costs product 1 and product 2 are zero.

2.3. Technical Imitation and Intellectual Property Protection

When a firm, for example firm 1, has not invested in R&D but its opponent (firm 2) does, firm 1 can imitate firm 2's successfully developed technology, to reduce the unit costs of production to c'.

For simplicity, we assume that the costs of imitation behavior are zero.[7]

2.4. Timing

Consider a three-stage game.

In the first stage, the government first chooses the type of its IPP policies, either prevention in advance or punishment afterward, and then decides the specific policy efforts, that is, the intensity of advance prevention or afterward punishment.

In the second stage, the two firms simultaneously decide whether to engage in R&D to reduce the marginal costs of production, and whether to imitate the opponent's technology if it does not innovate by itself but its opponent does.

In the third stage, two profits-maximizing firms compete in output quantities in the market.

For simplicity, we assume that the discount factor between stages equals to 1.

2.5. Social Welfare

Social welfare, W, is the sum of the utility of representative consumers, u, and firms' profits, π_1 and π_2:

$$W = u + \pi_1 + \pi_2 = q_1 + q_2 - \frac{1}{2}(q_1 + q_2)^2 + z + \pi_1 + \pi_2 \tag{2}$$

[7] The punishment of the government is not considered for now.

3. THE EQILIBRIUM WITHOUT POLICY INTERVENTION

In this section, we consider a basic model without policy intervention. Based on this model, we will discuss the case in which a firm's imitation behavior is beneficial to the social welfare as well as the case in which a firm's imitation behavior is harmful to the social welfare.

Proposition 1. *When there is no policy intervention:*

(1) If the possibility of technology imitation is zero, then at least one firm innovates in the equilibrium if the R&D cost satisfies the condition $F < \frac{4(1-c')(c-c')}{9}$*; neither firm innovates if the R&D cost satisfies the condition* $F \geq \frac{4(1-c')(c-c')}{9}$.

(2) If there exists technology imitation behavior, then only one firm innovates in the equilibrium if the R&D cost satisfies the condition $F < \frac{(2-c'-c)(c-c')}{9}$*; neither firm innovates if the R&D cost satisfies the condition* $F \geq \frac{(2-c'-c)(c-c')}{9}$.

Proof. See in Appendix. ▮

Without policy intervention and technology imitation, firms' R&D decision depends on the R&D cost (F), the reduction of unit costs after R&D, $c - c'$, and the market scale, $1 - c$. So given that the R&D cost is not excessively high compared with the benefits, specifically $F < \frac{4(1-c')(c-c')}{9}$ in our model, at least one firm will have the incentive to invest and innovate. However, when imitation behavior exists, given that its opponent does not innovate, the profits of the firm that innovates would be less than what it is able to obtain when imitation behavior does not exist, suggesting that more strict condition is required to make a firm innovate. It can be proved that

$$\frac{(2-c'-c)(c-c')}{9} < \frac{4(1-c')(c-c')}{9}$$

which means if there is only one firm innovates when technology imitation exists, then there must be at least one firm innovates when technology imitation does not exist.

According to Proposition 1, we would make some restrictions on the parameters before furthering our analyses.

Assumption 1. *Assume that the parameters satisfy the condition .*

In this paper, in order to analyze different types of IPP policies, we first clarify the condition in which the restriction of the technology imitation is beneficial for the social welfare. Assumption 1 guarantees that at least one firm innovates if we do not consider the technology imitation. This assumption is necessary for the analysis of technology imitation's effects and the comparison between different IPP policies. If innovation costs are so high that Assumption 1 does not hold, then no firm would innovate no matter whether technology imitation exists or not, needless to say technology imitation and any restriction measures on such behavior. Therefore, the following discussions in this paper are based on Assumption 1.

Furthermore, if Assumption 1 holds but F is still higher than the threshold value distinguishing between the case that only one firm innovates and the case that no firm innovates when technology imitation may exist, that is

$$\frac{(2-c-c')(c-c')}{9} < F < \frac{4(1-c')(c-c')}{9} \tag{3}$$

then at least one firm innovates when technology imitation is not allowed. However, if imitation is allowed, firm's incentive to innovate will be weakened and no firm innovates. As a result, in this case allowing technology imitation will reduce social welfare. It is summarized in Proposition 2.

Proposition 2. *Suppose that the parameters satisfy the condition (3), then:*

(1) If technology imitation is not allowed, then at least one firm innovates; if technology imitation is allowed, then no firm innovates.

(2) The social welfare in the situation where technology imitation is allowed is lower than in the situation where prohibits technology imitation is not allowed.

Proof. See in Appendix. ▮

When innovation costs F are lower than the threshold value distinguishing between the case that only one firm innovates and the case that no firm innovates when technology imitation may exist, that is $F < \frac{(2-c-c')(c-c')}{9}$, no matter whether technology imitation is allowed or not, there will be at least one firm to innovate. Further, if technology imitation is allowed, then there will be only one firm to innovate, while the other firm imitates the new technology directly; if technology imitation is not allowed, only one firm innovates or both firms innovate.[8] We make a comparison between these two cases and summarize the results in Lemma 1 and Lemma 2.

Lemma 1. *Suppose that the parameters satisfy the condition*

$$F < \min\left\{\frac{4(1-c)(c-c')}{9}, \frac{(2-c-c')(c-c')}{9}\right\}$$

[8] See Proposition 1.

then:

(1) If technology imitation is allowed, then only one firm innovates in equilibrium; if technology imitation is not allowed, then both firms innovate in equilibrium.

(2) The social welfare when technology imitation is not allowed is lower than that when technology imitation is allowed.

Proof. We directly obtain conclusion (1) above by **Proposition 1** and **Proposition 2**. For conclusion (2), note that in this case, no matter imitation happens or not, both firms obtain the new technology, and the innovation behaviors of both firms can be considered as a duplication of R&D investment and resource waste. ▮

LEMMA 2. *Suppose that the parameters satisfy the condition*

$$\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$$

then:

(1) No matter whether technology imitation is allowed or not, only one firm innovates in equilibrium.

(2) The social welfare when technology imitation is not allowed is lower than that when the technology imitation is allowed, if and only if $\frac{c-c'}{1-c} < \frac{8}{3}$.

Proof. See in Appendix. ▮

If $F < \min\{\frac{4(1-c)(c-c')}{9}, \frac{(2-c-c')(c-c')}{9}\}$, prohibition of technology imitation means that in the equilibrium both firms invest in R&D and innovate, so that they both have the new technology and enjoy lower unit production cost. Therefore, consumer surplus and gross profits of the two firms (without minusing the fixed R&D cost F) would be unchanged no matter whether imitation is allowed or not. The only difference is that if technology imitation is prohibited, the total R&D cost of the society equals $2F$, more than that in case that technology imitation is allowed, which is a net loss of social welfare.

If $\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$, then no matter whether technology imitation is allowed or not, only one firm innovates. In such circumstance, we need to judge whether the social welfare will be bettered off due to allowance of technology imitation. Intuitively, given that one firm invests and innovates while its opponent does not, the social welfare maximization choice is to let the other firm imitate the technology. However, that is not always the case.

We use $W(c_1, c_2)$ to denote the social welfare (in which the R&D costs are not considered) where c_1 and c_2 represent the unit production costs of firm 1 and firm 2, respectively. Suppose that one of the firms, say firm 1, operates with the unit production cost of $c_1 = c'$, and firm 2 operates with the unit production cost of $c_2 \in \{c', c\}$. The proof of the second part of **Lemma 2** is derived from the following facts:

(i) If $\frac{c-c'}{1-c} < \frac{8}{3}$, then $W(c', c') < W(c', c)$,

(ii) If $\frac{c-c'}{1-c} > \frac{8}{3}$, then $W(c', c') > W(c', c)$.[9]

By **Lemma 1** and **Lemma 2**, to compare the social welfare when technology imitation is allowed and not allowed, obviously we should contrast the highest R&D cost that makes only one firm innovate when technology imitation is allowed, $\frac{(2-c-c')(c-c')}{9}$, with the lowest R&D cost that makes only one firm to innovate when technology imitation is not allowed, $\frac{4(1-c)(c-c')}{9}$. It can easily be proved that $\frac{(2-c-c')(c-c')}{9} > \frac{4(1-c)(c-c')}{9}$ if and only if $\frac{c-c'}{1-c} > 2$, and $\frac{(2-c-c')(c-c')}{9} < \frac{4(1-c)(c-c')}{9}$ when $c < 2/3$. Combining **Lemma 1** with **Lemma 2**, **Proposition 3** summarizes the comparison of social welfare between the two cases given that $F < \frac{(2-c-c')(c-c')}{9}$.

PROPOSITION 3. *Suppose that parameters satisfy the condition* $F < \frac{(2-c-c')(c-c')}{9}$*, then:*

(1) If $c < 2/3$*, then* $F < \frac{(2-c-c')(c-c')}{9} < \frac{4(1-c)(c-c')}{9}$*. The social welfare when technology imitation is not allowed is lower than that when technology imitation is allowed.*

(2) If $c \geq 2/3$*, then: (i) When* $F < \frac{4(1-c)(c-c')}{9}$*, the social welfare when technology imitation is not allowed is lower than that when technology imitation is allowed. (ii) When* $\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$ *and* $\frac{c-c'}{1-c} > \frac{8}{3}$*, the social welfare when technology imitation is not allowed is higher than that when technology imitation is allowed. (iii) When*

[9] What we present here is actually a sufficient (but not necessary) condition of the second part of **Lemma 2**, which is equivalently to assume that if we can determine the unit production cost of firm 1 and firm 2 at will, then $W(c', c') < W(c', c)$ if $\frac{c-c'}{1-c} < \frac{8}{3}$, and $W(c', c') > W(c', c)$ if $\frac{c-c'}{1-c} > \frac{8}{3}$. Note that this condition is valid as long as we do not consider the R&D costs, no matter the production cost combination of the two firms can be supported an equilibrium strategy profile or not.
By **Proposition 1** and **Proposition 2**, when $\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$, no matter imitation is allowed or not, only one firm innovates in equilibrium (the first part of **Lemma 2**). Therefore, on the one hand, $(c_1, c_2) = (c', c')$ and $(c_1, c_2) = (c', c)$ are exactly the unit cost combination of the two firms when technology imitation is allowed and not allowed, on the other hand, the total R&D costs are the same when technology imitation is allowed and not allowed (both of which equal to F). This means that whether or not to take the R&D costs into consideration will not change the relative levels of social welfare of the two cases. Combined with previous conditions, we can obtain the second part of **Lemma 2**.

$\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$ *and* $\frac{c-c'}{1-c} < \frac{8}{3}$*, the social welfare when technology imitation is not allowed is lower than that when technology imitation is allowed.*

Proof. See in Appendix. ▌

FIG. 1. The comparison of social welfare when (a) $c < 2/3$, and (b) $c \geq 2/3$.

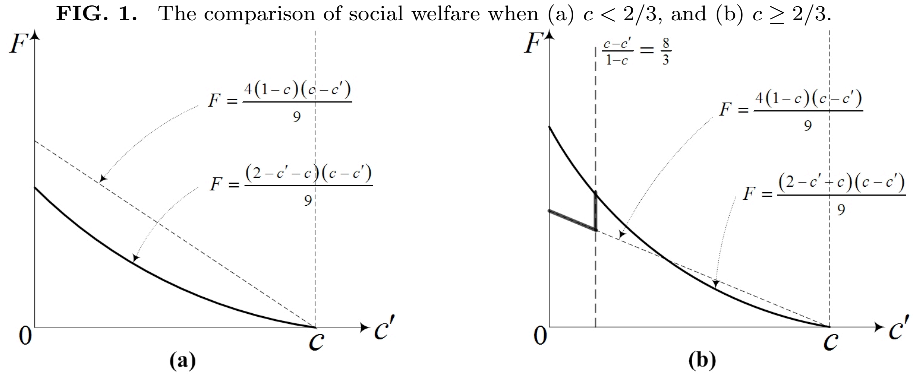

Figure 1 (a) and (b) depicts the first part ($c < 2/3$) and second part ($c \geq 2/3$) of **Proposition 3** respectively. Based on **Proposition 2** and **Proposition 3**, we can directly obtain **Corollary 1**, regarding whether we should take measures to restrict technology imitation.

Corollary 1.

(1) If $F > \frac{(2-c'-c)(c-c')}{9}$*, then the policy that restricts technology imitation should be taken;*[10]

(2) Given $F \leq \frac{(2-c'-c)(c-c')}{9}$*, then the policy that restricts technology imitation should not be adopted if* $F < \frac{4(1-c)(c-c')}{9}$.

(3) If $\frac{4(1-c)(c-c')}{9} < F \leq \frac{(2-c'-c)(c-c')}{9}$ *(If and only if* $c \geq 2/3$*, this interval exists), and* $\frac{c-c'}{1-c} > \frac{8}{3}$*, then the policy that restricts technology imitation should be adopted;*

(4) If $\frac{4(1-c)(c-c')}{9} < F \leq \frac{(2-c'-c)(c-c')}{9}$ *(If and only if* $c \geq 2/3$*, this interval exists), and* $\frac{c-c'}{1-c} < \frac{8}{3}$*, then the policy that restricts technology imitation should not be adopted.*

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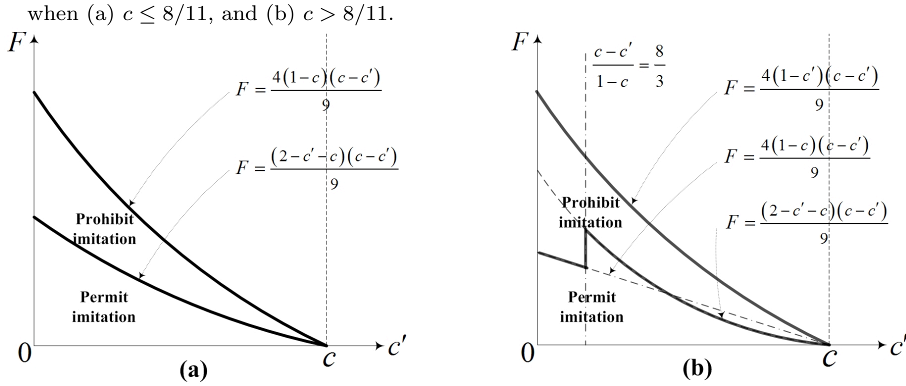
[10]Note that we always assume that $F < \frac{4(1-c')(c-c')}{9}$ (by Assumption 1). Otherwise, innovation cost is so high that no firm will invest and innovate even if any imitation is prohibited.

Proof. The conclusions can be obtained by comparing the social welfare in different equilibrium. ▌

Corollary 1 is straightforward. The negative effect of technology imitation reduces the R&D incentives of firms, while its positive effect may save the R&D costs and make the advanced technology not be confined within one firm. If the negative effect on firms' incentive prevents R&D behaviors, then the technology imitation is harmful to social welfare and should be prohibited. If the market benefits are large enough relative to the R&D cost, a firm would invest and innovate although its R&D achievements may be imitated. Under this circumstance, the development of new technology is obstructed; technology imitation is beneficial to social welfare and should be allowed.

Figure 2 shows the parameter intervals in the area of which prohibition policies and permission policies should be taken, where (a) corresponds to the case of $c \leq 8/11$ and (b) corresponds to the case of $c > 8/11$.[11]

FIG. 2. The dominantregion of prohibition of imitation and permission of imitation, when (a) $c \leq 8/11$, and (b) $c > 8/11$.



From above, we know that if and only if the parameter combination is located within the interval of "Prohibit imitation", that is, if and only if the parameter combination satisfies the condition:

$$\begin{cases} \frac{(2-c'-c)(c-c')}{9} < F < \frac{4(1-c')(c-c')}{9}, & \text{if } \frac{c-c'}{1-c} < \frac{8}{3} \\ \frac{4(1-c)(c-c')}{9} < F < \frac{4(1-c')(c-c')}{9}, & \text{if } \frac{c-c'}{1-c} \geq \frac{8}{3} \end{cases} \tag{4}$$

the social welfare maximization government should take measures to restrict technology imitation. Therefore, the following discussions about the

[11]It can be easily proved that if and only if $c > 8/11$, the parameter interval of $\frac{c-c'}{1-c} > \frac{8}{3}$ exists.

government's IPP polices, are based on the precondition that equation (4) is satisfied.

In the following two sections, we discuss two types of IPP policies, Prevention in advance and punishment afterward, respectively.

4. PREVENTION IN ADVANCE

Suppose that the government is to take prevent-in-advance policy measures to reduce the imitation firm's success probability to a level of $p \in (0,1)$, of which the imitation firm will successfully imitate its opponent's technology and reduce its unit costs of production to c'. Otherwise, the firm would still operate with unit production of c.

We use backward induction to solve the equilibrium. We will first consider firms' R&D game, then analyze the social welfare maximization policies.

4.1. The Maximization of Firms

First, we consider the maximization behavior of the firms given government's policy.

Proposition 4. *If the government takes prevent-in-advance measures to restrict technology imitation, making the success probability of imitation to be $p \in (0,1)$, then:*

(1) When $F < (1-p)\frac{4(1-c)(c-c')}{9}$, both firms innovate. That is, $\omega = (r,r)$ is the unique dominant strategy equilibrium of the R&D game.

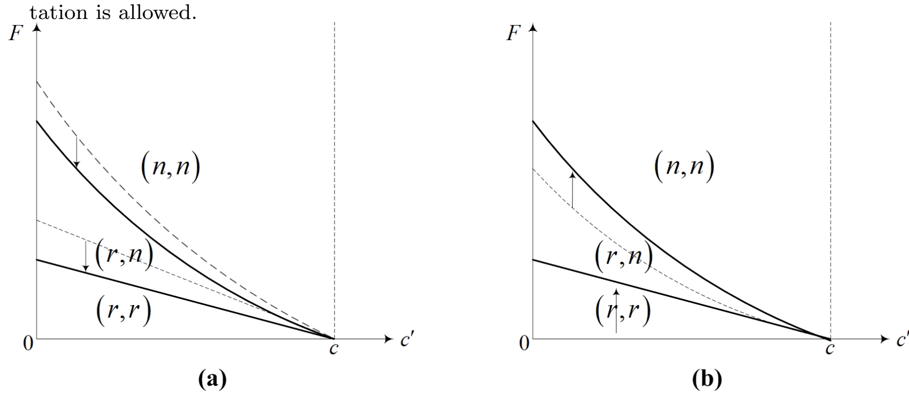
(2) When $(1-p)\frac{4(1-c)(c-c')}{9} < F < p\frac{(2-c-c')(c-c')}{9}$, only one firm innovates. That is, $\omega = (r,n)$ and $\omega = (n,r)$ are the only two (pure strategy) Nash equilibriums of the R&D game.

(3) When $p\frac{(2-c-c')(c-c')}{9} + (1-p)\frac{4(1-c')(c-c')}{9} < F$, neither firm innovates. That is, $\omega = (n,n)$ is the unique dominant strategy equilibrium of the R&D game.

Proof. See in Appendix. ▌

Intuitively, on the one hand, compared with the case that technology imitation is not allowed (see **Proposition 1**), a positive probability of technology imitation will decrease firms' R&D incentive, and switch part of the parameter interval in which only one firm innovates into that no firm innovates; at the same time part of parameter interval in which both firms innovate will be changed into that where only one firm innovates. Corresponding changes are presented in Figure 3 (a). On the other hand, compared with the case where technology imitation is allowed, the decrease in success probability of imitation increase firms' R&D incentive, switching part of the parameter interval where no firm innovates into that at least one firm innovates; at the same time, part of the parameter interval in which both firms innovate may come into being. Corresponding changes are presented in Figure 3 (b).

FIG. 3. Firms' equilibrium R&D strategy profile: before and after technology imitation is allowed.



4.2. Social Welfare Maximization

Suppose that the government can freely formulate some prevent-in-advance policy measures to choose $p \in (0,1)$. Then we want to examine: if the parameter combination satisfies expression (4)[12] and the social welfare when technology imitation is allowed is lower than that when it is not allowed, to maximize social welfare, should the government choose $p = 0$ or set the probability at some "middle level"? We will answer this question by two steps (**Proposition 5** and **Proposition 6**).

We will first prove that in the parameter interval that characterized by expression (4), the social welfare maximization policy should always be $p \in (0,1)$ which makes only one firm to innovate.

Proposition 4 shows that if the parameter combination satisfies expression (4), by choosing different values of $p \in (0,1)$, we can always divide the whole parameter interval into the three sub-intervals in which only one firm innovates, no firm innovates, and both firms innovate, respectively. So, we can obtain the following proposition.

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[12] We have known that if the parameters satisfy the condition $F < \frac{(2-c'-c)(c-c')}{9}$, even if there is no restriction on technology imitation, there will be at least one firm to innovate, and the socially total R&D costs can be reduced by technology imitation. As a result, the government should allow technology imitation, that is, to set $p = 1$. And if the parameters satisfy the condition $F > \frac{4(1-c')(c-c')}{9}$, even if there is no possibility to imitate, no firm will choose to innovate. As a result, no matter what kind of IPP policy the government takes, neither innovation nor imitation will happen.

PROPOSITION 5. *Suppose that the parameter combination satisfies expression (4), then whatever the value of p is (including 0 and 1), the (expected) social welfare (denoted by $EW^P(r,n)$) in case that only one firm innovates, is higher than that when no firm innovates (denoted by $W^P(n,n)$), and that when both firms innovate (denoted by $W^P(r,r)$).*

Proof. See in Appendix. ▮

Proposition 5 means that if the government adopts prevent-in-advance policy that restricts the success probability of imitation at $p \in (0,1)$, then a necessary condition under which this policy is optimal is that in equilibrium only one firm invests and innovates. Combining **Proposition 4** and **Proposition 5**, we know that the success probability of imitation which is socially optimal must satisfy the following conditions:

$$(1-p)\frac{4(1-c)(c-c')}{9} \leq F \leq p\frac{(2-c-c')(c-c')}{9} + (1-p)\frac{4(1-c')(c-c')}{9}$$

that is

$$1-\frac{9F}{4(1-c)(c-c')} \leq p \leq \frac{4(1-c')}{(c-c')+2(1-c')} - \frac{9F}{[(c-c')+2(1-c')](c-c')} \tag{5}$$

Based on the above conditions, we can derive the optimal level of p as in the following proposition.

PROPOSITION 6. *Suppose that the parameter combination satisfies expression (4). The government should set p at the social welfare maximization level, denoted by p^*, satisfying*

(1) $F = (1-p^*)\frac{4(1-c)(c-c')}{9}$ when $\frac{c-c'}{1-c} > \frac{8}{3}$, that is,

$$p^* = 1 - \frac{9F}{4(1-c)(c-c')}$$

(2) $F = p^*\frac{(2-c-c')(c-c')}{9} + (1-p^*)\frac{4(1-c')(c-c')}{9}$ when $\frac{c-c'}{1-c} < \frac{8}{3}$, that is,

$$p^* = \frac{4(1-c')}{(c-c')+2(1-c')} - \frac{9F}{[(c-c')+2(1-c')](c-c')}$$

Proof. See in Appendix. ▮

On the basis of **Proposition 5, Proposition 6** describes the level of success probability of imitation at which the social welfare is maximized.

By **Lemma 2**, we know that given only one firm innovates: (1) when $\frac{c-c'}{1-c} > \frac{8}{3}$, the imitation behavior of the low-tech firm will reduce social welfare. So the policy should choose the lowest possible success probability of imitation; (2) when $\frac{c-c'}{1-c} < \frac{8}{3}$, the imitation behavior of low-tech firm to high-tech firm may improve social welfare. So the optimal policy is to choose the highest possible success probability of imitation.

5. PUNISHMENT AFTERWARD

The government can also adopt measures that make no prevention in advance, but make punishment afterward to the imitation behavior that has occurred. In this paper, we consider the latter type of measures as a punishment standard set by the government, specifically, an amount of fine, denoted by T, imposed to the firm which has technology imitation behavior.[13]

Two points should be noted here. First, the government sets the punishment standard before firms decide their R&D and production strategies, but after one firm has invested in R&D while the other has not, the policy choice that maximizes social welfare might be to allow technology imitation. Therefore, we assume that the government has the commitment mechanism and cannot change the punishment standard that has been set. Second, to ensure the budget balance of the government, the confiscated income T would be redistributed to the representative consumer through transfer payments. Therefore, this part has been offset and thus does not have to appear in the social welfare function.

As in the previous section, here we first consider the equilibrium of the firms' R&D game taking the government's policy as given, and then discuss the policy that maximizes social welfare.

5.1. The Maximization of Firms

Assume that the parameter combination satisfies expression (4). Obviously, for any given punishment standard $T \geq 0$, if one firm innovates while the other firm does not, the latter would imitate the former's technology if and only if the profits increase due to imitation exceeds the penalty.

Note that a firm has three available choices given its opponent has innovated and got the new technology: innovates, does not innovates or imitates its opponent's technology, does not innovate but imitates its op-

[13] Assume that when the government only takes punishment measure to restrict technology imitation, the firm's imitation difficulties do not increase. Therefore, once a firm chooses to imitate its opponent's technology, it will succeed. We can also assume that in this case imitation can only succeed with a probability $p' \in (p, 1)$, but it would make nothing difference on the fundamental results of our discussion.

ponent's technology.[14] In order to distinguish the last two cases, we use "n" to denote "do not innovate and do not imitate its opponent's technology" and "s" to denote "do not innovate but imitate its opponent's technology". That is, the R&D game can be viewed as two steps: in the first step, each firm decides whether to innovate or not; in the second step, if it has not innovated in the first step while its opponent has it needs to decide whether to imitate its opponent's technology. Therefore, given the government's policy, we need to use the concept of Sub-game Perfect Equilibrium to analyze the firms' R&D game. We can obtain the following proposition.

PROPOSITION 7. *Assume that the parameter combination satisfies expression (4). If the government adopts measures, specifically, an amount of fine T, to punish technology imitation behavior afterward, then:*

(1) when the parameter combination satisfies the condition $F < \min\{\frac{4(1-c)(c-c')}{9}, T\}$, both firms innovate. That is, $\omega = (r, r)$, is the unique (pure strategy) sub-game perfect Nash equilibrium of the R&D game.

(2) when the parameter combination satisfies the condition $\frac{4(1-c)(c-c')}{9} < \min\{F, T\}$, one firm innovates and the other firm neither innovates nor imitates its opponent's technology. That is $\omega = (r, n)$ and $\omega = (n, r)$, are the two (pure strategy) sub-game perfect Nash equilibriums of the R&D game.

(3) when the parameter combination satisfies the condition $T < \min\{\frac{4(1-c)(c-c')}{9}, F\}$, neither firm innovates, while once a firm's opponent invests in R&D and innovates, it will imitate its opponent's technology. That is, $\omega = (s, s)$, is the unique (pure strategy) sub-game perfect Nash equilibrium of the R&D game.

Proof. See in Appendix. ∎

F, T and $\frac{4(1-c)(c-c')}{9}$ denote a firm's R&D cost, technology imitation cost and the sales benefit (produced by the new technology given the other firm has had the new technology), respectively. The equilibrium strategy profile is determined by the relative size of these three variables.

In the first case, on the one hand, when the R&D cost is smaller than the technology imitation cost, even if a firm's opponent has invested in

[14] This is different from the case of prevention in advance measures. When the government takes prevention in advance measures to restrict technology imitation, given one firm has innovated while the other has not, the latter will try to imitate the former's technology under any circumstances, but not necessarily successful. Therefore, in the previous section when we analyze the firms' R&D game we only need to consider two strategies, "innovate" and "not innovate".

R&D and obtained the new technology, it still would rather obtain the sales benefit by its independent innovation than imitation; on the other hand, the R&D cost is smaller than the technology imitation benefit (no special significance of this comparison here). As a result, in equilibrium, both firms innovate.

In the second case, on the one hand, given one firm has invested in R&D and innovated, the sales benefit of the other firm is smaller than the R&D cost, so that only one firm will invest in R&D and innovate;[15] on the other hand, since the imitation benefit is smaller than the imitation cost, once a firm innovates, the other firm will not imitate. As a result, in equilibrium, only one firm innovates, and the other firm neither innovates by itself nor imitates its opponent's technology.

In the third case, the imitation cost is smaller than the sales benefit, so that once a firm innovates, its opponent's imitation behavior will not be prevented; on the other hand, the imitation cost is smaller than the R&D cost, and no firm will invest in R&D and innovate, given that each firm knows that once it does so, the new technology will be imitated by its opponent. As a result, in equilibrium, neither firm innovates, and once a firm innovates, it's opponent will imitate its technology.

5.2. Social Welfare Maximization

Suppose that the government can set any penalty standard $T \geq 0$ by formulating appropriate punishment measures afterward. The issue we want to examine here is: if the relationship characterized by expression (4) holds[16] and the social welfare when technology imitation is allowed is lower than that when technology imitation is not allowed, what level of the penalty standard should the government set in order to maximize social welfare?

Note that since T is given to the representative consumer through transfer payments and is not counted in the social welfare function, the government's punishment merely affects the social welfare by changing the firms' R&D strategies. The optimal standard of punishment afterward is given by the following proposition.

[15] We know that when expression (4) holds, in equilibrium at least one firm will invest in R&D and innovate given that the innovating firm knows that its achievement will not be copied by its opponent.

[16] We know that when $F < \frac{(2-c'-c)(c-c')}{9}$, even if there is no restriction on technology imitation, firms will choose to innovate, so the government should allow technology imitation, that is, to set $T = 0$, to reduce the total R&D cost of the society; when $F > \frac{4(1-c')(c-c')}{9}$, however, even if there is no possibility to imitate, no firm will innovate, so no matter what punishment policy the government takes, neither innovation nor imitation will happen.

Proposition 8. *Assume that the parameter combination satisfies expression (4). If the firm which has imitation behavior must pay an amount of penalty T, then:*

(1) When $F < \frac{4(1-c)(c-c')}{9}$, the optimal policy is to set the penalty at any level higher than innovation cost, that is $T^* > F$. In equilibrium, both firms innovate, that is, $\omega^* = (r, r)$.

(2) When $F > \frac{4(1-c)(c-c')}{9}$, the optimal policy is to set the penalty at any level higher than the sales benefit, that is $T^* > \frac{4(1-c)(c-c')}{9}$. In equilibrium, only one firm innovates and the other firm neither innovates nor imitates its opponent's technology, that is, $\omega^* = (r, n)$.

Proof. See in Appendix. ▮

When $F < \frac{4(1-c)(c-c')}{9}$, the innovation cost is smaller than the sales benefit, so the equilibrium R&D strategy profile depends on the relative size of the penalty standard T and the innovation cost F. (i) If $T > F$, then both firms innovate in equilibrium, that is $\omega = (r, r)$. (ii) If $T < F$, then no firm innovates and once the a firm innovates, the other firm will imitate the new technology, that is $\omega = (s, s)$. It can easily be proved that the optimal punishment standard is to set the penalty at any level that is higher than the innovation cost, that is, $T^* > F$. In equilibrium both firms innovate, that is, $\omega^* = (r, r)$.

When $F > \frac{4(1-c)(c-c')}{9}$, the innovation cost is larger than the sales benefit. So, the equilibrium R&D strategy profile depends on the relative size of the penalty standard T and sales benefits $\frac{4(1-c)(c-c')}{9}$. (i) If $T > \frac{4(1-c)(c-c')}{9}$, then in equilibrium, only one firm innovates while the other neither innovates nor imitates, that is $\omega = (r, n)$ or $\omega = (n, r)$. (ii) If $T < \frac{4(1-c)(c-c')}{9}$, then in equilibrium, no firm innovates and once a firm innovates, the other firm will imitate, that is $\omega = (s, s)$. It can be proved that the optimal punishment standard is to set the penalty at any level higher than the sales benefit, that is, $T^* > \frac{4(1-c)(c-c')}{9}$. In equilibrium, only one firm innovates and the other firm neither innovates nor imitates, that is, $\omega^* = (r, n)$.

6. COMPARISION AND CONCLUSION

Based on the results obtained in Section 4 and 5, here we discuss what type of IPP policies the government should adopt to encourage technology innovation and maximize social welfare.[17]

6.1. Equilibrium

We first compare the equilibrium strategies of the firms under different types of IPP policies, prevention in advance and punishment afterward.

Different types of IPP policies give firms various incentives of technology imitation. When the government takes prevention in advance measures to restrict technology imitation and protect intellectual property, the difficulties of imitation is increased, but the infringement behaviors are not completely prevented. When the government takes punishment afterward measures, a firm can imitate its opponent's technology (if it has not innovated while its opponent has), but it must pay a certain amount of penalty — if the penalty is high enough it will actually be a complete prohibition of imitation.[18] Therefore, if the government adopt the policies regarding prevention in advance, it can flexibly choose the best level of policy stringency according to the specificsituation, to achieve any possible equilibrium outcomes; however, a punishment afterward measure is effective only if the imitation behavior is completely prevented, which means that no matter what R&D strategy of the firms have chosen, in equilibrium there is no technology imitation.

Different incentives of technology imitation suggest different incentives of R&D and innovation, which may lead to diverse equilibriums of the firms' R&D game. Specifically, if the government takes prevention in advance measures, as the imitation behavior is restricted to some extent (but not completely), the firms' R&D incentive behavior will be maintained at some certain level. If the government takes (any effective) punishment afterward measures, as the technology imitation will be completely prohibited, the protection of R&D incentive (and intellectual property rights) is at the highest possible level.

Proposition 5 and **Proposition 8** have summarized the different effects of IPP policies on the firms' R&D strategies. We prove that when the government takes prevention in advance measures to restrict technol-

[17]In practice, the government may adopt both types of policies simultaneously, which is beyond the discussion of this paper, because such circumstance is meaningful only when $\frac{c-c'}{1-c} = \frac{8}{3}$, suggesting a zero-measure set in the parameter space.

[18]Actually, **Proposition 8** has proved that when the government takes punishment afterward measures, no matter in which interval that parameter combination locates, the optimal policy is to set the punishment standard on a level that can completely prevent imitation. That is to say, because imitation behavior is actually prohibited in this case, the punishment does not occur in equilibrium.

ogy imitation, the optimal policy is to make only one firm innovate and the other imitate with a certain probability of success; when the government takes punishment afterward measures, according to different parameter conditions, the optimal policy may lead to two equilibrium outcomes: both firms innovate, or only one firm innovates and technology imitation is completely prevented by a sufficiently high penalty.

6.2. Social Welfare

Based on the comparisons in the previous sub-section, we are able to compare the effects of the two types of the IPP policies on social welfare. First, **Proposition 5** shows that regardless of the success probability of imitation (including 0 and 1), the social welfare when only one firm innovates is higher than either when no firms innovates or when both two firms innovate. The case that no firm innovates means that the new technology cannot be developed and the case that both firms innovate means that the social resource is wasted. As a result, neither case is socially optimal. Therefore, a prerequisite condition of the optimal IPP policies is that it must lead to an equilibrium in which only one firm innovates.

Second, we need to determine when allowance of imitate is beneficial or harmful to the social welfare. According to **Lemma 2**, we know that (1) if $\frac{c-c'}{1-c} < \frac{8}{3}$, then allowance of the imitation is beneficial for the social welfare. So, the optimal policy should assign the highest possible success probability of technology imitation, and (2) if $\frac{c-c'}{1-c} > \frac{8}{3}$, then allowance of the imitation is harmful for the social welfare. So, the optimal policy should assign the lowest possible success probability of technology imitation.

We use **Proposition 9** to summarize these results.

PROPOSITION 9. *Assume that the parameters satisfy expression (4).*

(1) When $F < \frac{4(1-c)(c-c')}{9}$, to maximize social welfare, the government should take prevention in advance rather than punishment afterward measures to restrict technology imitation.

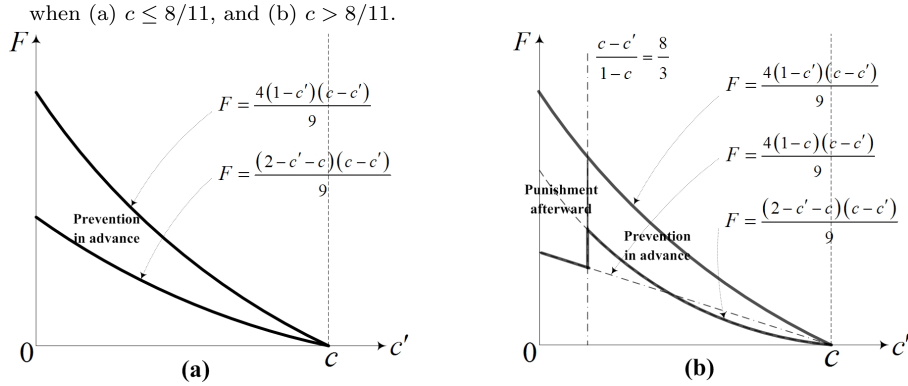
(2) When $F > \frac{4(1-c)(c-c')}{9}$, to maximize social welfare, (i) if $\frac{c-c'}{1-c} > \frac{8}{3}$, punishment afterward is superior to prevention in advance. (ii) if $\frac{c-c'}{1-c} < \frac{8}{3}$, prevention in advance is superior to punishment afterward.

Proof. By contrasting the social welfare under different equilibrium conditions, we can obtain the conclusions. ∎

$F < \frac{4(1-c)(c-c')}{9}$ means that the innovation cost is smaller than the sales benefit, so if the government takes punishment afterward measures, an equilibrium in which only one firm innovates cannot be achieved. So we have the conclusions of **Proposition 9** (1): when $F < \frac{4(1-c)(c-c')}{9}$, if the government takes prevention in advance measures, only one firm innovates in equilibrium; if the government takes punishment afterward measures, both firms innovate in equilibrium.

The second part of **Proposition 9**: when $F > \frac{4(1-c)(c-c')}{9}$, no matter what type of policies is taken, only one firm innovates in equilibrium (see **Proposition 5** and **Proposition 8**). As a result, when the government takes prevention in advance measures, the firm that has not innovated will imitate the new technology with a certain probability of success; and when the government takes punishment afterward measures, no imitation will happen. Therefore, the key point is whether the imitation behavior is beneficial or harmful for the social welfare. With the previous analysis we can prove that, if $\frac{c-c'}{1-c} > \frac{8}{3}$, the imitation is harmful for the social welfare. So, punishment afterward is superior to prevention in advance; if $\frac{c-c'}{1-c} < \frac{8}{3}$, the imitation is beneficial for then social welfare. So, prevention in advance is superior to punishment afterward.

FIG. 4. The dominant region of prevention in advance and punishment afterward, when (a) $c \leq 8/11$, and (b) $c > 8/11$.



The conclusions of **Proposition 9** are depicted in Figure 4. Here, (a) and (b) show the circumstance of $c \leq 8/11$ and $c > 8/11$, respectively.

6.3. Policy Implications

One of the advantages of prevention in advance is that this type of policies can ensure that only one firm innovates in equilibrium. Therefore, if the equilibrium with only one innovating firm is not sustainable under the circumstance of punishment afterward, adopting policies regarding prevention in advance is the optimal choice for the government. If both types of policies are able to achieve the equilibrium outcome in which only one firm innovates, then the priority of the policies depends on the welfare effects of the imitation behavior. In particular, if imitation behavior is beneficial for the social welfare, prevention in advance is superior to punishment afterward, while advance prevention is inferior otherwise.

APPENDIX A

A.1. PROOF OF PROPOSITION 1

(A) Without considering the technology imitation, we have:

For convenience, we denote the profits of firm 1 and firm 2 in stage two (that is, the gross profits before offset the innovation costs) by $\tilde{\pi}_1$ and $\tilde{\pi}_2$ respectively. Assume that the unit costs of firm 1 and firm 2 in stage two are c_1 and c_2. Then the profits maximization problem of firm 1 and firm 2 in stage two can be written as follows:

$$\begin{aligned}
\max_{q_1} \tilde{\pi}_1 &= q_1(1 - q_1 - q_2 - c_1) \\
\max_{q_2} \tilde{\pi}_2 &= q_2(1 - q_2 - q_1 - c_2) \\
q_1(q_2) &= (1 - c_1 - q_2)/2, \quad q_2(q_1) = (1 - c_2 - q_1)/2 \\
q_1^* &= \frac{2(1 - c_1) - (1 - c_2)}{3}, \quad q_2^* = \frac{2(1 - c_2) - (1 - c_1)}{3} \\
p_1^* &= 1 - \frac{1 - c_1}{3} - \frac{1 - c_2}{3}, \quad p_2^* = 1 - \frac{1 - c_2}{3} - \frac{1 - c_1}{3} \\
\tilde{\pi}_1 &= \left[\frac{2(1 - c_1) - (1 - c_2)}{3}\right]^2, \quad \tilde{\pi}_2 = \left[\frac{2(1 - c_2) - (1 - c_1)}{3}\right]^2
\end{aligned}$$

If one of the firm invests in R&D for F, then in stage two, its unit production cost equals c'. Otherwise, its unit production cost remains unchanged as c. Hence, if the innovation costs of firms in stage one are considered, then:

$$\begin{aligned}
\pi_1^*(r,r) &= \pi_2^*(r,r) = \left[\frac{2(1 - c')}{3} - \frac{(1 - c')}{3}\right]^2 - F = \frac{(1 - c')^2}{9} - F \\
\pi_1^*(r,n) &= \left[\frac{2(1 - c')}{3} - \frac{(1 - c)}{3}\right]^2 - F, \quad \pi_2^*(r,n) = \left[\frac{2(1 - c)}{3} - \frac{(1 - c')}{3}\right]^2 \\
\pi_1^*(n,r) &= \left[\frac{2(1 - c)}{3} - \frac{(1 - c')}{3}\right]^2, \quad \pi_2^*(n,r) = \left[\frac{2(1 - c')}{3} - \frac{(1 - c)}{3}\right]^2 - F \\
\pi_1^*(n,n) &= \pi_2^*(n,n) = \left[\frac{2(1 - c)}{3} - \frac{(1 - c)}{3}\right]^2 = \frac{(1 - c)^2}{9}
\end{aligned}$$

Hence, given that firm 2 innovates, firm 1 chooses to innovate if and only if $\pi_1^*(r,r) > \pi_1^*(n,r)$, that is:

$$\frac{4(1-c)(c-c')}{9} > F$$

Given that firm 2 dose not innovate, firm 1 chooses to innovate if and only if $\pi_1^*(r,n) > \pi_1^*(n,n)$, that is:

$$\frac{4(1-c')(c-c')}{9} > F$$

Since $c > c'$, we have:

$$\frac{4(1-c')(c-c')}{9} > \frac{4(1-c)(c-c')}{9}$$

As firm 1 and firm 2 are symmetrical, we can easily derive the following results when technology imitation is not considered:

(1) If $\frac{4(1-c')(c-c')}{9} < F$, then an unique dominant strategy equilibrium exists in stage one of R&D game, $\omega^* = (n,n)$, that is, neither firm innovates.

(2) If $\frac{4(1-c)(c-c')}{9} < F < \frac{4(1-c')(c-c')}{9}$, then two Nash equilibriums in pure strategy exist in stage one of R&D game, $\omega^* = (r,n)$ and $\omega^* = (n,r)$, that is, if the opponent does not innovate, the firm innovates, and vice versa.

(3) If $\frac{4(1-c)(c-c')}{9} > F$, then an unique dominant strategy equilibrium exists in stage one of R&D game, $\omega^* = (r,r)$, that is, both two firms innovate.

(B) When considering the technology imitation, we have:

By symmetry, we suppose that firm 2 does not innovate and consider the innovation behavior of firm 1. Note that because firm 2 can obtain the technology of the firm 1 by imitation, if firm 1 does not innovate, the unit costs of both two firms equal c in stage two. If firm 1 innovates, the unit costs of both two firms equal c' in stage two. If firm 1 innovates, its profits can be expressed as follows:

$$\pi_1^* = \left[\frac{2(1-c')}{3} - \frac{(1-c')}{3}\right]^2 - F = \frac{(1-c)^2}{9} - F$$

If firm 1 does not innovate, its profits can be expressed as:

$$\pi_1^* = \left[\frac{2(1-c)}{3} - \frac{(1-c)}{3}\right]^2 = \frac{(1-c)^2}{9}$$

Hence, firm 1 chooses to innovate if and only if:

$$\frac{(2-c'-c)(c-c')}{9} > F$$

Note that under this condition, given that firm 1 innovates, firm 2 would choose not to innovate.

A.2. PROOF OF PROPOSITION 2

The utility function is quasilinear, which means the consumption of valuation products z can be derived by directly calculating the income of representative consumers minus the expenditure of products 1 and products 2. That is:

$$z = w = p_1q_1 = p_2q_2$$

Therefore, the utility of a representative consumer can be expressed as:

$$u(q_1, q_2, z) = q_1 + q_2 - \frac{1}{2}(q_1 + q_2)^2 + w - p_1q_1 - p_2q_2$$

Assume that the parameters satisfy the conditions $\frac{(2-c'-c)(c-c')}{9} < F < \frac{4(1-c')(c-c')}{9}$.

(1) If imitation is not considered, then two cases exist:

(i) Only one firm innovates (we assume it to be firm 1 for convenience), then the social welfare equals:

$$\begin{aligned} W(r,n) &= u^* + \pi_1^*(r,n) + \pi_2^*(r,n) \\ &= q_1^*(r,n) + q_2^*(r,n) - \frac{1}{2}(q_1^*(r,n) + q_2^*(r,n))^2 \\ &+ w - c_1q_1^*(r,n) - c_2q_2^*(r,n) - F \end{aligned}$$

Where $c_1 = c'$, $c_2 = c$, $q_1^*(r,n) = \frac{2(1-c')-(1-c)}{3}$, $q_2^*(r,n) = \frac{2(1-c)-(1-c')}{3}$. Substituting them into the expression and rewriting it yield:

$$\begin{aligned} W(r,n) &= \frac{(1-c')+(1-c)}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 \\ &- \frac{c'(1-c')+c(1-c)-(c-c')^2}{3} + w - F \end{aligned}$$

(ii) If parameters further satisfy the condition $F < \frac{4(1-c)(c-c')}{9}$, both two firms innovate and the social welfare equals:

$$\begin{aligned} W(r,r) &= u^* + \pi_1^*(r,r) + \pi_2^*(r,r) \\ &= q_1^*(r,r) + q_2^*(r,r) - \frac{1}{2}(q_1^*(r,r) + q_2^*(r,r))^2 \\ &+ w - c_1 q_1^*(r,r) - c_2 q_2^*(r,r) - 2F \end{aligned}$$

Where $c_1 = c_2 = c'$, $q_1^*(r,r) = q_2^*(r,r) = \frac{1-c'}{3}$. Substituting them into the expression and rewriting it yield:

$$W(r,r) = \frac{2(1-c')}{3} - \frac{1}{2}\left(\frac{2(1-c')}{3}\right)^2 - \frac{2c'(1-c')}{3} + w - 2F = \frac{4(1-c')^2}{9} + w - 2F$$

(2) If imitation is considered, then none of the firm innovates. The social welfare equals (superscript "S" indicates that technology imitation is considered):

$$\begin{aligned} W^S(n,n) &= u^* + \pi_1^*(n,n) + \pi_2^*(n,n) \\ &= q_1^*(n,n) + q_2^*(n,n) - \frac{1}{2}(q_1^*(n,n) + q_2^*(n,n))^2 \\ &+ w - c_1 q_1^*(n,n) - c_2 q_2^*(n,n) \end{aligned}$$

Where $c_1 = c_2 = c$, $q_1^*(r,r) = q_2^*(r,r) = \frac{1-c}{3}$. Substituting them into the expression and rewriting it yield:

$$W^S(n,n) = \frac{2(1-c)}{3} - \frac{1}{2}\left(\frac{2(1-c)}{3}\right)^2 - \frac{2c(1-c)}{3} + w = \frac{4(1-c)^2}{9} + w$$

In order to prove that the allowance of technology imitation may reduce social welfare, we need prove that $W^S(n,n) < W(r,n)$ and $W^S(n,n) < W(r,r)$. When parameters satisfy the conditions $\frac{(2-c'-c)(c-c')}{9} < F <$

$\frac{4(1-c')(c-c')}{9}$, it is straightforward that:

$$
\begin{aligned}
& W^S(n,n) - W(r,n) \\
= \ & \frac{2(1-c)}{3} - \frac{1}{2}\left(\frac{2(1-c)}{3}\right)^2 - \frac{2c(1-c)}{3} - \frac{(1-c')+(1-c)}{3} \\
+ \ & \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{c'(1-c')+c(1-c)-(c-c')^2}{3} + F \\
= \ & \frac{(1-c)^2}{3} - \frac{(1-c')^2}{3} - \frac{1}{2}\left[\left(\frac{2(1-c)}{3}\right)^2 - \left(\frac{(1-c')+(1-c)}{3}\right)^2\right] - \frac{(c-c')^2}{3} + F \\
= \ & \frac{(1-c)^2}{3} - \frac{(1-c')^2}{3} + \frac{1}{2}\left[(1-c) + \frac{(1-c')}{3}\right]\frac{(c-c')}{3} - \frac{(c-c')^2}{3} + F \\
= \ & -\frac{2(1-c')(c-c')}{3} + \frac{1}{2}\left[(1-c) + \frac{(1-c')}{3}\right]\frac{(c-c')}{3} + F \\
< \ & -\frac{2(1-c')(c-c')}{3} + \frac{1}{2}\left[(1-c) + \frac{(1-c')}{3}\right]\frac{(c-c')}{3} + \frac{4(1-c')(c-c')}{9} \\
= \ & -\frac{2(1-c')(c-c')}{9} + \frac{1}{2}\left[(1-c) + \frac{(1-c')}{3}\right]\frac{(c-c')}{3} \\
= \ & \left[\frac{(1-c)}{3} - \frac{(1-c')}{3}\right]\frac{(c-c')}{3} < 0
\end{aligned}
$$

If the parameters further satisfy the conditions $F < \frac{4(1-c)(c-c')}{9}$. It is straightforward:

$$
\begin{aligned}
& W^S(n,n) - W(r,r) \\
= \ & \frac{2(1-c)}{3} - \frac{1}{2}\left(\frac{2(1-c)}{3}\right)^2 - \frac{2c(1-c)}{3} - \frac{2(1-c')}{3} + \frac{1}{2}\left(\frac{2(1-c')}{3}\right)^2 \\
& + \frac{2c'(1-c')}{3} + 2F \\
= \ & \frac{2(1-c)^2}{3} - \frac{2(1-c')^2}{3} - \frac{1}{2}\left[\left(\frac{2(1-c)}{3}\right)^2 - \left(\frac{2(1-c')}{3}\right)^2\right] + 2F \\
= \ & -\frac{2[(1-c)+(1-c')](c-c')}{3} + \frac{(1-c)+(1-c')}{3}\frac{2(c-c')}{3} + 2F \\
= \ & -\frac{2[(1-c)+(1-c')]}{3}\frac{2(c-c')}{3} + 2F \\
< \ & -\frac{2[(1-c)+(1-c')]}{3}\frac{2(c-c')}{3} + \frac{8(1-c)(c-c')}{9} \\
= \ & \frac{2[(1-c)-(1-c')]}{3}\frac{2(c-c')}{3} < 0
\end{aligned}
$$

Proof of Lemma 2

For simplicity, we use $W(c_1, c_2)$ to denotes the social welfare in the situation where the marginal costs of production of firm 1 is c_1 and marginal costs of production of firm 2 is c_2 (no innovation costs). Assume that one of the firm (say, firm 1) operates on the marginal costs of production $c_1 = c'$, while the other firm (firm 2) operates on the marginal costs of production $c_2 \in \{c', c\}$.

By **Proposition 1**, the first part of **Lemma 2** can be directly proved. Then, we may separate the proof of the second part into two steps.

In the first step, combining with the proof of **Proposition 2**, we have:

$$\begin{aligned} W(c', c') &= \frac{4(1-c')^2}{9} \\ W(c', c) &= \frac{(1-c')^2 + (1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c') + (1-c)}{3}\right)^2 + \frac{(c-c')^2}{3} \end{aligned}$$

It is straightforward that:

$$\frac{4(1-c')^2}{9} > \frac{(1-c')^2 + (1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c') + (1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}$$

if and only if

$$\frac{c-c'}{1-c} < \frac{8}{3}$$

Hence, if $\frac{c-c'}{1-c} < \frac{8}{3}$, then $W(c', c') < W(c', c)$, and if $\frac{c-c'}{1-c} > \frac{8}{3}$, then $W(c', c') > W(c', c)$. Note that this condition does not depend on whether the marginal cost of two firms is supported by the equilibrium strategy combination. In other words, this condition holds regardless of whether their marginal costs are supported by the equilibrium strategy combination under certain situation or not, this condition is true.

In the second step, by **Proposition 1**, when $\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c-c')(c-c')}{9}$, no matter whether imitation is allowed or not, only one firm innovates in the equilibrium (the first part of **Lemma 2**). Therefore, on the one hand, $(c_1, c_2) = (c', c')$ and $(c_1, c_2) = (c', c)$ exactly indicate the marginal cost of two firms when imitation is allowed and when imitation is not allowed, respectively. On the other hand, the innovation costs of whole society are equivalent (are equal to F) in the situation where imitation is allowed and in the situation where imitation is not allowed, which means whether innovation costs are considered or not has no influence on the social welfare in these two situations.

Based on the previous two steps, we can directly prove the second part of **Lemma 2**.

A.3. PROOF OF PROPOSITION 3

In the first step, we discuss the equilibrium outcome.

Text and **Proposition 1** have proved that, when $F < \frac{(2-c'-c)(c-c')}{9}$, under the condition that technology imitation is not considered, only one firm innovates (if $F > \frac{4(1-c)(c-c')}{9}$) or two firms innovate ($F < \frac{4(1-c)(c-c')}{9}$). As $c' < c$, we can easily prove that:

(1) If $c \leq 2/3$, then $\frac{4(1-c)(c-c')}{9} \geq \frac{(2-c'-c)(c-c')}{9}$. Hence, $F < \frac{(2-c'-c)(c-c')}{9}$ means if technology imitation is not considered, both two firms innovate.

(2) If $c > 2/3$, then: (i) when $2(1-c) < c-c'$, then $\frac{4(1-c)(c-c')}{9} < \frac{(2-c'-c)(c-c')}{9}$. Hence, if $F < \frac{4(1-c)(c-c')}{9}$ and technology imitation is not considered, both firms innovate; if $\frac{4(1-c)(c-c')}{9} < F < \frac{(2-c'-c)(c-c')}{9}$ and technology imitation is not considered, only one firm innovates. (ii) when $2(1-c) \geq c-c'$, $\frac{4(1-c)(c-c')}{9} \geq \frac{(2-c'-c)(c-c')}{9} > F$. Hence, $F < \frac{(2-c'-c)(c-c')}{9}$ means if technology imitation is not considered, both firms innovate.

In the second step, we compare the social welfare in the situation where imitation is allowed and that in the situation where imitation is not allowed.

Note that when $F < \frac{(2-c'-c)(c-c')}{9}$, if imitation is allowed, only one firm innovates, while finally both firms obtain the new technology (low costs). But if imitation is not allowed, then it may lead to two outcomes:

(1) Only one firm innovates. In this case, no matter whether imitation is considered or not, the innovation costs of the whole society are equivalent (and equal F). While if imitation is not allowed, then only one firm is able to operate on the low production costs and the other firm operates on high production costs. Comparing with the situation where imitation is allowed, this may reduce the social welfare.

(2) Both firms innovate. In this case, from the point of unit production costs, product price in the market, and sales quantities in the stage two, no matter whether imitation is considered or not, the consumption and production of product 1 and product 2 are completely equivalent for the whole society. However, in the situation where imitation is not allowed, both firms pay for the innovation expenditure in the stage one, hence the total social welfare is lower than that in the situation where imitation is allowed.

A.4. PROOF OF PROPOSITION 4

Suppose that the firm which imitates its opponent can only succeed with a probability $p \in (0, 1)$ and reduce its unit costs to c'.

In the first step, given that the opponent (say, firm 1) innovates and obtains the new technology, the firm (firm 2) has two choices: innovate by itself, or imitate its opponent (and does not innovate). According to the proof of **Proposition 1**, if firm 2 chooses to innovate by itself, it will get the profits:

$$\pi_2^*(r,r) = \frac{(1-c')^2}{9} - F$$

If firm 2 chooses to imitate firm 1 and gets its technology, it will get the expected profits:

$$E\pi_2^*(r,n) = p\frac{(1-c')^2}{9} + (1-p)\left[\frac{2(1-c)}{3} - \frac{(1-c')}{3}\right]^2$$

It is straightforward that, firm 2 chooses to innovate by itself if and only if:

$$(1-p)\frac{4(1-c)(c-c')}{9} > F$$

Otherwise, firm 2 chooses to imitate firm 1 and get the new technology.
In the second step, by previous proof, we have:
(1) If parameters satisfy the conditions

$$(1-p)\frac{4(1-c)(c-c')}{9} > F$$

Then both firm innovate.
(2) If parameters satisfy the conditions

$$(1-p)\frac{4(1-c)(c-c')}{9} < F$$

As mentioned before, given that firm 1 innovates, firm 2 will not innovate, but imitate firm 1. Given that firm 1 does not innovate, then if firm 2 innovates, firm 1 will imitate firm 2. Hence, the expected profits of firm 2 when it chooses to innovate or not to innovate can be respectively expressed as:

$$E\pi_2^*(n,r) = p\frac{(1-c')^2}{9} + (1-p)\left[\frac{2(1-c')}{3} - \frac{(1-c)}{3}\right]^2 - F$$

$$\pi_2^*(n,n) = \frac{(1-c)^2}{9}$$

In the case that firm 2 innovates, it may be imitated by firm 1 for probability p, or it may exclusively maintain the new technology and operate at low production costs. We can easily prove that firm 2 will choose to innovate by itself if and only if:

$$p\frac{(2-c-c')(c-c')}{9}+(1-p)\frac{4(1-c')(c-c')}{9}>F(>\frac{4(1-c)(c-c')}{9})$$

Otherwise, firm 2 will choose not to innovate.

In the third step, from the above, if the government take measure prevention in advance to restrain the technology imitation, and make the firm which imitates its opponent's technology could only succeed with a probability $p \in (0,1)$, then:

(1) If the parameters satisfy the conditions

$$F<(1-p)\frac{4(1-c)(c-c')}{9}$$

Then both firms innovate, which means $\omega=(r,r)$ is the unique dominant strategy equilibrium in the R&D game of firms.

(2) If the parameters satisfy the conditions

$$(1-p)\frac{4(1-c)(c-c')}{9}<F<p\frac{(2-c-c')(c-c')}{9}+(1-p)\frac{4(1-c')(c-c')}{9}$$

Then only one firm innovates and the other firm does not innovate, which means $\omega=(r,n)$ and $\omega=(n,r)$ are two Nash equilibriums in pure strategy in the R&D game of firms.

(3) If the parameters satisfy the conditions

$$p\frac{(2-c-c')(c-c')}{9}+(1-p)\frac{4(1-c')(c-c')}{9}<F$$

Then neither firm innovates, which means $\omega=(n,n)$ is the unique dominant strategy equilibrium in the R&D game of firms.

A.5. PROOF OF PROPOSITION 5

We use the superscript "P", "S", and "L" to represent the circumstances where "the government take measure prevention in advance to restrain the technology imitation, and make the firm which imitates its opponent's technology could only succeed with a probability, the firm without innovation succeeds in imitating its opponent's technology", and "the firm without innovation does not succeed in imitating its opponent's technology", respectively.

In the first step, we derive the social welfare in different equilibriums. By **Proposition 4**:

(1) When the parameters satisfy the conditions

$$F < (1-p)\frac{4(1-c)(c-c')}{9}$$

both firms innovate, that is, $\omega = (r, r)$. In this case, the social welfare equals:

$$W^P(r,r) = W^L(r,r) = \frac{4(1-c')^2}{9} + w - 2F$$

(See also the proof of **Proposition 2**)

(2) When the parameters satisfy the conditions

$$(1-p)\frac{4(1-c)(c-c')}{9} < F < p\frac{(2-c-c')(c-c')}{9} + (1-p)\frac{4(1-c')(c-c')}{9}$$

only one firm innovates (assumed to be firm 1), while the other firm (firm 2) does not innovate, that is $\omega = (r, n)$. In this case, the (expected) social welfare equals:

$$\begin{aligned} EW^P(r,n) &= pW^S(r,n) + (1-p)W^L(r,n) \\ &= p\frac{4(1-c')^2}{9} \\ &+ (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] + w - F \end{aligned}$$

(See also the proof of **Proposition 2**)

(3) When the parameters satisfy the conditions

$$p\frac{(2-c-c')c-c'}{9} + (1-p)\frac{4(1-c')(c-c')}{9} < F$$

Neither firm innovates, that is $\omega = (n, n)$. In this case, the social welfare equals:

$$W^P(n,n) = W^L(n,n) = \frac{4(1-c)^2}{9} + w$$

(See also the proof of **Proposition 2**)

In the second step, we prove that: no matter what value p is (including 0 and 1), the (expected) social welfare in the situation where only one firm innovates, is higher than that in the situation where no firm innovates, and also higher than that in the situation where both two firms innovate.

We compare the situation where only one firm innovates and the situation where no firm innovates. For any value of $p \in [0,1]$, we have:

$$
\begin{aligned}
& EW^P(r,n) - W^P(n,n) \\
= \; & p\frac{4(1-c')^2}{9} + (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
- \; & \frac{4(1-c)^2}{9} - F \\
= \; & p\frac{4(1-c')^2}{9} - \frac{4(1-c')^2}{9} + (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
- \; & \frac{4(1-c)^2}{9} + \frac{4(1-c')^2}{9} - F \\
= \; & (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
- \; & (1-p)\frac{4(1-c')^2}{9} + \frac{4(2-c-c')(c-c')}{9} - F \\
= \; & (1-p)\left[\frac{(1-c)^2}{6} - \frac{(1-c')^2}{6} + \frac{(1-c)^2-(1-c')(1-c)}{9} + \frac{(c-c')^2}{3}\right] \\
+ \; & \frac{4(2-c-c')(c-c')}{9} - F \\
= \; & (1-p)\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + \frac{4(2-c-c')(c-c')}{9} - F \\
> \; & (1-p)\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + \frac{4(2-c-c')(c-c')}{9} - \frac{4(1-c')(c-c')}{9} \\
= \; & (1-p)\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + \frac{4(1-c)(c-c')}{9} \\
= \; & (1-p)\frac{(c-c')^2}{6} + p\frac{4(1-c)(c-c')}{9} > 0
\end{aligned}
$$

Hence, the (expected) social welfare in the situation where only one firm innovates, is higher than the social welfare in the situation where no firm innovates.

We compare the situation where only one firm innovates and the situation where both two firms innovate. For any value of $p \in [0,1]$, we have:

$$
\begin{aligned}
& EW^P(r,n) - W^P(r,r) \\
= \; & p\frac{4(1-c')^2}{9} + (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
- \; & \frac{4(1-c')^2}{9} + F \\
= \; & (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
- \; & (1-p)\frac{4(1-c')^2}{9} + F \\
= \; & (1-p)\left[\frac{(1-c)^2+(1-c')^2}{6} + \frac{(1-c)^2-(1-c')(1-c)}{9} + \frac{(c-c')^2}{3}\right] + F \\
= \; & (1-p)\left[-\frac{(2-c-c')(c-c')}{6} - \frac{(1-c)(c-c')}{9} + \frac{(c-c')^2}{3}\right] + F \\
= \; & (1-p)\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + F \\
> \; & (1-p)\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + (1-p)\frac{4(1-c)(c-c')}{9} \\
> \; & (1-p)\frac{(c-c')^2}{6} \geq 0
\end{aligned}
$$

Hence, the (expected) social welfare in the situation where only one firm innovates, is higher than the social welfare in the situation where both two firms innovate.

Thus it can be seen that if possible, the government should take measures to lead to the situation where only one firm innovates.

A.6. PROOF OF PROPOSITION 6

Here we continue to use the symbols in the proof of **Proposition 5**. We try to find the optimal policy that maximizes the social welfare (to find the optimal "p") by making a comparison among different social welfare under different values of p.

First of all, by **Proposition 1 to Proposition 5**, for all parameter combinations satisfying expression (3), the government is able to choose different value of p to make only one firm innovate, or to make no firm innovate.

Based on the previous proof, we have that the government should choose the value of p which satisfies:

$$(1-p)\frac{4(1-c)(c-c')}{9} \leq F \leq p\frac{(2-c-c')(c-c')}{9} + (1-p)\frac{4(1-c')(c-c')}{9}$$

to make only one firm innovate.

Furthermore, the expected social welfare in this case equals (by step one):

$$\begin{aligned}
EW^P(r,n) &= p\frac{4(1-c')^2}{9} + (1-p)\left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
&+ w - F \\
&= \left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\
&- p\left[\frac{(c-c')^2}{6} - \frac{4(1-c)(c-c')}{9}\right] + w - F
\end{aligned}$$

where $\frac{4(1-c')^2}{9}$ denotes the social welfare when both two firms' marginal cost are c', $\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}(\frac{(1-c')+(1-c)}{3})^2 + \frac{(c-c')^2}{3}$ denotes the social welfare when one of the firm's marginal cost is c and the other firm's marginal cost is c'. By **Lemma 2**, we have proved that:

$$\frac{4(1-c')^2}{9} > \frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}$$

if and only if

$$\frac{c-c'}{1-c} < \frac{8}{3}$$

Therefore,

(i) when $\frac{c-c'}{1-c} > \frac{8}{3}$, $EW^P(r,n)$ is a decreasing function of p. Hence, in feasible interval, the government should choose the value of p as low as possible to satisfy:

$$(1-p)\frac{4(1-c)(c-c')}{9} = F$$

that is

$$p = 1 - \frac{9F}{4(1-c)(c-c')}$$

It is easy to prove that, the expected social welfare in this case equals:

$$EW^P(r,n) = \frac{5(1-c')^2}{18} + \frac{(1-c)^2}{6} + \frac{(2-c-c')(c-c')}{6} + \frac{3(c-c')}{8(1-c)}F - 2F + w$$

(ii) when $\frac{c-c'}{1-c} < \frac{8}{3}$, $EW^P(r,n)$ is an increasing function of p. Hence, in feasible interval, the government should choose the value of p as high as possible to satisfy:

$$F = p\frac{(2-c-c')(c-c')}{9} + (1-p)\frac{4(1-c')(c-c')}{9}$$

that is

$$p = \frac{4(1-c')}{(c-c')+2(1-c')} - \frac{9F}{[(c-c')+2(1-c')](c-c')}$$

It is easy to prove that, the expected social welfare in this case equals:

$$\begin{aligned} EW^P(r,n) &= \left[\frac{(1-c')^2+(1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c')+(1-c)}{3}\right)^2 + \frac{(c-c')^2}{3}\right] \\ &- \frac{2(1-c')(c-c')}{9}\frac{3(c-c')-8(1-c)}{(c-c')+2(1-c')} + \frac{1}{2}\frac{3(c-c')-8(1-c)}{(c-c')+2(1-c')}F \\ &+ w - F \end{aligned}$$

A.7. PROOF OF PROPOSITION 7

(1) Assume that firm 1 chooses to innovate. Then firm 2 faces three choices: to innovate by itself (r), not to innovate or imitate (n) and not to innovate but to imitate (s). By the proof of **Proposition 1**, if firm 2 chooses to innovate by itself, its profits can be rewritten as:

$$\pi_2^*(r,r) = \frac{(1-c')^2}{9} - F$$

If firm 2 chooses not to innovate or imitate (n), its profits can be rewritten as:

$$\pi_2^*(r,n) = \left[\frac{2(1-c)}{3} - \frac{(1-c')}{3}\right]^2$$

If firm 2 chooses not to innovate but to imitate (s), its profits can be rewritten as:

$$\pi_2^*(r,s) = \frac{(1-c')^2}{9} - T$$

It is easy to prove that, firm 2 chooses to innovate by itself (r) if and only if:

$$F < \min\left\{\frac{4(1-c)(c-c')}{9}, T\right\}$$

Firm 2 chooses not to innovate or imitate (n) if and only if:

$$\frac{4(1-c)(c-c')}{9} < \min\{F, T\}$$

Firm 2 chooses not to innovate but to imitate (s) if and only if:

$$T < \min\left\{\frac{4(1-c)(c-c')}{9}, F\right\}$$

(2) Assume that firm 1 chooses n, that is, not to innovate and once firm 2 innovates, firm 1 chooses not to imitate. In this case, firm 2 faces two choices: to innovate by itself (r) or not to innovate (n or s). If firm 2 chooses to innovate by itself (r), its profits can be rewritten as:

$$\pi_2^*(n,n) = \left[\frac{2(1-c')}{3} - \frac{(1-c)}{3}\right]^2 - F$$

If firm 2 chooses not to innovate (n or s), its profits can be rewritten as:

$$\pi_2^*(n,n) = \pi_2^*(n,s) = \frac{(1-c)^2}{9}$$

It is easy to prove that, firm 2 chooses to innovate (r) if and only if:

$$F < \frac{4(1-c')(c-c')}{9}$$

Also, firm 2 chooses not to innovate (n or s) if and only if:

$$F > \frac{4(1-c')(c-c')}{9}$$

(3) Assume that firm 1 chooses s, that is, not to innovate and once firm 2 innovates, firm 1 chooses to imitate. In this case, firm 2 faces two choices: to innovate by itself (r) or not to innovate (n or s). If firm 2 chooses to innovate by itself (r), its profits can be rewritten as:

$$\pi_2^*(s,r) = \frac{(1-c')^2}{9} - F$$

If firm 2 chooses not to innovate (n or s), its profits can be rewritten as:

$$\pi_2^*(s,n) = \pi_2^*(s,s) = \frac{(1-c)^2}{9}$$

It is easy to prove that, firm 2 chooses to innovate (r) if and only if:

$$F < \frac{(2-c-c')(c-c')}{9}$$

Also, firm 2 chooses not to innovate (n or s) if and only if:

$$\frac{(2-c-c')(c-c')}{9} < F$$

(4) By the previous proof, we have derived the reaction functions of firms (since two firms are symmetrical, the reaction function of firm 1 to firm 2 is equivalent to the reaction function of firm 2 to firm 1). Through the analysis of two reaction functions, we can solve for the equilibrium of the R&D game given the government's policy.

As we only need to consider the parameter interval that satisfies expression (3), in conclusion, we know that if the government takes measure punishment afterward to limit technology imitation and impose fine on the firm which has imitation behavior for penalty T, then:

(1) When parameters satisfy the condition

$$F < \min\left\{\frac{4(1-c)(c-c')}{9}, T\right\}$$

both firms innovate, that is, $\omega = (r, r)$, is the unique (pure strategy) sub-game perfect Nash equilibrium of the R&D game.

(2) When parameters satisfy the condition

$$\frac{4(1-c)(c-c')}{9} < \min\{F, T\}$$

one firm innovates and the other firm does not innovate or imitate opponent's technology, that is, $\omega = (r, n)$ and $\omega = (n, r)$, are the two (pure strategy) sub-game perfect Nash equilibriums of the R&D game.

(3) When parameters satisfy the condition

$$T < \min\left\{\frac{4(1-c)(c-c')}{9}, F\right\}$$

neither firm innovates and once its opponent innovates, it will imitate opponent's technology, that is, $\omega = (s, s)$, is the unique (pure strategy) sub-game perfect Nash equilibrium of the R&D game.

Note that the reason why we use sub-game perfect Nash equilibrium is that the R&D game of firms is separated into two stages. In the first stage, firms decide whether to innovate or not and if its opponent innovates the firm that does not innovate should decide whether to imitate or not, which means when firm chooses strategy "n" and "s" depends on the setting of the parameters. Specifically, by the analysis in step one, when the parameters satisfy the condition

$$T > \min\left\{\frac{4(1-c)(c-c')}{9}, F\right\}$$

neither of the firms would choose strategy "s". When parameters satisfy condition

$$\frac{4(1-c)(c-c')}{9} > \min\{F, T\}$$

neither of the firms would choose strategy "n".

A.8. PROOF OF PROPOSITION 8

Suppose that the parameters satisfy the expression (3). By **Proposition 7**,

(1) When the parameters satisfy the condition

$$F < \frac{4(1-c)(c-c')}{9}$$

the innovation costs are lower than the imitation benefits. In this case, the equilibrium depends on the relative level between the penalty standard and innovation costs.

(i) If the penalty standard is higher than the innovation costs, that is, $T > F$, then both firms innovate in the equilibrium. Both two firms obtain the new technology, and the social welfare equals

$$W^T(r, r) = \frac{4(1-c')^2}{9} + w - 2F$$

(ii) If the penalty standard is lower than the innovation costs, that is, $T < F$, then no firm innovates and once the opponent innovates, the firm will imitate its technology, that is, $\omega = (s, s)$. Neither firm obtains the new technology, and the social welfare equals

$$W^T(s, s) = \frac{4(1-c)^2}{9} + w$$

Since the parameters satisfy the condition $F < \frac{4(1-c)(c-c')}{9}$, it is easy to prove that,

$$\begin{aligned}
W^T(r,r) - W^T(s,s) &= \frac{4(1-c')^2}{9} + w - 2F - \frac{4(1-c)^2}{9} - w \\
&= \frac{4(1-c')^2}{9} - \frac{4(1-c)^2}{9} - 2F \\
&= \frac{4(2-c-c')(c-c')}{9} - 2F \\
&> \frac{4(2-c-c')(c-c')}{9} - \frac{8(1-c)(c-c')}{9} \\
&= \frac{4(c-c')[(2-c-c')-2(1-c)]}{9} = \frac{4(c-c')^2}{9} > 0
\end{aligned}$$

Therefore, the optimal policy of the government is to set the penalty at any level which is higher than innovation costs, that is,

$$T > F$$

which means both firms innovate in the equilibrium, that is, $\omega^* = (r, r)$, and obtain the new technology.

(2) When the parameters satisfy the condition

$$F > \frac{4(1-c)(c-c')}{9}$$

the innovation costs is higher than the imitation benefits. In this case, the equilibrium depends on the relative level between the penalty standard and imitation benefits.

(i) If the penalty standard is higher than the imitation benefits, that is, $T > \frac{4(1-c)(c-c')}{9}$, then in the equilibrium, only one firm innovates and the other firm neither engages in R&D nor imitates opponent's technology, that is, $\omega = (r, n)$ or $\omega = (n, r)$. Only one firm obtains the new technology and the social welfare equals

$$W^T(r,n) = \frac{(1-c')^2 + (1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c') + (1-c)}{3}\right)^2 + \frac{(c-c')^2}{3} + w - F$$

(ii) If the penalty standard is lower than the imitation benefits, that is, $T < \frac{4(1-c)(c-c')}{9}$, then none of the firm innovates and once the opponent innovates, the firm will imitate its technology, that is, $\omega = (s, s)$. Neither firm obtains the new technology, and the social welfare equals

$$W^T(s,s) = \frac{4(1-c)^2}{9} + w$$

Since the parameters satisfy the expression (3), it is easy to prove that,

$$
\begin{aligned}
& W^T(r,n) - W^T(s,s) \\
= \; & \frac{(1-c')^2 + (1-c)^2}{3} - \frac{1}{2}\left(\frac{(1-c') + (1-c)}{3}\right)^2 \\
+ \; & \frac{(c-c')^2}{3} + w - F - \frac{4(1-c)^2}{9} - w \\
= \; & \frac{5(1-c')^2}{18} - \frac{(1-c)^2}{6} - \frac{(1-c')(1-c)}{9} + \frac{(c-c')^2}{3} - F \\
= \; & \frac{(1-c')^2}{6} - \frac{(1-c)^2}{6} + \frac{(1-c')^2}{9} - \frac{(1-c')(1-c)}{9} + \frac{(c-c')^2}{3} - F \\
= \; & \frac{(2-c-c')(c-c')}{6} + \frac{(1-c')(c-c')}{9} + \frac{(c-c')^2}{3} - F \\
> \; & \frac{(2-c-c')(c-c')}{6} + \frac{(1-c')(c-c')}{9} + \frac{(c-c')^2}{3} - \frac{4(1-c')(c-c')}{9} \\
= \; & \frac{(2-c-c')(c-c')}{6} + \frac{(c-c')^2}{3} - \frac{(1-c')(c-c')}{3} \\
= \; & \frac{(2-c-c')(c-c')}{6} - \frac{(1-c)(c-c')}{3} = \frac{(c-c')^2}{6} > 0
\end{aligned}
$$

Therefore, the optimal policy of the government is to set the penalty at any level which is higher than imitation benefits, that is,

$$T^* > \frac{4(1-c)(c-c')}{9}$$

which means only one firm innovates (and the other firm neither engages in R&D nor imitates opponent's technology), that is, $\omega^* = (r, n)$. The firm that innovates could obtain the new technology.

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