Taxation or subsidization policy for new technology adoption in oligopoly

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Abstract

Adoption of new technology by firms is very important for economic growth of a country. However, it may be insufficient or excessive in less competitive industries from the point of view of social welfare. Then, subsidization or taxation by the government is necessary. We present an analysis about subsidy or tax policy for adoption of new technology in an oligopoly with a homogeneous good. The unit cost with the new technology is lower than that with the present technology, but each firm must expend a fixed set-up cost to adopt and use the new technology. We will show that if the number of firms is small, and the set-up cost is large, subsidization to promote adoption of new technology may be the optimum policy. However, if the number of firms is not so small, or the set-up cost is not so large, taxation to prevent adoption of new technology is likely to be the optimum policy.

Keywords: subsidy or tax policy, new technology adoption, oligopoly

JEL Classification code: D43, L13.

1. Introduction

We consider the following story. There is an oligopolistic industry in a country. The firms in the industry produce a homogeneous good. The firms can use a common new production technology which is more efficient than the present technology. The production cost with the new technology is lower than that with the present technology, however each firm in the industry must expend some fixed set-up cost to adopt and use the new technology. Adoption of new technology by firms is very important for economic growth of a country. However, it may be insufficient or excessive in less competitive industries from the point of view of social welfare. Then, subsidization or taxation by the government is necessary.

There are many references about technology adoption or R&D investment in duopoly or oligopoly. Examples are Katz and Shapiro (1985) , Kamien and Tauman (1986) , Sen and Tauman (2007), Kabiraj (2004), Wang and Yang (2004), Filippini (2005), La Manna (1993). Matsumura, Matsushima and Cato (2013) and Pal (2010). Concerning empirical studies H. Tanaka (2013, 2014) examined success factors of technology transfer from Japan to Taiwan (Republic of China) in post Word War 2 period. He stressed the importance of social capability which reduces the technology transfer cost such as human capacity of bureaucracy and managers, and the role of the government for improvement of infrastructure, education and training of workers and engineers. Also, he claims that government should choose the industry where foreign company can receive the tax benefit. And he concludes that these factors which promote technology transfer lead Taiwan to economic growth.

We think that public policy for technology adoption, or international technology assistance has not been studied except for few works. In Hattori and Y. Tanaka (2014) adoption of new technology by firms in a Cournot duopoly with differentiated goods is analyzed. Also, Hattori and Y. Tanaka (2015) analyzed tax or subsidy policy for new technology adoption in a duopoly. This paper extends that analysis to a case of oligopoly.

We analyze the optimum subsidization or taxation policies about adoption of new technology by firms in an oligopoly with a homogeneous good. We consider the following three-stage game.

1. The first stage: The government determines the level of subsidies to (or taxes on) the firms.
2. The second stage: The firms decide whether they adopt new technology or not.
3. The third stage: The firms determine their outputs.

The social welfare is defined to be consumers' utility (evaluated by monetary measure) plus firms' profits. Subsidies to the firms are financed by lump-sum taxes on consumers, and revenues from taxes on the firms are transferred to consumers in a lump-sum manner. These lump-sum taxes and transfers are not related to the good of this industry. Excluding income effect, they do not affect the demand for the good, and they are canceled out in the social welfare.

We will show that if the number of firms is small, and the set-up cost is large, subsidization to promote adoption of new technology may be the optimum policy. In this case the increase in the social welfare (excluding set-up cost) due to adoption of new technology by a firm exceeds the increase in the profit of that firm (excluding set-up cost). However, if the number of firms is not so small, or the set-up cost is not so large, taxation to prevent adoption of new technology is likely to be the optimum policy. In this case the increase in the profit of a firm due to adoption of new technology by that firm exceeds the increase in the social welfare.

The reason why the optimum policy is likely to be taxation seems to be that the increase in the social welfare (excluding set-up cost) due to adoption of new technology is the difference between the social welfare when m firms adopt new technology and the social welfare when $m-1$ firms adopt new technology; on the other hand, the increase in the profit of a firm (excluding set-up cost) due to adoption of new technology is the difference between the profit of an *adopting firm* when m firms adopt new technology and the profit of a *non-adopting firm* when $m-1$ firms adopt new technology. Please see the examples in Subsection 5.4.

In the next section we present the model of this paper, in Section 3 we analyze firm behavior, in Section 4 we consider the social welfare, and in Section 5 we examine the optimum policies.

2. The model

There are n firms which produce a homogeneous good, and consider adoption of new technology. n is an integer number which is not smaller than 2. The unit cost with the new technology is lower than the unit cost with the present technology, however, each firm must expend a fixed set-up cost to adopt and use the new technology.

Suppose that the first m firms adopt new technology, and the remaining $n-m$ firms do not adopt. m is an integer number such that $0 \le m \le n$. Call a firm which adopts new technology *adopting firm* and denote it by i. Call a firm which does not adopt *non-adopting firm* and denote it by j.

Denote the output of and the demand for the good of Firm i (or j) by x_i (or x_j), the price of the good by p. The utility function of consumers is

$$u = a\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right) - \frac{1}{2}\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right)^2 + v,$$

where a is a positive constant, and v is consumption of the numéraire good. We normalize the population of consumers as one. Let y be a fixed income of consumers. The budget constraint for consumers is written as follows.

$$v = y - p\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right),$$

Then, the utility of consumers is rewritten as

$$u = a\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right) - \frac{1}{2}\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right)^2 - p\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_i\right) + y.$$

The inverse demand function is derived as follows.

$$p = a - \left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right).$$

The cost function of Firm i (or j) before adoption of new technology is cx_i (or cx_j), and the production cost of each firm after adoption of new technology is zero. A fixed set-up cost is e. c and e are positive constants and common to all firms. There exists no fixed cost other than the set-up cost. We assume $a > nc$ so that the output of each firm is positive.

The total profit of firms is

$$\sum_{i=1}^{m}\left(px_i - c_i(x_i)\right) + \sum_{j=m+1}^{n}\left(px_j - c_j(x_j)\right) + S.$$

$c_i(x_i)$ or $c_j(x_j)$ generally denotes the cost function of Firm i or j which may include the set-up cost of new technology. S is the total lump-sum subsidy to the firms. If $S < 0$, it is the total tax. Subsidies to the firms are financed by lump-sum taxes on consumers, and revenues from taxes on the firms are transferred to consumers in a lump-sum manner. Let T be the total lump-sum tax on consumers. If $T < 0$, it is the total lump-sum transfer to consumers. The social welfare is written as

$$\begin{aligned} W &= a\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right) - \frac{1}{2}\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right)^2 - \sum_{i=1}^{m} c_i(x_i) - \sum_{j=m+1}^{n} c_i(x_i) \\ &\quad + S - T + y \\ &= a\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right) - \frac{1}{2}\left(\sum_{i=1}^{m} x_i + \sum_{j=m+1}^{n} x_j\right)^2 - \sum_{i=1}^{m} c_i(x_i) - \sum_{j=m+1}^{n} c_j(x_j) + y, \end{aligned}$$

because $S = T$. Hereafter we eliminate y because it is fixed. The lump-sum taxes and transfers are not related to the good of this industry. Since the utility function of our model is quasi-linear, there is no income effect of consumers' demand. Thus, lump-sum taxes and transfers do not affect the demand for the good. Also our analysis is a partial equilibrium analysis.

If adoption of new technology and non-adoption are indifferent for a firm, then it adopts new technology. Similarly, if adoption of new technology and non-adoption are indifferent for the society, the government chooses adoption.

3. Firm Behavior

The profit of an adopting firm is written as

$$\pi_i = \left(a - \sum_{k=1}^{m} x_k - \sum_{j=m+1}^{n} x_j\right)x_i - e,$$

and the profit of a non-adopting firm is

$$\pi_j = \left(a - \sum_{i=1}^{m} x_i - \sum_{l=m+1}^{n} x_l\right)x_j - cx_j.$$

We assume Cournot type behavior of firms. In this section e may include a lump-sum subsidy to or a lump-sum tax on each firm. The first order condition of profit maximization for an adopting firm is

$$a - 2x_i - \sum_{k=1,k\neq i}^{m} x_k - \sum_{j=m+1}^{n} x_j = 0,$$

and the first order condition of profit maximization for a non-adopting firm is

$$a-2x_j-\sum_{i=1}^{m}x_i-\sum_{l=m+1,l\neq j}^{n}x_l-c=0.$$

At the equilibrium the outputs of all adopting firms are equal, and the outputs of all non-adopting firms are equal. Thus, these equations are rewritten as

$$a-(m+1)x_i-(n-m)x_j=0,$$

and

$$a-mx_i-(n-m+1)x_j-c=0.$$

Denote the equilibrium outputs of Firm i and j when m firms adopt new technology by x_i^m and x_j^m. Then,

$$x_i^m=\frac{a+(n-m)c}{n+1},$$

$$x_j^m=\frac{a-(m+1)c}{n+1}.$$

Denote the equilibrium price of the good and the equilibrium profits of Firm i and j by p^m, π_i^m and π_j^m. Then,

$$p^m=\frac{a+(n-m)c}{n+1},$$

$$\pi_i^m=\left[\frac{a+(n-m)c}{n+1}\right]^2-e,$$

$$\pi_j^m=\left[\frac{a-(m+1)c}{n+1}\right]^2.$$

A superscript m means that the number of new technology adopting firms is m.
When $m-1$ firms adopt new technology, we have

$$\pi_j^{m-1}=\left(\frac{a-mc}{n+1}\right)^2.$$

Let

$$\Phi(m)=\pi_i^m+e-\pi_j^{m-1}=\frac{nc[2a+(n-2m)c]}{(n+1)^2}.$$

This is strictly decreasing with respect to m. We can see

1. If $\Phi(m)>e$, adoption of new technology by a non-adopting firm is beneficial when $m-1$ firms adopt.
2. If $\Phi(m)<e$, abandon of new technology by an adopting firm is beneficial and non-adoption is the best response for each non-adopting firm when m firms adopt.
3. If $\Phi(m)=e$, adoption and non-adoption are indifferent for each firm.

Let $\tilde{m}$ be an integer number such that

$$\Phi(m)\geq e \text{ and } \Phi(m+1)<e.$$

Then, since $\Phi(m)$ is strictly decreasing in m, $\tilde{m}$ is the equilibrium number of new technology adopting firms, that is, at the sub-game perfect equilibrium of the game after the second stage $\tilde{m}$ firms adopt new technology. $\tilde{m}$ is decreasing with respect to e. If $e \le \Phi(n)$, the equilibrium number of adopting firms is n, and if $\Phi(1) < e$, the equilibrium number of adopting firms is 0.

4. Social welfare

Denote the total output of the good when m firms adopt new technology by X^m. Then,

$$X^m = \frac{na-(n-m)c}{n+1}.$$

The social welfare when m firms adopt new technology is denoted as

$$W^m = aX^m - \frac{1}{2}(X^m)^2 - (n-m)cx_j^m - me = \frac{A}{2(n+1)^2} - me,$$

where

$$A = 2c^2mn^2 + c^2n^2 - 2acn^2 + a^2n^2 - 2c^2m^2n + 2c^2mn + 2acmn + 2c^2n - 4acn + 2a^2n$$
$$-3c^2m^2 - 2c^2m + 4acm.$$

Let

$$\Psi(m) = W^m + e - W^{m-1} = \frac{(4a + 2cn^2 - 4cmn + 4cn + 2an - 6cm + c)c}{2(n+1)^2}.$$

This is strictly decreasing with respect to m. We can see

1. If $\Psi(m) > e$, adoption of new technology by a non-adopting firm improves the social welfare when $m-1$ firms adopt.
2. If $\Psi(m) < e$, abandon of new technology by an adopting firm improves the social welfare when m firms adopt.
3. If $\Psi(m) = e$, they are indifferent.

Let m^* be an integer number such that

$$\Psi(m) \ge e \text{ and } \Psi(m+1) < e.$$

Since $\Psi(m)$ is strictly decreasing in m, m^* is the optimum number of new technology adopting firms for the society, that is, when m^* firms adopt new technology the social welfare is maximized. m^* is decreasing with respect to e.

If $e \le \Psi(n)$, the optimum number of adopting firms is n, and if $\Psi(1) < e$, the optimum number of adopting firms is 0.

5. Subsidies or taxes

5.1. The optimum policies

In this section we consider a subsidy or tax policy by the government for new technology adoption in an oligopoly. Here e denotes only the set-up cost. It does not include a lump-sum subsidy nor tax.
There are three cases.

1. If $m^* > \tilde{m}$, the government should give subsidies to the firms for new technology adoption. In this case the government should give chances to receive subsidies to all firms. Let s be the level of the subsidy. Then,

$$\Phi(m^*+1) < e - s \leq \Phi(m^*)$$

must be satisfied. The level of the subsidy to each firm must not be smaller than $e - \Phi(m^*)$ and must be smaller than $e - \Phi(m^*+1)$.

In actuality m^* firms receive the subsidies and adopt new technology.

2. If $m^* < \tilde{m}$, the government should impose taxes on the firms so as to decrease the number of new technology adopting firms. In this case the government should impose taxes on all firms. Let t be the level of the tax. Then,

$$\Phi(m^*+1) < e + t \leq \Phi(m^*)$$

must be satisfied. The level of the tax on each firm must not be larger than $\Phi(m^*) - e$ and must be larger than $\Phi(m^*+1) - e$.

In actuality m^* firms pay the taxes and adopt new technology.

3. If $m^* = \tilde{m}$, the government should do nothing.

5.2. Condition for subsidization to be the optimum policy

Comparing $\Phi(m)$ and $\Psi(m)$ yields

$$\Phi(m) - \Psi(m) = \frac{(2an - 4a + 6cm - c - 4cn)c}{2(n+1)^2}. \tag{1}$$

If $n \geq 2$ and $a \geq 2c$, this is increasing in m and a, and increasing in n when n is not so large. It represents the difference between the increase in the profit of a firm (excluding set-up cost) when it adopts new technology and the increase in the social welfare (excluding set-up cost) by that adoption. (1) implies that if a and n are small, and e is large (because the equilibrium value of m is small when e is large), $\Phi(m) - \Psi(m)$ may be negative. If it is negative, the increase in the social welfare due to adoption of new technology by a firm exceeds the increase in the profit of that firm, and then subsidization is the optimum policy.

Since $\Phi(m) - \Psi(m)$ is increasing in m, we need $\Phi(1) - \Psi(1) \leq 0$ for subsidization to be the optimum policy. Solving $\Phi(1) \leq \Psi(1)$, we get $n \leq \frac{4a-5c}{2(a-2c)}$. Since $a > nc$, n must not be larger than 3. Thus, the optimum policy is never subsidization when the number of firms is larger than 3. Also, the set-up cost need to be large for subsidization to be the optimum policy. Summarizing the results,

Proposition 1.

1. The optimum policy may be subsidization if the number firms in the industry is small, and the set-up cost is large.
2. The optimum policy is taxation or to do nothing if the number firms in the industry is not so small or the set-up cost is not so large.

5.3. Discussion about the effects of the number of firms

As shown in Hattori and Y. Tanaka (2015) and the examples in the next section when the number of firms is small (two or three), subsidization may be the optimum policy, but when the number of firms is large, subsidization cannot be optimum. Let us consider the reason.

As we pointed out just before Proposition 1 subsidization can be optimum only if $\Phi(1)-\Psi(1)\leq 0$. We have

$$\Phi(m)=\frac{nc[2a+(n-2m)c]}{(n+1)^2},\Psi(m)=\frac{(4a+2cn^2-4cmn+4cn+2an-6cm+c)c}{2(n+1)^2},$$

and $\Phi(m)-\Psi(m)$ is expressed in (1). $\Phi(m)$ is the difference between the profit of each adopting firm when m firms adopt the new technology and the profit of each non-adopting firm when $m-1$ firms adopt. $\Psi(m)$ is the difference between the social welfare when m firms adopt new technology and the social welfare when $m-1$ firms adopt. Denote the numerators of $\Phi(m)$ and $\Psi(m)$, respective, by φ and ψ. Denominators of $\Phi(m)$ and $\Psi(m)$ are equal. Now compare the derivatives of φ and ψ with respect to n. Then, for any value of m

$$\frac{\partial\varphi}{\partial n}-\frac{\partial\psi}{\partial n}=(a-2c)c>0.$$

Thus, as the number of firms n increases, the numerator of $\Phi(m)$ more rapidly increases than the numerator of $\Psi(m)$. It is the reason why the larger the number of firms in oligopoly, the more likely taxation is optimum.

5.4. Examples

We consider the following four cases to illustrate the results of this paper.

1. Assume $a=12$, $c=2$, $n=5$. The values of $\Phi(m)$ and $\Psi(m)$ are shown in Table 1. $W+e$ in the following tables represents the social welfare excluding the set-up cost.

m	$\Phi(m)$	$\Psi(m)$	$W+e$	π_i^m+e	π_j^m
0			48.61		2.8
1	8.3	7.17	55.78	11.1	1.78
2	7.22	5.7	61.5	9	1
3	6.1	4.3	65.8	7.1	0.4
4	5	2.8	68.6	5.4	0.1
5	3.9	1.4	70	4	

Table 1. $a=12$, $c=2$, $n=5$

The optimum policies are as follows.

When $e>8.3$, $\tilde{m}=0,m^*=0$, the optimum policy is to do nothing.

When $7.22<e\leq 8.3$, $\tilde{m}=1,m^*=0$, the optimum policy is taxation.

When $7.17<e\leq 7.22$, $\tilde{m}=2,m^*=0$, the optimum policy is taxation.

When $6.1 < e \leq 7.17$, $\tilde{m} = 2, m^* = 1$, the optimum policy is taxation.
When $5.7 < e \leq 6.1$, $\tilde{m} = 3, m^* = 1$, the optimum policy is taxation.
When $5 < e \leq 5.7$, $\tilde{m} = 3, m^* = 2$, the optimum policy is taxation.
When $4.3 < e \leq 5$, $\tilde{m} = 4, m^* = 2$, the optimum policy is taxation.
When $3.9 < e \leq 4.3$, $\tilde{m} = 4, m^* = 3$, the optimum policy is taxation.
When $2.8 < e \leq 3.9$, $\tilde{m} = 5, m^* = 3$, the optimum policy is taxation.
When $1.4 < e \leq 2.8$, $\tilde{m} = 5, m^* = 4$, the optimum policy is taxation.
When $e \leq 1.4$, $\tilde{m} = 5, m^* = 5$, the optimum policy is to do nothing.

2. Assume $a = 6.9$, $c = 2$, $n = 3$. The values of $\Phi(m)$ and $\Psi(m)$ are shown in Table 2.

m	$\Phi(m)$	$\Psi(m)$	$W + e$	$\pi_i^m + e$	π_j^m
0			11.25		1.5
1	5.93	5.94	17.19	7.43	0.53
2	4.4	3.7	20.9	4.95	0.1
3	2.9	1.4	22.3	3.0	

Table 2. $a = 6.9$, $c = 2$, $n = 3$

The optimum policies are as follows.
When $e > 5.94$, $\tilde{m} = 0, m^* = 0$, the optimum policy is to do nothing.
When $5.93 < e \leq 5.94$, $\tilde{m} = 0, m^* = 1$, the optimum policy is **subsidization**.
When $4.4 < e \leq 5.93$, $\tilde{m} = 1, m^* = 1$, the optimum policy is to do nothing.
When $3.7 < e \leq 4.4$, $\tilde{m} = 2, m^* = 1$, the optimum policy is taxation.
When $2.9 < e \leq 3.7$, $\tilde{m} = 2, m^* = 2$, the optimum policy is to do nothing.
When $1.4 < e \leq 2.9$, $\tilde{m} = 3, m^* = 2$, the optimum policy is taxation.
When $e \leq 1.4$, $\tilde{m} = 3, m^* = 3$, the optimum policy is to do nothing.

3. Assume $a = 5$, $c = 2$, $n = 2$. The values of $\Phi(m)$ and $\Psi(m)$ are shown in Table 3.

m	$\Phi(m)$	$\Psi(m)$	$W + e$	$\pi_i^m + e$	π_j^m
0			4		1
1	4.4	5.1	9.1	5.4	0.1
2	2.7	2	11.1	2.8	

Table 3. $a = 5$, $c = 2$, $n = 2$

The optimum policies are as follows.
When $e > 5.1$, $\tilde{m} = 0, m^* = 0$, the optimum policy is to do nothing.
When $4.4 < e \leq 5.1$, $\tilde{m} = 0, m^* = 1$, the optimum policy is **subsidization**.

When $2.7 < e \leq 4.4$, $\tilde{m} = 1, m^* = 1$, the optimum policy is to do nothing.
When $2 < e \leq 2.7$, $\tilde{m} = 2, m^* = 1$, the optimum policy is taxation.
When $e \leq 2$, $\tilde{m} = 2, m^* = 2$, the optimum policy is to do nothing.

4. Assume $a = 17$, $c = 2$, $n = 8$. The values of $\Phi(m)$ and $\Psi(m)$ are shown in Table 4.

m	$\Phi(m)$	$\Psi(m)$	$W + e$	$\pi_i^m + e$	π_j^m
0			111.11		2.77
1	9.08	7.23	118.34	11.86	2.08
2	8.29	6.29	124.64	10.38	1.49
3	7.50	5.35	130	9	1
4	6.71	4.41	134.41	7.71	0.6
5	5.92	3.48	137.90	6.53	0.3
6	5.13	2.54	140.44	5.44	0.11
7	4.34	1.6	142.04	4.45	0.01
8	3.55	0.66	142.71	3.56	

Table 4. $a = 17$, $c = 2$, $n = 8$

The optimum policy is to do nothing if $e > 9.08$ or $e \leq 0.66$. In all other cases the optimum policy is taxation.

The optimum policy is subsidization in only two cases. These examples suggest that if the number of firms in the industry is not so small or the set-up cost is not so large, the optimum policy is unlikely subsidization.

6. Concluding Remark

In this paper we have analyzed the optimum policy for new technology adoption in an oligopoly using a simple model with a homogeneous good. The type of optimum policies, subsidization or taxation or do-nothing, depends on the level of the set-up cost and the number of firms in the oligopoly. We have shown that taxation is more likely the optimum policy than subsidization. Subsidization may be the optimum policy only when the number of firms is small, and the set-up cost is large.

The reason why the optimum policy is likely to be taxation seems to be that the value of $\Psi(m)$ is the difference between the social welfare when m firms adopt new technology and the social welfare when $m-1$ firms adopt new technology; on the other hand, $\Phi(m)$ is the difference between the profit of an *adopting firm* when m firms adopt new technology and the profit of a *non-adopting firm* when $m-1$ firms adopt new technology.

We want to generalize the analyses in this paper to a case of heterogenous goods and a case of general demand and cost functions.

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