How Should We Protect Innovations?

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Abstract

We present simple Cournot and Stackelberg models to study methods for protecting innovations from imitation. We find that policymakers should allow some imitation if innovation efficiency is low, even when imitation can be prohibited at no cost. Moreover, we demonstrate that social welfare in a monopoly can exceed that in the Cournot and Stackelberg duopoly, given relatively efficient innovation and a high degree of imitation. Therefore, where both innovation efficiency and degree of imitation are high, entry restrictions can be supported for social welfare.

Keywords: Innovation investment, R&D investment, Imitation, Cournot duopoly, Stackelberg duopoly

JEL Classification: L12, L13, L52

1. Introduction

The relationship between the degree of competition and innovation has been a major question in the literature on the economics of innovation (Aghion et al., 2005). No cost-reducing R&D will be performed under perfect competition if new technology is not protected. However, as Stiglitz (1986) showed, if technology resulting from R&D is perfectly protected, a competitive firm has a larger incentive to invest in R&D than a monopolist. Thus, the degree to which technology is protected crucially affects the relationship between competition and innovation. In order to reap the most benefit from innovation, thus, the design of intellectual property policies is of crucial importance.

The actual methods used to ensure appropriability from innovation differ somewhat for different types of innovation and for different countries. Based on large-scale questionnaire surveys of manufacturing firms, Cohen, Nelson and Walsh (2000) and Cohen, Goto, Nagata, Nelson and Walsh (2002) found that, in the US, the most frequently used method of securing profits from new technologies is secrecy for both product and process innovation, while, in Japan, the most frequently used method is secrecy for process innovation and patents for product innovation. The differences stem partly from the details and implementation of patent protection and trade secret protection in different countries, resulting in different degrees of protection. In Japan recently, there has been a renewed interest in the design of intellectual property protection. The Unfair Competition Prevention Act was amended in 2018 to create remedies for damages caused by data breaches. In a closely related development, discussions are under way for revising METI's Contract Guidelines on Data Utilization Rights. There are also discussions about the possibility of extending patent protection to AI-enabled technologies (Intellectual Property Strategy Headquarters, Government of Japan, 2017). Understanding the interaction among the degree of spillovers, nature of competition and size of innovation will give us important insights towards appropriate design of intellectual property policies.

D'aspremont and Jacquemin (1988, 1990) analyzed how spillovers affect the equilibrium in a setting where duopolists engage in cost-reducing R&D before engaging in volume competition. Suzumura (1992) generalized their conclusions to an oligopoly setting. While both D'aspremont and Jacquemin (1988, 1990) and Suzumura (1992) analyzed symmetric settings, in many markets there are leader firms who actively innovate and are first-movers in the product market, and follower firms who observe and react to the leaders. Thus, in certain circumstances, it is more appropriate to analyze the effect of spillovers and the relationship between competition and innovation, in an asymmetric setting with a leader and a follower. In this paper, therefore, we investigate an asymmetric duopoly setup where the leader engages in cost-reducing R&D before product market competition. We compare Cournot and Stackelberg competition, and also analyze the monopoly case as a benchmark.

Duopolistic cost-reducing investment model is extended in various directions. For example, Poyago-Theotoky (1999) endogenizes the extent of spillovers, and shows that both duopolistic firms select zero spillover in non-cooperative competition. Atallah (2005a, b, 2007) considers asymmetric spillover. While both firms prefer research joint venture cartelization to R&D competition under symmetric spillover, asymmetric spillover leads to preferable R&D competition. Tesoriere (2008) examines endogenous timing of R&D investment. In this model, while sequential play exhibits spillover, only simultaneous play with no spillover is observed in equilibrium.

Our model is different from these analyses mainly in two ways. First, since we consider one-sided R&D investment, the innovator is not influenced by the other firm's spillover. Thus, we deal with the case of extremely asymmetric spillover. We consider exogenous different timing of quantity competition. Second, our main focus is on welfare comparison between monopoly and oligopolies. Our clear assumption about asymmetry enables us to compare welfare under different market structures.

The rest of this paper is organized as follows. In section 2-1 we investigate the monopolistic innovator case as a bench mark. Next, in section 2-2, we look at the Cournot duopoly. In section 2-3, we then consider the Stackelberg duopoly. Finally, the last section presents conclusions.

2. The Model and Result

2-1. Monopoly by the Innovator

We first show the basic model in which a monopolistic innovator determines the innovation investment (or R&D investment) required to reduce costs. The inverse demand function is $p = a - q$ where the notations have the usual meanings. The profit function is

$$\pi_n = pq_n - (c - x)q_n - \frac{t}{2}x^2 \tag{1}$$

where q_n is the innovator's output, c is the constant marginal cost, x is the innovation investment and t is the parameter that represents the innovation efficiency. We assume $a - c > 0$ and $t > \frac{a}{2c}$ for interior solutions in the monopoly case.

From the first-order condition, we have the following equilibrium values:

$$q_n^* = \frac{t(a-c)}{2t-1},\ x^* = \frac{a-c}{2t-1},\ \pi_n^* = \frac{t(a-c)^2}{2(2t-1)},\ SW^* = \frac{t(a-c)^2(3t-1)}{2(1-2t)^2} \tag{2}$$

where superscript * shows the equilibrium value in this case and SW is social welfare, which comprises consumer and producer surplus.

2-2. Cournot Duopoly by the Innovator and Imitator

We next show the model of the Cournot duopoly that comprises an innovator and imitator. In the first stage, the innovator determines the innovation investment and in the second stage, the innovator and imitator determine their output simultaneously. We solve the game backward.

The profit functions of the innovator and imitator are respectively

$$\pi_n = pq_n - (c-x)q_n - \frac{t}{2}x^2,\ \pi_m = pq_m - (c-sx)q_m \tag{3}$$

where q_m is the imitator's output, s is the degree of imitation and $0 < s \leq 1$. We assume $a - 2c \geq 0$ and $t > \frac{2(2-s)(a+c(1-s))}{9c}$ for interior solutions in the Cournot case. From the first-order condition, we obtain the equilibrium in the second stage:

$$q_n = \frac{a-c+x(2-s)}{3},\ q_m = \frac{a-c+x(2s-1)}{3}. \tag{4}$$

Then, the routine calculations yield the following SPNE:

$$x^{**} = \frac{2(a-c)(2-s)}{9t-2(2-s)^2},\ q_n^{**} = \frac{3t(a-c)}{9t-8-2s^2+8s},\ q_m^{**} = \frac{(a-c)(3t-2s^2+6s-4)}{9t-8-2s^2+8s}, \tag{5}$$

$$\pi_n^{**} = \frac{t(a-c)^2}{9t-8-2s^2+8s},\ \pi_m^{**} = \frac{(a-c)^2(4-6s+2s^2-3t)^2}{(9t-8-2s^2+8s)^2}, \tag{6}$$

$$SW^{**} = \frac{2(a-c)^2(3(2-3s+s^2)^2-t(s-2)(13s-14)+18t^2)}{(2(s-2)^2-9t)^2} \tag{7}$$

where superscript ** shows the equilibrium in this case.

When the imitator does not imitate the innovator (i.e., $s = 0$), we know from (2) and (5) that

$$x^* - x^{**} \gtreqless 0 \Leftrightarrow t \gtreqless 4.$$

Thus, we have the following lemma.

Lemma 1: ***Supposing no imitation, when the innovation efficiency is sufficiently low (i.e.,*** $t > 4$***), the innovation investment by the monopolist exceeds that by the Cournot duopolist, and vice versa.***

The innovation investment could enhance profits by reducing the marginal cost (direct effect). Because the Cournot innovator has a smaller market share than the monopolist, this direct effect is also small. However, in the case of a duopoly a reduction in the marginal cost for any one firm can grow the market share of that firm at the expense of its rival (indirect effect). Therefore, if the innovation efficiency is high enough, the Cournot innovator invests more than the monopolist. In other words, if the innovation efficiency is low, both direct and indirect effects are small, and the investment volume for the Cournot innovator is lower than for the monopolist.

How does s affect social welfare? To check this, we depict the function $SW^{**}(s)$ given $t = 1.95$, $t = 2$, and $t = 5$[1]. Figures 1 to 3 show each of these cases[2]. From these figures, we know a policymaker must ban imitation for social welfare when the innovation efficiency is high enough. However, when innovation efficiency is low, a policymaker should allow a degree of imitation. Note that we do not consider the cost of prohibiting imitation.

Suppose that a policymaker can choose s at no cost. Let s^{**} be the optimal interior solution and we evaluate $\tilde{t}$ that makes $SW^{**}(0) - SW^{**}(s^{**}) = 0$[3]. That is, when t is lower than $\tilde{t}$, we have the corner solution and the optimal value of s is zero. Then we have $\tilde{t} \approx 2.03115$. Thus, we get the following proposition.

Proposition 1: ***Suppose*** $\boldsymbol{a = 100}$, $\boldsymbol{c = 30}$ ***and the Cournot duopoly prevails. The optimal value of*** $\mathbf{s}$ ***is zero iff*** $\mathbf{t < \tilde{t}}$***, while the optimal value is positive iff*** $\mathbf{t > \tilde{t}}$***, where*** $\boldsymbol{\tilde{t} \approx 2.03115}$***.***

Efficient innovation should be strictly protected for social welfare because imitation decreases innovation. However, we should not strictly protect inefficient innovation. In addition, we should not also permit imitation freely, even when innovation efficiency is very low. Because we know from (7) and assumptions for interior solutions:

$$\left.\frac{dSW^{**}}{ds}\right|_{s=1} = \frac{-2(a-c)^2(63t-2)}{(9t-2)^2} < 0.$$

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[1] In order to get clear results, we set $a = 100$ and $c = 30$. However, we know from (7) that properties of the proposition obviously hold true regardless of values of a and c.
[2] The assumptions for interior solutions are met when $t = 1.95$, $t = 2$, and $t = 5$.
[3] The calculations are performed by Mathematica.

This indicates that social welfare is never maximized by setting $s = 1$.

2-3. Stackelberg Duopoly by the Innovator and Imitator

Next, we present the model of the Stackelberg duopoly with an innovator and imitator. We consider the following three stage game: in the first stage, the innovator determines the innovation investment, in the second stage, the innovator determines the output, and in the third stage, the imitator determines the output. We assume $a - 3c > 0$, and $t > \frac{(2-s)(a+c(1-s))}{4c}$ for interior solutions in the Stackelberg case. Let us solve the game backward.

In the third stage, we obtain the output of the imitator as the function of the output of the innovator and the innovation investment:

$$q_m = \frac{a-q_n-c+sx}{2}. \tag{8}$$

In the second stage, we get the output of the innovator and the imitator as the function of the innovation investment:

$$q_n = \frac{a-c+2x-sx}{2},\ q_m = \frac{a-c-2x+3sx}{4}. \tag{9}$$

Routine calculations yield the SPNE as follows:

$$x^{***} = \frac{(a-c)(2-s)}{4(t-1)+s(4-s)},\ q_n^{***} = \frac{2t(a-c)}{4(t-1)+s(4-s)},\ q_m^{***} = \frac{(a-c)(t-2+s(3-s))}{4(t-1)+s(4-s)} \tag{10}$$

$$\pi_n^{***} = \frac{t(a-c)}{8(t-1)+2s(4-s)},\ \pi_m^{***} = \frac{(a-c)^2\left(2-3s+s^2-t\right)^2}{(4(t-1)+s(4-s))^2} \tag{11}$$

$$SW^{***} = \frac{(a-c)^2\left(3s^4-18s^3+s^2(39-11t)+s(34t-36)+3(5t^2-8t+4)\right)}{2(4(t-1)+s(4-s))^2} \tag{12}$$

where the superscript *** represents the equilibrium in this case.

When the imitator does not imitate the innovator (i.e., $s = 0$), then from (2) and (9) we know the following

$$x^* - x^{***} < 0.$$

Thus, we get the following lemma.

Lemma 2: ***Suppose there is no imitation. The innovation investment by the Stackelberg duopolist always exceeds that by the monopolist.***

Lemma 2 differs from the Cournot case. The Stackelberg leader produces more than the Cournot duopolist. Therefore, in the Stackelberg case innovation investment can enhance profits by reducing the marginal cost more than in the Cournot case (direct effect). Moreover, as in the Cournot case, reduction in the marginal cost can also expand market share at the expense of the rival firm (indirect effect). That is, the Stackelberg case involves relatively large direct effects in addition to the indirect effect. Thus, the Stackelberg innovator always invests more than the monopolist.

To check the effect of s on social welfare, we depict the function $SW^{***}(s)$ in the cases of $t = 3$, $t = 4$, and $t = 6$[4]. Figures 4 to 6 show each case, respectively[5]. From these figures, the results closely resemble those of the Cournot model.

Suppose that a policymaker can again choose s at no cost. Letting s^{***} be the optimal interior solution, we evaluate the value of $\hat{t}$ at which $SW^{***}(0) - SW^{***}(s^{***}) = 0$. That is, when t is less than $\hat{t}$, we have the corner solution and the optimal value of s is zero. Then we have $\hat{t} \approx 5.0694$. Thus, we get the following proposition.

Proposition 2: ***Suppose*** $\boldsymbol{a = 100}$, $\boldsymbol{c = 30}$ ***and the Stackelberg duopoly prevails. The optimal value of*** $\mathbf{s}$ ***is zero iff*** $\mathbf{t < \hat{t}}$***, while the optimal value is positive iff*** $\mathbf{t > \hat{t}}$***, where*** $\hat{t} \approx 5.0694$.

The Cournot and Stackelberg cases differ in the range of the corner solution. The Stackelberg duopoly case tends to yield the corner solution more than does the Cournot case. This indicates that we should protect innovation completely in the Stackelberg case even when innovation is relatively inefficient. The logic for this is as follows. The output of the Stackelberg imitator is lower than that of the Cournot imitator, and therefore, the Stackelberg imitator contributes less to social welfare than does the Cournot imitator. That is, the imitation by the Stackelberg imitator is no better than that by the Cournot imitator, and thus we should protect the innovation completely even when t is relatively large.

Also in this Stackelberg case, we should not permit imitation freely, even when innovation efficiency is very low. Because we know from (12) and assumptions for interior solutions:

$$\left.\frac{dSW^{***}}{ds}\right|_{s=1} = \frac{-2t(a-c)^2(3t+2)}{(4t-1)^3} < 0.$$

[4] In order to get clear results, we set $a = 100$ and $c = 30$. However, we know from (12) that properties of the proposition obviously hold true regardless of values of a and c.

[5] The assumptions for interior solutions are met when $t = 3$, $t = 4$, and $t = 6$.

This indicates that social welfare is never maximized by setting $s = 1$.

2-4. Welfare comparison

Now we compare the monopoly and Cournot cases. Let us define $\Delta SW^{**} \equiv SW^{*} - SW^{**}$ and depict the function $\Delta SW^{**}(s)$ in the cases of $t = 1.5$, $t = 2$, and $t = 3$. Figures 7 to 9 show each case, respectively[6]. Then, we find that social welfare is greater in the monopoly case than in the Cournot duopoly case, when t is small and s is large. Thus, we have the following proposition.

Proposition 3: ***Social welfare in the monopoly case exceeds that in the Cournot case, when innovation is relatively efficient and imitation is significant.***

Reverse of welfare order is explained by change of producer and consumer surpluses. For low spillover effect, producer surplus in Cournot competition is lower than that in monopoly. However, large output in Cournot competition with efficient technology increases consumer surplus. This effect makes Cournot welfare exceeding monopoly welfare. As spillover effect enhances, investment level in Cournot competition decreases. This leads to decline of that consumer surplus. Finally, monopoly welfare outweighs Cournot welfare.

Finally, we compare the monopoly and Stackelberg cases. Let us define $\Delta SW^{***} \equiv SW^{*} - SW^{***}$ and depict the function $\Delta SW^{***}(s)$ in the cases of $t = 1.5$, $t = 1.55$, and $t = 3$. Figures 10 to 12 show each case, respectively[7]. Then, we find that social welfare is greater in the monopoly case than in the Stackelberg duopoly case, when t is small and s is large. Thus, we have the following proposition.

Proposition 4: ***Social welfare in the monopoly case exceeds that in the Stackelberg case, when innovation is relatively efficient and imitation is significant.***

Note that this reversal of social welfare could be widely seen in the Cournot case rather than in the Stackelberg case. Imitation decreases innovation investment in both the Cournot and Stackelberg cases. In the Stackelberg duopoly case, however, the effect of imitation on innovation and social welfare is smaller than that in the Cournot one, since

[6] Note that we require $s > 0.318665$ when $t = 1.5$.

[7] Note that we require $s > 0.45353$ (resp. $s > 0.416919$) when $t = 1.5$ (resp. $t = 1.55$).

the output of the Stackelberg follower is small. Thus, social welfare for the monopoly hardly exceeds that for the Stackelberg duopoly.

To summarize, social welfare is highest under the Stackelberg duopoly, followed by the Cournot duopoly, and finally the monopoly, provided neither innovation nor imitation exists. However, social welfare for the monopoly could exceed that for the Cournot and Stackelberg duopoly if both innovation and imitation exist.

3. Conclusion

The results in this paper suggest that the best approach for a policymaker might be to accept some imitation, even if imitation could be prohibited without cost. Of course, efforts to ban imitation would naturally have costs in the real world. Therefore, imitation should be more widely accepted.

Additionally, if policymakers cannot ban imitation, entry restrictions could be supported for social welfare in industries with high innovation efficiency and degree of imitation.

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Figures

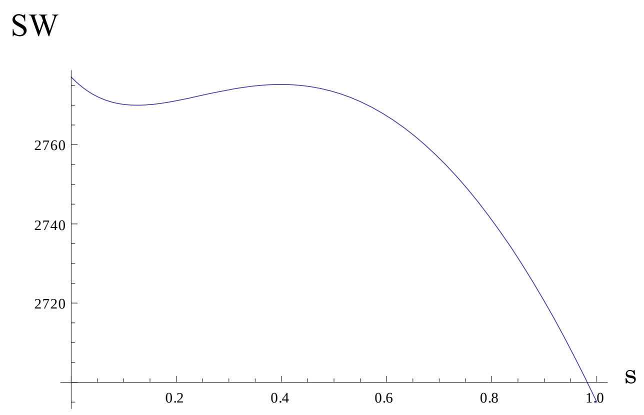

Fig. 1 Social welfare ($t = 1.95$)

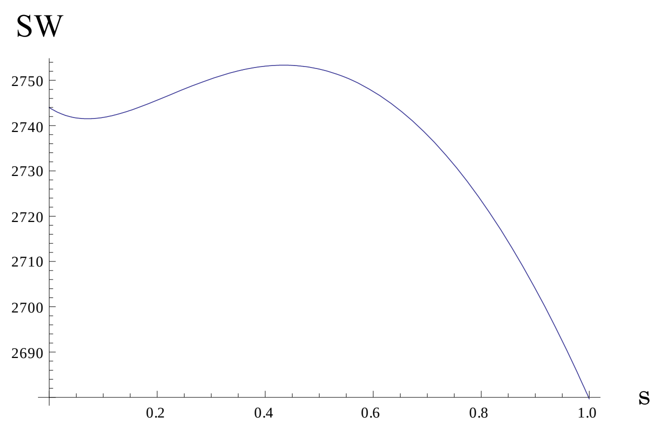

Fig. 2 Social welfare ($t = 2$)

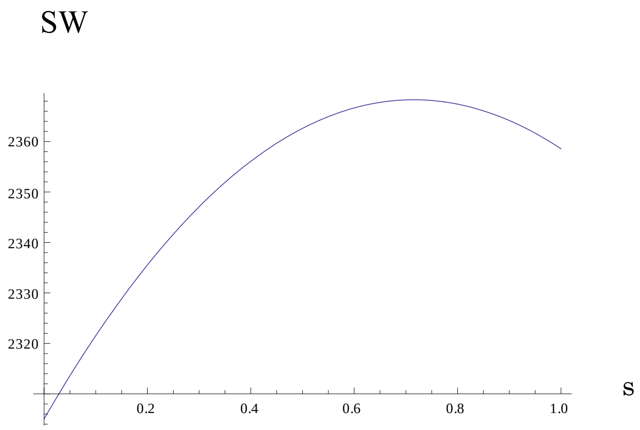

Fig. 3 Social welfare ($t = 5$)

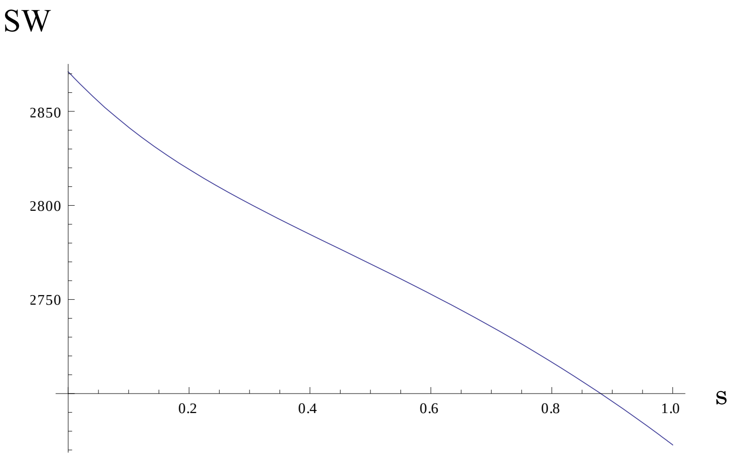

Fig. 4 Social welfare ($t = 3$)

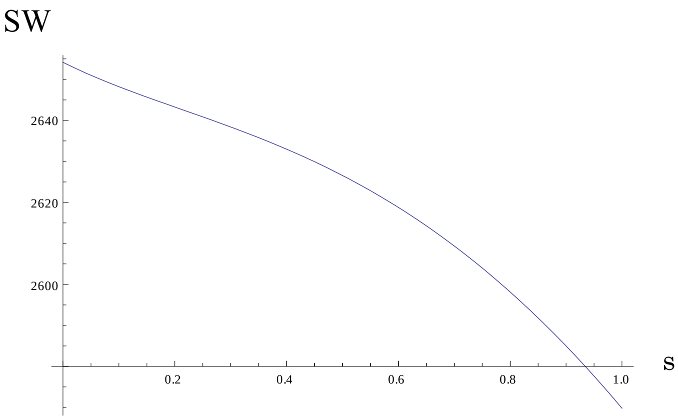

Fig. 5 Social welfare ($t = 4$)

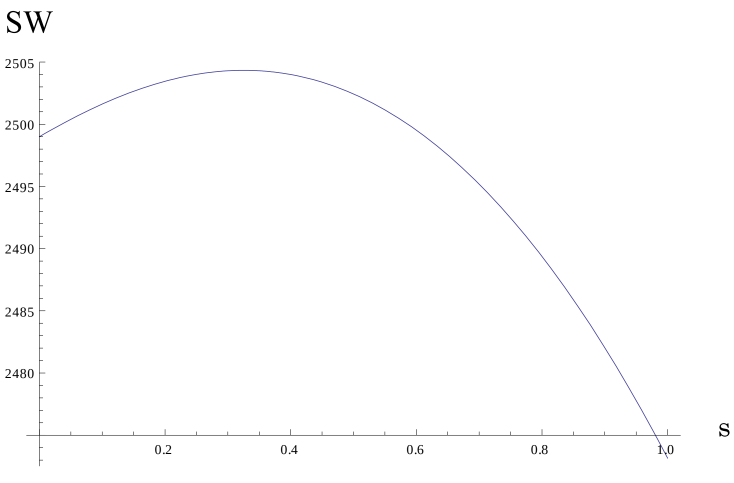

Fig. 6 Social welfare ($t = 6$)

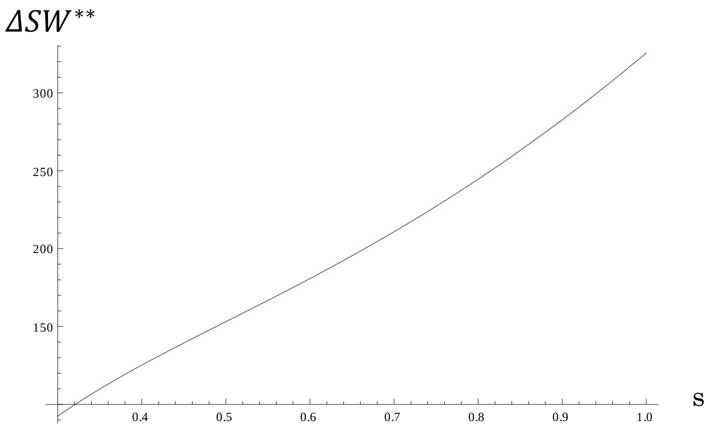

Fig. 7 Difference of social welfare ($t = 1.5$)

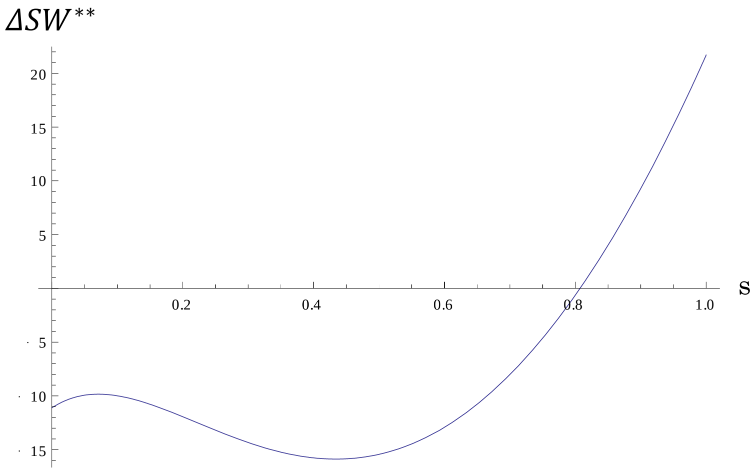

Fig. 8 Difference of social welfare ($t = 2$)

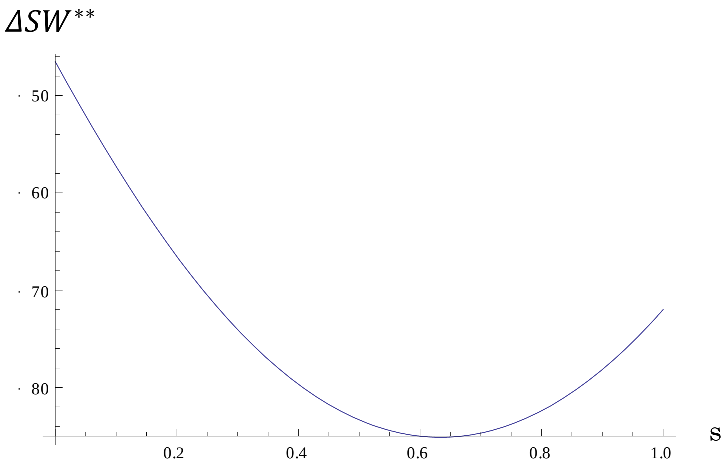

Fig. 9 Difference of social welfare ($t = 3$)

ΔSW^{***}

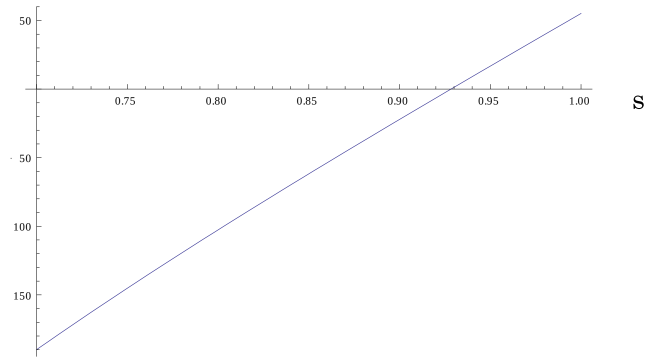

Fig. 10 Difference of social welfare ($t = 1.5$)

ΔSW^{***}

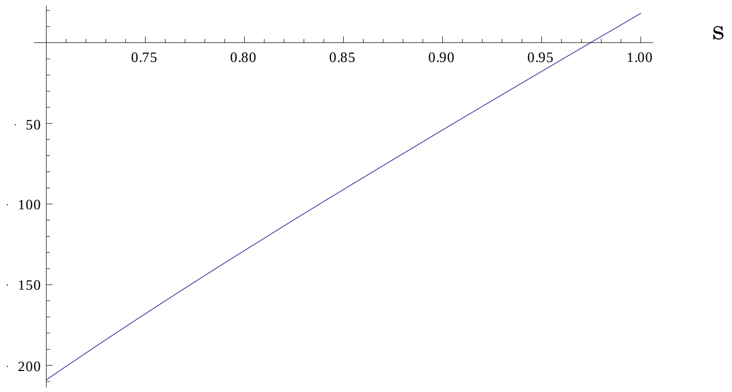

Fig. 11 Difference of social welfare ($t = 1.55$)

ΔSW^{***}

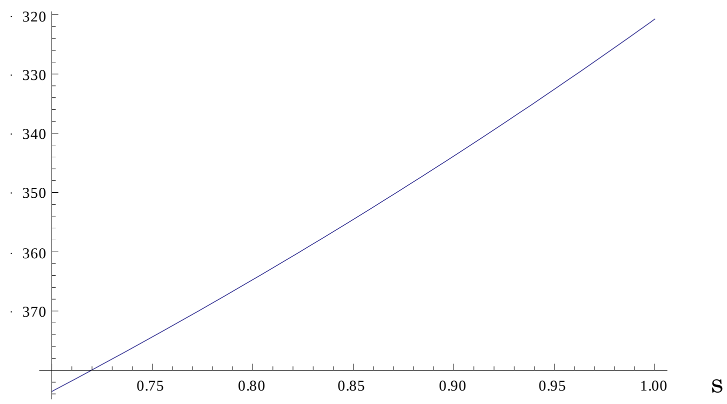

Fig. 12 Difference of social welfare ($t = 3$)