
The Economic Effects of R & D Subsidies and R&D Spillovers

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Table of Contents

1. Introduction
2. Market failure
 - 2.1. Spillovers, appropriability, and public goods
 - 2.2. Patent protection
3. R&D subsidies in oligopoly models
 - 3.1. Cooperative and noncooperative R&D
 - 3.2. R&D subsidies in two-stage games
 - 3.3. Asymmetric oligopoly
 - 3.4. Conjectural variations
4. R&D subsidies and product differentiation
 - 4.1. Vertical product differentiation
 - 4.2. Horizontal product differentiation
5. International markets and uncertainty
 - 5.1. International market in Oligopoly
 - 5.2. Uncertainty in R&D subsidies
 - 5.2.1. Cost-side uncertainty
 - 5.2.2. Demand-side uncertainty
6. Empirical evidence
7. Conclusions

The Economics Effects of R&D Subsidies

Abstract

This paper reviews the main theoretical models of R&D subsidies as well as the main empirical results. R&D subsidies have been proven to be beneficial to encourage R&D investments contributing to reduce costs, improve quality, lower entry barriers, increase competition, and improve allocative efficiency. However, in general, the socially optimal level of R&D expenditures can not be achieved due to market failures related to spillovers, externalities, appropriability, and the public good aspect of information. This paper evaluates and compares R&D subsidies under varying oligopoly models, and examines the effects of improvement of product quality. In the international trade market, R&D subsidies have been employed to capture more market share in the world market and boost the profits of domestic firms.

Keywords: R&D subsidies, R&D, Spillovers, Appropriability

1. Introduction

Why would public authorities subsidize the R&D of privately owned firms? What types of firms end up getting public subsidies? Should the authorities subsidize high-quality or low-quality firms? Are there interaction effects between a firm's participation in a public R&D program and its R&D effort? What is the optimal level of R&D subsidies? These questions drove numerous economists to research R&D policies and R&D subsidies. Economists are seeking to understand the market performance, firm behaviour, and correct market failures.

Competition authorities have realized that innovation plays an important role of determining the competitiveness of an industry.¹ Firms develop new products with lower costs to improve their competitive position which improves industry performance.² R&D investment is one of the more effective means of cost reduction. Market forces provide firms with economic incentives to engage in R&D investment. However, when firms invest in R&D, the negative effect of spillovers has to be taken into account in that spillovers reduce the incentives of firms to conduct R&D investment, and influence both the "causes and consequences" of R&D investment.³ Government authorities intervene to restore R&D incentives. The most direct way to deal with that problem is to subsidize the activity for which the market provides suboptimally low incentives.

Government authorities design various R&D subsidies programs in response to

¹ Siebert, 2003

² Spence, 1984

³ Lee, 1998, p. 77

the type of competition (Cournot versus Bertrand), type of market conditions (domestic versus international setting), and also the type of R&D (cost reducing versus quality improving).⁴

The purpose of this paper is to review the theoretical as well as empirical literatures on the economic aspects of R&D subsidies. The paper is organized as follows. Section 2 reviews the market failures associated with R&D activities, including spillovers and appropriability, and studies the remedy of patent protection. Section 3 evaluates oligopoly models. The optimal R&D subsidies may vary in response to different market structures. Section 4 examines the effects of R&D subsidies on quality improvement and product differentiation. Section 5 reviews theories and applications of R&D subsidies as a trade and industrial policy instrument in the international market. The deterministic model of international R&D rivalry of Spencer and Brander is generalized by introducing uncertainty. Section 6 reviews the empirical works associated with R&D subsidies. Section 7 concludes.

2. Market failures

It is important to understand how market failures work in technology markets. Petrakis and Poyago-Theotoky (2002) explored the process. Suppose there is no involuntary information sharing, so firms have a tendency to over-invest in R&D to

⁴ Siebert, 2003; Haaland and Kind, 2004; Spencer and Brander, 1983

gain an advantage over their rivals. This is called a strategic over-investment effect. When there are positive spillovers, firms tend to under-invest in R&D. Here comes the familiar appropriability problem which leads to a strategic under-investment effect.⁵ Both effects induce an R&D market failure – firms choose the wrong level of R&D relative to social optimum. In addition, the leading innovators are not rewarded for sharing information, creating a public good problem.

This issue has received considerable attention in the theoretical literature. Spence (1984) evaluated the performance, incentives, competition, and cost reduction under different level of spillovers. Arrow (1962) and Usher (1964) argued that the market fails to provide the socially optimal level of R&D expenditure because of the public properties of information. The purpose of Romano (1989) is to explore the usefulness of R&D subsidization in markets where patent protection is available. Petrakis and Poyago-Theotoky (2002) reviewed the patent system problem in the context of spillovers and pollution.

In the following sections, market failures related to spillovers, appropriability, and free riding (public good) will be discussed based on Spence (1984). Patent protection as one of the suggested solutions to correct these problems will be studied as well.

2.1. Spillovers, appropriability, and public goods

In the presence of spillovers, the private R&D expenditure is lower than the

⁵ Petrakis and Poyago-Theotoky, 2002.

socially desirable level. Spence (1984) evaluated the performance of markets with varying structures, including concentration, spillovers, and the technology of cost reduction.

The principle conclusion is that potential performance (performance with subsidies) is significantly better with high spillovers. While spillovers reduce the incentives for cost reduction, they also reduce the costs at the industry level of achieving a given level of cost reduction. The incentives can be restored through subsidies. Subsidies therefore are sufficient to determine the costs at the industry level, and induce optimal R&D investment.

While spillovers have a negative effect on cost reduction and performance, they provide other benefits. In Spence's model, 1) the absence of spillovers does not eliminate performance problems. In the first best unregulated market, the highest performance occurs when there are two firms and the spillover rate is 0.25. 2) Appropriability raises industry R&D costs associated with a given level of cost reduction. When there are no spillovers, the cost reduction is too expensive because each firm has to invest own R&D so that there is too much R&D in the market. When the spillover rate is equal to 1 (firms share all information), a small amount of R&D leads to higher performance and more effective cost reduction. Spence suggested that if one wants to operate on incentives through subsidizing R&D, it is better to do it in the lower cost environment (i.e. higher spillovers).

However, Nakao (1989) found that if the spillover rate is large, the R&D

equilibrium point may become unstable unless the R&D behaviour of oligopolists becomes, at least partly, collusive under a conjectural variations model. Because rival firms' R&D investment can affect the firm's profits through patents (the first innovator's patent makes it difficult for the following innovators to use the information), the effect of a change in a firm's R&D investment on its own profits is exceeded by the total effect of a change in the rival firms' R&D investment, which makes the equilibrium unstable.

In addition, Spence studied the case where firms might "imperfectly anticipate or even ignore the effects of their own R&D investments on the costs of other firms and/or industry prices"⁶. The effect of underestimating or ignoring spillovers is to make the investment decisions of firms more aggressive. Intuitively, more aggressive R&D investments based on underestimated or ignored spillovers increase entry barriers and reduce the number of viable competitors. Ignoring the effects of spillovers is equivalent to removing a negative term in the expression for the marginal return on R&D investment. Spence found that markets in which there are high spillovers but firms underestimate spillovers' effects on prices, perform much better than the same markets populated by fully informed firms. The positive effect on performance comes from the increasing efficiency of R&D investments. The failure of anticipating spillovers partially solves the incentive problem created by spillovers under full information.

In markets with high spillovers (above .25), performance is improved

⁶ Spence, 1984, p. 115

significantly when firms ignore spillovers. The positive effect on performance comes from the increased efficiency of the R&D investments, while the failure to anticipate spillovers partially solves the incentive problem. Spence illustrated an example that certain of the electronics industries have high spillovers but perform quite well in terms of dynamic technical efficiency.

Although almost all of the studies in the strategic investment literature deal with horizontal spillovers between competing firms, spillovers between buyers and seller, which are called vertical spillovers, are one example of interindustry spillovers. Atallah (2002) examined vertical spillovers between upstream and downstream firms, focusing on the interplay between vertical and horizontal spillovers. The conclusion is that vertical spillovers always increase R&D efforts and welfare while horizontal spillovers may increase or decrease them.

Spence mentioned that the output of R&D has the character of a public good as well, thus firms have weak incentives to supply it. He stated that it is preferable to supply the public good publicly or subsidize the private supplier without paying for the subsidy by charging the users on the basis of use. The R&D problem is essentially the same as the public good.

2.2. Patent protection

Market failures exist in the innovation process. Government authorities designed a number of policies to address these problems, most notably the patent system, which temporarily assigns the property right to the patented information for some period of

time. The first innovator's patent makes it difficult for the coming innovators to utilize effectively the related knowledge.

Romano (1989) studied the effectiveness of R&D subsidies when patents are available. With the opportunity to obtain patent protection, firms will have an incentive to invest in R&D. However, the market is unlikely to produce the socially optimal R&D. Subsidies can be a useful policy tool to induce firms to invest optimally. A number of variables have to be considered: the length of the patent life, the character of competition for the patent, and the extent of any excess burdens associated with subsidies⁷. Romano examined how optimal subsidies are affected by these variables.

He found that the optimal subsidy is always positive when there is monopoly in the research market.⁸ The monopolized research market is likely to produce too little research relative to the social optimum given the patent life because the value of the patent is lower than the socially optimal level, except for the infinite patent. To correct this problem, the monopolist can be initially induced to increase his private R&D expenditure through the subsidy.

In contrast, the optimal subsidy is zero if the patent life is long or the excess burden is high when there are no barriers to enter the research market. Any number of researchers may seek the innovation, though the property right to the innovation is awarded only to the first innovator. A competitive research places a lower value on the

⁷ There may be administrative or monitoring costs associated with R&D subsidies. In addition, the excess burdens resulting from tax revenues may finance the subsidies.

⁸ There is research monopoly if only one researcher can seek the innovation.

patent than a monopolist does. But the common property of a competitive research market offsets this discrepancy, and induces the socially optimal R&D expenditures. Moreover, the increase in social welfare resulting from optimal subsidies is always greater in a monopolized research market than in a free entry research market.

Nakao (1989) pointed out that the patent effect and the spillover effect are contradictory externalities because patent protection makes it difficult for rival firms to utilize the knowledge granted to the innovator. Through spillovers, the R&D activities have beneficial effects on other firms' activities, but R&D also has negative externalities: the patent effect.⁹ In line with Romano (1989), Nakao concluded that the optimal R&D subsidies are positive in collusive oligopoly. However in competitive oligopoly with low spillovers, the optimal R&D subsidies are negative because the patent effect overwhelms not only the spillover effect but also the gains in consumer surplus caused by the reduction in price.

Miyagiwa and Ohno (1997) investigated the linkage between the degree of appropriability of the new technology and the nature of the optimal R&D policy in the international market. In the cases of either low or high degrees of appropriability, R&D taxes are the optimal policy. However, at a first glance, taxing domestic R&D apparently hurts the home country to win a patent race, and affects welfare adversely. In two extreme cases, perfect appropriability and zero appropriability, R&D taxes have been clearly proved to improve domestic welfare. In the case of perfect appropriability, the patent race is important to competitors because losing a patent

⁹ Firms may be unable to share information and have to invest repeatedly.

means no access to the new technology. R&D investments are strategic complements, thus domestic firms invest more in the presence of R&D rivalry than under no competition. R&D taxes soften competition and lead to a welfare improvement. In the case of zero appropriability, the patent is not crucial because the new technology benefits both firms so that R&D investments are strategic substitutes. R&D taxes reduce the level of the domestic firm's investment, and cause the rival firms to pay for the R&D costs. However, the domestic firm can benefit from the rival's innovation as much as possible. Thus, R&D taxes improve domestic welfare.

3. R&D subsidies in oligopoly models

Governments seek to maximize the total surplus when providing R&D subsidies, supposing that firms' output and R&D investments correspond to the equilibrium outcome of a market. D'Aspremont and Jacquemin (1988) presented a two-stage duopoly model¹⁰ that is considered as a benchmark model in comparing noncooperative and cooperative R&D with different level of spillovers. Hinloopen (1997, 2001) analyzed a three-stage game with an additional stage in which authorities can subsidize R&D. Stenbacka and Tombak (1998) considered the interaction of subsidies and R&D cooperation in imperfectly competitive markets. Lahiri and Ono (1999) analyzed the question of optimal R&D subsidies in the context of a two-stage asymmetric Cournot duopoly model with endogenous R&D. They

¹⁰ In the first stage both firms simultaneously determine their R&D investment level. In the second stage they play with the price or quantity competition game in the product market.

conclude that a firm with an initial cost advantage invests more in R&D so that the difference between the two firms increases.

3.1. Cooperative and noncooperative R&D

D'Aspremont and Jacquemin (1988) argued that in some cases firms compete in some fields but cooperate in others, which is contrary to the usual assumption in most oligopoly models. They studied a two-stage duopoly with homogeneous products. In the first stage both firms simultaneously determine their R&D investment levels. In the second stage they play a price or quantity competition game in the product market. Under this framework, three different cases are presented: no cooperation in either the first or second stage; cooperation in R&D and competition in output; cooperation in both stages.

The results showed that for large spillovers, the level of R&D increases when firms cooperate in R&D and the amount of production is also higher with cooperation in R&D than in the noncooperative situation. The amount of R&D in the case of collusion in both output and R&D stages is higher than in pure R&D cooperation. Intuitively, less competition in the product market allows firms to capture more benefits created by R&D and induce more R&D expenditures.

D'Aspremont and Jacquemin also considered social welfare given these results. A higher level of R&D could induce excess duplication of R&D efforts ignoring R&D externalities. The clear conclusion is that cooperation in R&D (not in production) increases both R&D expenditures and the amount of production, whenever the

spillover effect is large enough; otherwise it is the reverse.

The purpose of Suzumura's (1992) paper is to examine the effects of cooperative R&D, where firms commit to a joint profit maximizing level of R&D in the first stage and then compete in the product market. The paper provides a careful examination of D'Aspremont and Jacquemin (1988) analysis with a more appropriate perspective as follows.

Suzumura found that the industry aggregate output at the Cournot Nash equilibrium always increases when one of the firms increases its cost-reducing R&D regardless of whether the R&D spillovers are large or small. An increase in R&D by a firm will increase the output of that firm. However, an increase in cost reduction R&D by one firm exerts two conflicting effects on other firms: increasing other firms' output through spillovers, and decreasing other firms' output by increasing the firm's competitive power. The former effect dominates the latter.

Suzumura questioned D'Aspremont and Jacquemin' (1988) another main point: first-best welfare (market surplus)¹¹function which gives rise to the problems of implementation for any government in a democracy. "...the enforcement of the first-best arrangement may require considerable leverage on the government vis-à-vis private firms, something which may be hard to secure in reality"¹² Therefore, he suggested a second best welfare function as an alternative welfare criterion. The welfare function presupposes that the oligopolistic competition in the second-stage

¹¹ D'Aspremont and Jacquemin, 1988: social welfare is the sum of the consumer's surplus and the producer's surplus. The solution to maximize social welfare requires not only more production but also a higher level of R&D than what is obtained with of the noncooperative and cooperative equilibria.

¹² Suzumura, 1992, p. 1308

quantity game lies beyond the regulatory power of the government. Suzumura examined and compared social welfare and profits of first-best and second-best in the cases of large spillovers and no-spillovers. The crucial findings are as follows. 1) The qualitative conclusions remain the same even if one uses the second-best welfare function instead of the first-best welfare function. 2) In the presence of large spillovers, not only the noncooperative but also the cooperative equilibrium R&D level is socially insufficient at the margin, so that the technology policy is marginally welfare-improving regardless of whether firms cooperate or not. The spillover effect dominates and leads to insufficient R&D investment. 3) In the absence of spillovers, the cooperative equilibrium R&D level is socially too small, while the noncooperative equilibrium R&D level is socially excessive at the margin. Thus, the technology policy should facilitate R&D investment if firms cooperate. 4) The increment of R&D at the noncooperative equilibrium marginally increases (decreases) joint profits if spillovers effects are large (small).

3.2. R&D subsidies in two-stage games

Besides cooperative R&D, R&D subsidies are another policy to stimulate private R&D expenditures.

Generalizing the D'Aspremont and Jacquemin (1988) two-stage model, Hinlopen (1997) introduced an active government which sets an R&D subsidy prior to the R&D stage. A three-stage game is presented in his work in which in the first stage authorities (optimally) subsidize R&D; in the second stage firms invest in R&D

either cooperatively or noncooperatively; in the last stage firms determine their production either cooperatively or noncooperatively.

Hinloopen re-examined and explained the main findings of d'Aspremont and Jacquemin (1988) and illustrated the main disadvantage of allowing firms to cooperate in the precompetitive stage. He found that when spillovers are relatively small, allowing for cooperative R&D will actually lower the R&D investment. While when spillovers are high, cooperative R&D investments are socially desirable. These findings depend on the interaction between two externalities associated with strategic R&D investments: a combined-profits externality and a competitive-advantage externality.¹³

Hinloopen concluded that subsidizing R&D optimally increases the level of R&D, output, and net total surplus, but lowers prices and net profit, regardless of the size of spillovers. The intuition is based on the incentives for investing in R&D. When there are no spillovers, there is no need for any government intervention if firms compete in both stages of the production process. But firms' incentives for investing in R&D are diluted if spillovers increase rivals' production efficiency. If spillovers are positive, governments can always improve the competitive market output, hence increase total welfare. Hinloopen showed that optimal R&D subsidies are positive, which confirms d'Aspremont and Jacquemin's (1988) results, and pointed out that fundamental research should be subsidized more than applied research, because R&D subsidies are

¹³ Defined by Kamien et al, 1992. A combined-profits externality is that any firm's R&D investment has an impact on both firms' profits. The innovator increases its production and has a larger market share at the expense of his rival. A competitive-advantage externality is that R&D investment benefits will spill over to its rival, and increase rival's production.

always increasing in the spillover rate, and fundamental research generates more spillovers than applied research. He also showed that subsidizing noncooperative R&D or subsidizing R&D cartels leads to the same market outcome so that sustaining R&D cooperatives is a redundant industry policy.

Moreover, from a social welfare point of view, there is no need to allow for R&D cooperatives when optimal R&D subsidies can be provided. To implement this policy, authorities can tax sales in the product market and subsidize R&D if firms confine themselves to sharing the outcomes of their R&D efforts. Hinloopen (2001) concluded that providing R&D subsidies to a competitive market enhances more private R&D investments than sustaining an R&D cooperative. Through the provision of R&D subsidies, government induces firms to comply with a level of R&D activity that maximizes net total surplus given the production stage.

Katz (1986) formalizes a four-stage game. In the first stage is a membership stage in which each firm decides simultaneously whether to participate in a cooperative research agreement. In the second stage, the member firms choose the R&D cost-sharing and R&D output-sharing rules with which members play the game. Each firm chooses its level of R&D investment to maximize its own profits taking the rules as given in the third stage. Finally, in the production stage, firms choose their levels of output in the product market given the production cost. Firms behave noncooperatively in the output market. Each firm makes its decision taking into account rivals' actions and the equilibrium of the prior stages. Specific models in the product market are considered such as independent product market, a homogeneous

good market, and imperfect substitutes market.

Katz intended to examine whether allowing firms in a given industry to form a cooperative R&D agreement can be effective to correct market failures (private R&D investment is lower than the socially optimal level), when members commit to the agreement. The most important conclusion is that R&D cost sharing raises the incentives to conduct R&D because firms can benefit from each other's cost reduction and invest more in R&D. The greater the competition among firms, the less possible it is to form an agreement to increase effective R&D. Under the assumption that a cooperative R&D agreement affects the product-market equilibrium only through unit costs, each firm's share of cooperative R&D cost depends on the output level. Firms may form the RJV to produce output, and a cooperative R&D agreement might increase the incentive to collude in the product market. But even under the agreement, the incentives to conduct R&D may be insufficient because part of the gains from R&D accrues to consumers.

Lee (1998) analyzed the regulated firms' attitudes toward R&D activities in the presence of interindustry spillovers, and also proposed an optimal R&D subsidy mechanism under local monopolies. A two-stage model has been considered in which regulated firms operate in different industries. Firms choose the level of R&D in the first stage, and then each regulated firm chooses its profit-maximizing output under welfare constrained regulation. If the monopolist is regulated to produce output at marginal cost in each market, cooperative investment equilibrium in R&D can be socially optimal. This implies that if well-controlled output regulation is imposed, it is

not necessary to control the firms' R&D choice under cooperation because cooperative firms can internalize the externality in their R&D activities. Lee proposed optimal R&D subsidies to achieve the social optimum regardless of whether firms cooperate or not. In line with d'Aspremont and Jacquemin (1988), he suggested that cooperative behaviour is more desirable in implementing the proposed regulatory scheme.

Kauko (1996) explored whether the oligopolistic nature of R&D is one reason of the low effectiveness of subsidies in a three-stage game. In his paper, R&D expenditures are strategic complements. When R&D expenditures are strategic complements, subsidizing firm A will lead to a positive effect on firm B which will expand its R&D expenditure, and as well stimulate firm A's R&D investment further. The R&D race therefore can easily become excessively aggressive, and firms may optimally reject R&D subsidies.

Atallah (2004) applied a more realistic approach, where firms engage simultaneously in noncooperative and cooperative R&D. There are two identical firms producing a homogeneous good using a constant returns to scale technology and competing a la Cournot. The game has two stages. In the first stage firms determine the optimal investments in both types of R&D, and in the second stage they compete in output. Atallah found that information sharing between cooperating firms contributes not only to cooperative R&D, but also to noncooperative R&D. These two types of R&D reinforce each other. The direct effect of information sharing is to increase cooperative R&D and reduce firms' cost. Meanwhile, the cost reduction

enhances noncooperative R&D investment, while the magnitude of the impact of information sharing on noncooperative R&D is smaller than that on cooperative R&D. Each type of R&D, by lowering the firms' cost, makes the other type of R&D more attractive, so as to increase its level.

Meanwhile, Atallah evaluated the subsidization of cooperative and noncooperative R&D. He pointed out that R&D subsidies are not a substitute for R&D cooperation, and suggested that R&D subsidies and R&D cooperation are independent. Because R&D subsidies and R&D cooperation both increase the marginal value of innovation, there is positive relationship between each other, and hence one should reinforce the other. It is optimal for the government to subsidize half the costs of cooperative R&D, while the optimal subsidy to noncooperative R&D is not affected by the presence of cooperative R&D. Subsidization of both types of R&D would lead their levels to approach the first best, as long as there is underinvestment in both.

3.3. Asymmetric oligopoly

Lahiri and Ono (1999) examined a two-stage game of duopoly. In the first stage two firms with different initial marginal costs decide on their cost-reducing R&D investments, and in the second stage compete in quantities. They showed that the distribution of profits among domestic firms has a very important implication for global welfare. Allowing for asymmetry in the marginal cost level among duopolists, the firm with higher market share should be subsidized in its R&D activities and the

other should be taxed. Intuitively, subsidizing a minor firm increases its profits and decreases the profits of rival firms. If the major firm is sufficiently large, it is socially desirable to improve its profits and subsidize its R&D investments.

In a model of asymmetric oligopoly without R&D, Lahiri and Ono (1988) and Ono (1990) showed that removing a firm which contributes little to domestic total surplus is welfare improving. While in the presence of R&D, a firm with even a slight cost advantage should be subsidized and the other firms should be taxed.

Spencer and Brander (1983) also considered three types of asymmetry in marginal costs. First, there may be exogenous asymmetry in demand for the two products or in costs. Second, a less restrictive model would admit multiple equilibria, including asymmetric equilibria. Finally, one country might have a timing advantage and be able to gain an advantage by moving first.

3.4. Conjectural variations

Extending Spence's (1984) analysis, Nakao (1989) explored competition in cost-reducing R&D and inter-firm externalities under a conjectural variations model. It is possible that R&D investments of one firm affect those of other firms, which cause externalities that are ignored by them. This paper attempted to close this interaction gap by constructing a conjectural variations model.

It is found that the collusive oligopoly requires subsidies for R&D to maximize total surplus because price competition is imperfect in such a market. Nakao concluded that the optimal subsidies become larger as either the number of firms in a

market decreases or the conjectural variation in output increases. Intuitively, the entry of a new firm into a market leads to the cost reduction which has the effect to reduce the incentives for R&D. The larger conjectural variation means the larger increase in the rival firms' R&D investment in response to the increase in its R&D investment, which results in lower incentives for R&D. In contrast, when the conjectural variation in both output and R&D are small, taxes might reduce the excessive R&D investment.

Nakao analyzed the welfare effect of the firms' collusive behaviour independently of those of market structure by "the anti-collusion policy" and "the demonopolization policy".¹⁴ A change in the number of firms affects both output and R&D investment directly, but a change in conjectural variation does not. The performance of the market is likely to be improved in collusive oligopoly subsidies. However, welfare may not be maximized by anti-collusion policy alone because reducing excessive R&D investment increases welfare as long as the patent effect exceeds the spillover effect.¹⁵

4. Quality and product differentiation

In the literature of product differentiation, goods can be either horizontally or vertically differentiated. R&D investments have the effect of improving the quality of products.

4.1. Vertical product differentiation

¹⁴ Nakao, 1989, p. 142

¹⁵ Nakao, 1989, p. 132: "Through the spillovers the R&D activities exert beneficial effects on each other's activities, but R&D also has negative externalities: 'the patent effect'." The first innovator's patent makes it difficult for following innovators to use knowledge.

As one type of R&D, quality-oriented R&D targets the improvement of product quality, such as new product introduction to a vertical product differentiation setting. Incumbents introduce new improved products of higher quality and withdraw existing models from the market. Governments have instituted various R&D programs to subsidize firms' R&D. The aim of subsidies to this type of R&D is to promote "national champions"¹⁶, which have been pursued in key industries in the 1950s and 1960s, and intend to keep current pace with international competition and provide higher product quality.

Siebert (2003) examined the impact of R&D subsidies provided to different firms to improve the product quality, price and variety offered in the market. He presented a duopoly model in which incumbents may introduce a new product with a certain quality. Siebert modeled a three-stage game. First, the innovator chooses the quality of its new product. Second, the innovator decides whether to withdraw the existing product from the market. Finally, firms maximize profits.

Siebert studied the equilibrium under different conditions: new product introduction by the low quality firm or the high quality firm. The conclusions are essentially based on the degree of product differentiation, the amount of R&D subsidies, and the property of high or low quality firms. First, it is profitable for the low quality firm to introduce a new product with high quality and withdraw the existing product from the market so as to soften price competition. Second, the high quality firm always has incentives to introduce a new product with high quality and

¹⁶ Stenbacka and Tombak, 1998; Siebert 2003.

withdraw the existing product from the market, in order to reduce price competition. The price of the low-quality product increases as well. This result is consistent with the leadership persistence of a high-quality firm (Lehmann-Grube, 1997).

This study confirmed that the result by Champsaur and Rochet (1989), established in a horizontal product differentiation setting, also holds in a pure vertical differentiation model. Firms will differentiate their products according to the principle of “maximal product differentiation” (Shaked and Sutton, 1982).

The implications of R&D subsidy in these cases are straightforward. For the low quality firm, if the subsidy is small, and the degree of product differentiation is large, even a small amount of cost reduction will reduce prices and trigger firms to introduce a new high quality product to earn more profits. While if the degree of product differentiation is low, the low quality firm may not innovate further, so as to soften price competition. If the high quality firm receives R&D subsidies, it always induces the firm to introduce a higher quality product and withdraw the existing product, which reduces price competition and increases the prices of both products. However, consumers have to pay higher prices, even those who were buying the low-quality product.

4.2. Horizontal product differentiation

Haaland and Kind (2004) constructed a simple model with horizontally differentiated consumer goods, where firms may invest in R&D to improve the quality of and hence the demand for their products. It is assumed that the goods are

produced in different countries within an economic union. Haaland and Kind analyzed the implications of non-cooperative and cooperative R&D policies across countries where only one firm exists and there are no spillovers. They examined the effect of R&D subsidies on the country's welfare through two means, by increasing consumer surplus through improving the overall quality of products, and by improving the competitive position of the domestic firm at home and abroad. They showed that net exporters of R&D intensive goods have relatively small incentives to provide R&D subsidies because of the possibility of vertical product differentiation between products in different countries. However, if R&D policies can be centralized at a union level, this problem may be solved. On the other hand, with cooperative R&D between several countries, union welfare may be lower than if there is no R&D coordination. Noncooperative R&D tends to give too small subsidies for horizontally differentiated goods and too high subsidies for goods that are close substitutes. In addition, output and R&D investments are higher the less horizontally differentiated the consumer goods are. This result reflects that an R&D subsidy reduces the marginal costs of quality improvements, and that a larger share of this cost reduction accrues to the consumers, the higher the competitive pressure between the firms.

Furthermore, while Leahy and Neary (1997) only focused on the interaction between innovators and imitators in symmetric countries, Haaland and Kind also studied the asymmetric cases. They considered the case with one small and one large country. Firm A is located in country A, and exports all its output to country B, where firm B and all the consumers are located. Suppose that good A is produced in a small

country, while good B is produced in a large country. The goods will be vertically differentiated. Country B will provide larger R&D subsidies than country A, and produce goods of a higher quality. The difference in product quality is increasing in the degree of horizontal differentiation between the goods. The closer horizontal substitutes the firms produce, the larger the vertical product differentiation will be. Intuitively, if the goods are completely independent (firms are monopolists), the government in country A has no incentive to provide subsidies to firm A, while country B will subsidize firm B in order to increase consumer surplus. If the goods are horizontally differentiated, both countries have incentives to subsidize their home firms to enlarge the share of the world market in terms of the business stealing effect. The smaller the price increase, the stronger the competitive pressure between the firms. Because country A cares about the producer surplus, a relatively small price effect for a high degree of horizontal differentiation given quality improvement may have a negative impact on country A. In contrast, it may be good for country B. Therefore, the R&D investments will be higher in country B than in country A.

5. International trade markets and uncertainty

5.1. International trade market in oligopoly

Spencer and Brander (1983) presented a theory to explain that industrial strategy policies play an important role when there is R&D rivalry between firms competing in an imperfectly competitive market. Spencer and Brander set up a two-stage game

played by two firms located in different countries but competing in a third country: in the first stage, firms choose R&D levels, and in the second stage output. This basic game is extended in several ways. 1) The government of one country is allowed to make a prior commitment to subsidize R&D. 2) Both governments are allowed to simultaneously set such R&D subsidies. 3) The domestic government is allowed to announce an export subsidy simultaneously with its announcement of a subsidy (or tax) on R&D. In each case, the subgame perfect equilibrium is examined for the extended three-stage game.

Spencer and Brander assumed that a government can credibly commit itself to R&D subsidies before the R&D decisions are made by firms. The domestic firm chooses the level of R&D to maximize its profit in the three-stage game. By providing R&D subsidies, the government facilitates the cost reduction (the domestic firm's reaction function shifts outward and its output and market share increases), and allows the domestic firm to earn higher profits net of the subsidy. The government is assumed able to offer a credible R&D subsidy, and can influence the final equilibrium. In addition, R&D subsidies financed by the government also allow firms to enjoy a higher level of profits without a price war which might result from the breakdown of the perfect Nash equilibrium.

Dixit (1988) found that such subsidies are sensitive to the number of domestic firms in the industry. Dixit extended the Spencer and Brander result to cases with more than two firms, and showed that an export subsidy in a Cournot oligopoly equilibrium is optimal as long as the number of domestic firms is not too large. Eaton

and Grossman (1986) considered the welfare effects of trade policy and industrial policy (production taxes and subsidies), and explored the optimal policy in output quantities competition with arbitrary conjectural variations. Consumers benefit from lower prices when the subsidy is employed, and the net effect on world welfare is positive, since the policy pushes prices toward their competitive levels.

5.2. Uncertainty in R&D subsidies

In the literature on international trade theory, a number of criticisms have been issued that an important element has been ignored by Spencer and Brander (1983): the existence of uncertainty associated with R&D investment.

5.2.1. Cost-side uncertainty

By introducing uncertainty into the Spencer and Brander model, Bagwell and Staiger (1994) considered two exporting countries and a third importing country, and examined subgame perfect equilibria of a three-stage game. First, the exporting governments simultaneously choose the unit costs of investment for their respective firms. A home country subsidy (tax) on investment then occurs if its cost is less (greater) than the social cost of investment. Second, having observed the policy choices of both exporting governments, both firms then simultaneously choose investment levels. At the third stage, firms compete in the product market (in prices or quantities). The introduction of uncertainty not only makes the Spencer and Brander model more realistic, but also strengthens their case for the usefulness of R&D subsidies. Bagwell and Staiger pointed out that the potential crucial problem is the

“inherent uncertainty associated with R&D”¹⁷. This uncertainty is associated with the potential results of the R&D project at the time of investment. If the production process is uncertain, and associated with a cost distribution, the investment might affect this distribution directly (alter the distributional properties of an existing technology).

Bagwell and Staiger concluded that the crucial determinant of R&D policy is not the form of product market competition, but rather the nature of uncertainty in the R&D process itself. They found that a negative externality is associated with investment and that investment reaction curves are negatively sloped, whether firms compete in prices or quantities. Particularly, with a single firm in each country, because a strategic domestic R&D subsidy¹⁸ raises domestic R&D and lowers foreign R&D, this result is beneficial to the domestic country. When there is more than one domestic firm engaged in R&D, a negative externality arises among these domestic firms, and so a corrective incentive emerges for an R&D tax. This can also be applied to explain an export subsidy. The appropriate R&D policy balances the strategic incentives to subsidize, and a subsidy is relatively more attractive the smaller the number of domestic firms.

Bagwell and Staiger also considered a game with either Hotelling competition in prices or Cournot competition in quantities with differentiated products. R&D has two opposite effects: mean effect (lowers the costs) and risk effect (increases the risk of

¹⁷ Bagwell and Staiger, 1994, p. 134

¹⁸ Strategic issues are explored in the context of national welfare and general determinants of R&D policy in a strategic international setting. Corrective issues study whether too little or too much R&D is undertaken relative to some socially optimal level.

the cost distribution), and the optimal R&D policy depends on the total result of these two effects. Considering price competition, the optimal R&D policy depends on the balance of those two effects, and on the relative number of domestic and foreign firms. In quantity competition, the results are analogous to those established by Spencer and Brander (1983).

In addition, Bagwell and Staiger (1992) explored the case in which firms battle for a monopoly position, and concluded that strategic subsidies and correctives taxes are optimal. In contrast, Miyagiwa and Ohno (1997) suggested that neither firm makes positive flow profits before innovation, and only the patent race winner makes a monopoly profit forever after innovation. If the patent is infinite, R&D taxes are an optimal policy.

While Bagwell and Staiger focused on uncertainty over cost reduction, innovators are also concerned with uncertainty over an “actual date of discovery”¹⁹ which is better analyzed in intertemporal models than in stage-game models. Therefore, Miyagiwa and Ohno (1997) studied the uncertainty of timing when the cost-reducing effect of R&D investment takes place within an intertemporal model. They extended Spencer and Brander’s (1983) analysis in two aspects: non-commitment on the part of the government, and the case in which R&D costs are borne over time; the degree of appropriability of the new technology and the nature of optimal R&D policy (patent protection is neither perfect nor permanent). Their paper complements the work of Bagwell and Staiger.

¹⁹ Miyagiwa and Ohno, 1997, p. 126

Miyagiwa and Ohno set up an intertemporal model in which each firm can improve its probability of discovery by investing in R&D, and then the winner can require the exclusive right to use the new technology for a given time interval, T . They concluded that R&D investments are strategic complements when T is large and strategic substitutes when T is small. Intuitively, at a low degree of appropriability, the benefits of the new technology spill over to the non-innovating firm quickly. An increase in the foreign firm's investment has little or no effect on the domestic firm's marginal benefits from R&D. Thus the marginal cost of R&D is high, and the domestic firm reduces R&D investments. Because subsidies do not affect the foreign firms' best-response schedule in this model, R&D subsidies always increase the domestic firm's equilibrium investment, and their effect on the foreign firm's R&D level depends on the slope of the foreign firm's best-response function. If R&D costs are borne over time, R&D taxes improve domestic welfare and become an optimal policy when T is either small or large. When T has an intermediate value, either R&D subsidies or taxes are likely to be the optimal policy according to the property of investments: strategic complements or strategic substitutes. If R&D costs are to be committed at time zero, R&D taxes are still an optimal policy at a low degree of appropriability while R&D subsidies are optimal at a high degree of appropriability.

5.2.2. Demand-side uncertainty

In the real world, it is very common that firms face not only cost-side uncertainty but also demand-side uncertainty. Arvan (1991) and Shivakumar (1993) have incorporated demand-side uncertainty into their model to examine relationships

among the degree of uncertainty, the number of firms, and the effects (or timing) of policy. They presented some new results which could not have been deduced in a deterministic model. Arvan (1991) considers a tax-subsidy game played between governments, and incorporates strategic interactions between governments. Demand uncertainty complicates the policy choice. Governments move either prior to or subsequent to the demand shock. Shivakumar (1993) considered a trade policy game in which the choice of policy and the time of implementation are endogenously determined.

In Arvan (1991) and Shivakumar (1993) papers, they assumed that firms are risk neutral, and do not face any uncertainty at the time of their decision-making while the authorities make political decisions under demand uncertainty. However, these assumptions are often unlikely to hold in reality. Recently, Ishii (2000) re-examined Spencer and Brander's (1983) R&D strategic policy model in an international Cournot duopoly. Ishii set up a two-stage game: firms decide an R&D levels facing demand uncertainty in the first stage, given governments' R&D subsidies, and then they choose output levels when demand uncertainty is resolved in the second stage. He questioned Spencer and Brander's assumption that firms do not face any uncertainty, and assumed that firms are risk averse under uncertainty, and incorporated a variable subsidy.

The paper showed that firms' R&D levels depend on a fixed subsidy as well as on a variable subsidy, and subsidies on firms' R&D levels vary depending on firms' attitudes toward risk. His paper aimed to discuss the effects of R&D subsidies and

firms' risk aversion on R&D levels, and some results conflict with those of Spencer and Brander (1983). For example, if a home firm's absolute risk aversion function is nondecreasing, a rise in the home R&D subsidy reduces home R&D and raises foreign R&D, which is contrary to Spencer and Brander (1983). It was shown that the firms' output or investment is usually smaller when it is risk averse than when it is risk neutral, and this result also holds in the R&D choice of an international Cournot firm facing demand uncertainty.

However, Ishii (2000) overlooked important sources of uncertainty, such as output uncertainty, input uncertainty, R&D spillovers uncertainty, and so on. He has also not discussed Stackelberg or Bertrand duopolies, and heterogeneous goods.

6. Empirical evidence

A number of empirical works have attempted to evaluate the effects of R&D subsidies on the R&D recipients, and the productivity of firms receiving them. Although the theoretical literature generally predicts that R&D subsidies have positive welfare effects, empirical evidence is needed to support the implications for policy makers in the actual decision-making process.

While the theoretical literature discusses the presence of "market failure" associated with government support to R&D, empirical studies are required to quantify the efficiency of R&D subsidies. Guellec and van Pottelsberghe de la Potterie (1997) stated that there are two important market failures: imperfect

appropriability and risk, and policy authorities use two focused policy instruments: government-funded R&D and fiscal incentives.²⁰ They empirically investigated whether fiscal incentives and direct subsidies stimulated R&D in 17 OECD countries over the period 1981-1996.

Guellec and van Pottelsberghe de la Potterie found that both fiscal incentives and direct subsidies stimulate private R&D investments, at least in the short run. In the long run, direct subsidies are more effective than fiscal incentives because direct subsidies lead firms to launch new projects while fiscal incentives may induce firms to focus on ongoing projects. There are also three main findings differentiating these policies across countries. 1) Countries that provide a level of subsidies that is too low or too high stimulate private R&D less than countries with an intermediate level of subsidisation. Intuitively, when firms are highly subsidized they may substitute government R&D for private funds. When R&D subsidies are low, firms may not have substantial incentive to conduct innovation and launch new R&D projects. 2) Countries with more stable fiscal and subsidisation policies are more likely to be effective than countries with less stable policies. The reason is that the R&D investment involves long term commitment, which can be translated into a sunk cost. Therefore, countries with more stable policies invest more credibly, and public authorities have less uncertainty arising from fiscal or government funding. 3) Because fixed incentives and direct subsidies are substitutes, the increased use of one

²⁰ Guellec and van Pottelsberghe de la Potterie, 1997, p. 96 'Fiscal incentives are "horizontal" because they are available to all firms. Government funded R&D is rather "vertical" since it is selective, targeting projects directly.'

of them reduces the effectiveness of the other. This implies that it is more effective to use these two policies in a co-ordinated manner.

Griliches (1986) studied the relationship between R&D expenditures, especially expenditures on basic research, and productivity growth in U.S. manufacturing firms during the 1970s. The paper reported some new results and updated his earlier work (1980) using a larger, more recent, and more representative sample of firms. Griliches used a Cobb-Douglas-type production function model to estimate and test the effects of publicly provided R&D funding on the productivity of firms receiving it. The data set was based on the National Science Foundation (NSF) R&D Census match for approximately 1000 largest manufacturing firms from 1957 through 1977, where 883 companies accounted for over 90% of total sales and R&D expenditures of all firms. The results implied strong divergence between the trends of the federally and privately supported industrial R&D. About 40 percent reduction in the relative intensity of industrial investment is in basic research, and almost all declines came from federally financed R&D.

There are three major findings in this paper. 1) A positive relationship between productivity growth and investments in R&D, and a relatively high rate of return. This result is consistent with his previous works. 2) Basic research appears to be more important as a productivity determinant than other types of R&D. Firms that spend a large amount of R&D expenditures on basic research are more likely to have a higher level of output. 3) Privately financed R&D expenditures are more effective than federally financed ones. Again spillover effects may explain this finding. Griliches

also mentioned that most of direct output of federal research dollars is “sold” back to the government and is unlikely to show up as an increase in the firm’s own productivity.

Nadiri and Mamuneas (1994) empirically examined the effects of publicly financed infrastructure and R&D capitals on the cost structure and productivity performance. Both the cost structure and factor demand are affected in each industry. They used pooled time-series cross-section data for twelve two-digit U.S. manufacturing industries for the period 1956-1986 as the basis of their analysis. The results suggest that there are significant positive effects of public R&D on the cost structure of industries, but also implied that these effects vary over time and across industries. In addition, they calculated the marginal benefits of these services in each industry, and estimated the social rates of return to these capitals for the industries.

R&D capital affects the cost structure in two ways. First, through the “productivity effect”, the cost function shifts downward if the industry receives any benefit from public capital services in terms of cost reduction. Second, firms would adjust their demand for labor, intermediate inputs, and physical capital stock if public sector services can be used as either substitutes or complements to the factors of production in the private sector. Thus input decisions would be affected as well. Consistently, the results indicated that both types of public capital services reduce costs in each industry, but the magnitudes are much smaller than reported in previous studies. Nadiri and Mamuneas explicitly pointed out that there are several other issues that require further research, such as a need to specify analytically the determinants of

usage of public sector services by the private sector; a need to introduce dynamic effects, and a need to include public sector investment in education and training as well.

Recent studies paid particular attention to the composition of R&D, the measurement of spillovers, and the interaction between public and private R&D. As a first step to investigate the firm's immediate response to subsidies, Busom (1999) developed an empirical model to analyze an R&D subsidy program in Spain focusing on both the determinants of firms' participation in the program and on the effects that participation has on the firms' R&D effort. He pointed out that there are two shortcomings from prior simple regression models: endogeneity of public funding²¹ and the negative relationship between public and private R&D expenditure²². Thus his paper intended to investigate the factors associated with receiving R&D subsidies, and to estimate the degree of R&D efforts made by firms which received the subsidies. Using a sample of 154 Spanish firms that were conducting R&D activities in 1988, 75 (45%) of which received public funding for their R&D projects through the Centro para el Desarrollo Tecnológico e Industrial (CDTI), an agency of the Spanish Ministry of Industry. That year, the CDTI granted subsidies to 213 projects of a total of 541 applications. Some firms had more than one project approved. Public funding amounted to 39% of total R&D investment for approved projects (CDTI, 1988).

Busom set up four equations to test the probability of applying for an R&D

²¹ Public funding may become an endogenous variable when a firm applies for funding but the public agency may or may not award funding.

²² In some cases, the public agency may finance and subsidize R&D projects with higher spillovers, where private firms may have lower incentives to invest.

subsidy relative to not applying, the decision rule of the public agency granting the subsidies, and the total R&D effort made by firms, measured by R&D expenditures or R&D personnel, respectively.

The main findings are as follows. 1) Smaller firms have a higher chance of being participants, which means that smaller firms are more likely to apply for and be granted a subsidy. Based on a systematic selection criterion, the public agency does not randomly choose firms and projects. It may want to encourage R&D in small firms because of “fixed costs involved in R&D and of capital market imperfections.”²³ In addition, small firms may be more credit constrained so that the public agency is likely to grant their applications. 2) Firm size remained positively related to R&D intensity, whether or not a firm received public funding, but R&D intensity diminishes more slowly with size for participants. R&D expenditure is explained by firm size, and the evidence showed that participating in a European-level R&D program does not lead to increased expenditure. 3) Public funding induced more effort by firms, but for some firms (about 30%) crowding out²⁴ effects cannot be ruled out. Overall, public subsidies have a positive effect on private firms’ effort because the public funding induced an additional 20% of private expenditure. The results rule out complete crowding out, but there are some cases where firms reduced private funds after receiving the subsidy. The results obtained in this paper should be interpreted with caution because the number of firms participating in European R&D

²³ Busom, 1999, p. 123.

²⁴ Crowding out occurs when public funding reduces private funding partially or completely. Complete crowding out occurs when firms would have made the R&D effort anyway and private returns were high enough. Partial crowding out occurs when total effort increases, but the private contribution is smaller than if the firm had been on its own.

programs in this sample is small and because of the novelty of these programs for Spanish firms (Spain had joined the EU only in 1986).

Svensson (1998) empirically analyzed whether economic or political considerations dominate in the formation of government R&D policy. Svensson used data from 13 OECD countries on 24 manufacturing sectors at the two digit level for the year 1985. Externalities and the existence of markets with above-normal rents have been included to justify government trade policy. Svensson also concentrated on four characteristics that are essential from an economic point of view: market concentration, returns to capital, returns to labour, and technological spillovers. The author used a simple graphic model to choose the optimal level of R&D subsidies where the marginal utility of increasing subsidies equals marginal costs.

The main finding is that both economic and political considerations are important in the shaping of R&D policy. First, industries characterized by a high technological level of production are more likely to receive more than average R&D support. It can be assumed that industries where innovations play an important role generate higher technological spillovers. This implies that high technology industries are appropriate for support. Second, industries with a high degree of concentration also receive more R&D support in that "the more concentrated an industry, the smaller the number of domestic non-support firms negatively affected by the supported firm's capture of market shares."²⁵ Third, industries experiencing a decline are more likely to get political support. Because the benefits of supporting this industry are direct and easy

²⁵ Svensson, 1998, p. 263.

to understand, it is easier to receive political support to protect an industry experiencing a decline. The returns in those industries are relatively high, and the competition from the entry of new firms is likely to be low, which will increase government effort. Finally, labour intensity is positively correlated with R&D subsidies. Because labour intensity is associated with votes, supporting a labour intensive industry affects more voters and saves more jobs than supporting a capital intensive industry.

7. Conclusions

This paper reviewed the main theoretical studies of the economic effects of R&D subsidies and R&D spillovers as well as the main empirical results.

There are a number of reasons why R&D subsidies receive so much attention. 1) R&D is potentially very important for economic development and growth, and thus policies may have a great impact. 2) The typical characteristics of R&D, such as spillovers, externalities, and public goods property, lead to market failures. 3) R&D investments may be used strategically in multi-period games between firms. 4) While other types of trade and industrial policies are more and more regulated internationally, R&D subsidies still remain a national responsibility with little or no supranational regulation.

Governments are aware of the important role R&D subsidies play in economic development and technological progress. A large body of research has proved the

effectiveness of R&D subsidies to benefit both firms and consumers in cost reduction and quality improvement. In addition, benefits such as lowering entry barriers, increasing competition, lowering margins and improving allocative efficiency have also received considerable attention.

In perfectly competitive markets, in the absence of market failures, information can be fully shared by firms so that the market will provide no R&D investment, but still there is underinvestment. In imperfectly competitive markets, the socially optimal level of R&D expenditure can not be achieved due to the lack of appropriability. When firms invest in R&D, the negative effect of spillovers has to be taken into account in that spillovers reduce the incentives for the firms to conduct R&D investment, and influence both the motives and results of R&D investment.

Meanwhile, in the literature, a suggested solution to correct these market failures is patent protection. Patents have the negative externality in that the innovator who has been granted a patent disallows other innovators from using the information. Therefore some economists suggested combining patent protection with other policy tools. Romamo (1989) examined the interaction between patent protection and subsidies in the cases of monopoly and perfect competition. Kanniainen and Stenbacka (1995) studied the combination of patent and subsidy policies. However, this aspect of R&D subsidies still needs further research in the context of varying markets structures and government policies.

Empirical evidence supports the implications of the theoretical literature in this

paper. These analyses often provide a challenge for further research, such as obtaining better data sets.

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